Mr. John T. Goodwin
(*President* 1927-28.)

Mr. Goodwin, who for the last 20 years has been general manager of the foundries and engineering departments of the Sheepbridge Coal & Iron Company, Limited, of Chesterfield, was trained originally at the Butterley Works. After spending some time on the North-East Coast he returned to Derbyshire to take up his present position. During the war he erected a factory for the complete manufacture of shells for the Admiralty up to 15 ins. diameter. He was at that time Captain of the Northern Command of the Derbyshire Motor Transport Corps, and in recognition of his services he received the M.B.E. He has been a member of the Institute since 1905. He is also a member of the Institution of Mechanical Engineers, the Iron and Steel Institute, and the Institute of Metals. He has read several papers before the Institute.

PROCEEDINGS
OF THE . .
INSTITUTE OF
BRITISH FOUNDRYMEN.

VOLUME XX. 1926-1927.

Containing the Report of the Twenty-fourth Annual Conference, held in Sheffield, July 5th, 6th, 7th and 8th, 1927; and also Papers and Discussions presented at Branch Meetings held during the Session 1926-1927.

Institute of British Foundrymen.
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THE INSTITUTE OF BRITISH FOUNDRYMEN.

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* Elected at Annual Conference. † Branch Delegates.

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

General Secretary and General Office:

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

AWARDS 1926—1927.

THE "OLIVER STUBBS" GOLD MEDAL

1927 Award to PROFESSOR THOMAS TURNER, M.Sc., Emeritus Professor of the University of Birmingham, "for long and distinguished services to Metallurgy and to the Institute."

DIPLOMAS OF THE INSTITUTE

were awarded as follows

H. C. DEWS, for his Paper on "Contraction in Alloy Casting," given before the London Branch.

J. W. DONALDSON, for his Paper on "The Heat Treatment and Growth of Cast Iron," given before the Lancashire Branch

H. V. GRUNDY and A. PHILLIPS, for their Paper on "Refractories in the Foundry," given before the Lancashire Branch.

J. E. HURST, for his Paper on "The Influence of Sulphur in Cast Iron," with its special relation to the mechanical properties of cast iron, given before the Sheffield Branch.

W. J. MOLINEUX, for his Paper on "The Manufacture of Iron Castings for Petrol Engines," given before the Newcastle Branch.

A. E. PEACE, for his Paper on "A Comparison of Whiteheart and Blackheart Malleable Cast Iron," given before the East Midlands Branch.

H. FIELD, for his Paper on "Some Experiences in the Production of Malleable Castings," given before the Birmingham Branch.

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The Institute of British Foundrymen

ANNUAL CONFERENCE HELD IN SHEFFIELD.

July 5, 6, 7 and 8, 1927.

The twenty-fourth annual meeting and conference of the Institute of British Foundrymen was held in Sheffield from Tuesday to Friday, July 5 to 8, under the presidency of Mr. J. T. Goodwin, M.B.E., M.I.Mech.E., of the Sheepbridge Coal and Iron Company, Limited There were present more than 300 members and visitors, the latter including representatives of foundrymen's associations in foreign countries, and many ladies. An excellent programme was provided for their instruction and enjoyment, which included the reading and discussion of papers, visits to works and social functions, and, as usual, a feature of the programme was the excellent manner in which the interests of the ladies were catered for.

TUESDAY, JULY 5.

On Tuesday evening the members and visitors attended a reception at the Cutlers' Hall, at the invitation of the Master and Mistress Cutler (Mr. and Mrs. David Flather), and spent an enjoyable evening renewing old friendships and making new ones. Dancing was also a feature of the evening's programme.

WEDNESDAY, JULY 6.

Thanks to the courtesy of the Sheffield University authorities, the meetings were held in the Mappin Hall at the Department of Applied Science, at St. Georges' Square, and the members assembled there on Wednesday morning, when a cordial welcome was extended to them on behalf of the city and of the University by the Lord Mayor (Alderman J. G. Graves, J.P.), and the Vice-Chancellor of the University (Sir Henry Hadow, C.B.E., M.A., D.Mus., LL.D., J.P.) respectively.

Mr. V. C. Faulkner (the retiring president) occupied the chair during the early proceedings, and the duty of introducing the Lord Mayor and the Vice-Chancellor devolved upon him. It gave him very great pleasure, he said, to speak in that hall, where he had made, perhaps, his first speech to a metallurgical audience, some twenty years ago, and it was with a feeling of personal satisfaction that he found himself in his present position, addressing a national and even an international audience of foundrymen. In asking the Lord Mayor to address the meeting, he said he would like him to know that the audience, while cognisant of, and grateful for, the wonderful facilities which were provided by the City of Sheffield—of which the Lord Mayor was so distinguished a head—in the way of transport, sanitary and other services, which services were so very efficient, they did view with alarm the cost which those facilities imposed upon their industry. It was said that the rates of Sheffield were costing the steel industry something like 10s. per ton, as against a very few shillings per ton in pre-war days. Speaking of the industrial importance of Sheffield, he said that not only was it a great iron founding centre, but it was also a very important steel founding centre—actually the most important in Europe. The non-ferrous foundry industry, however, was but sparsely represented in this great city.

The Lord Mayor said he accepted Mr. Faulkner's invitation with very great pleasure indeed, for he felt particularly proud to act upon this occasion as the spokesman of the city. He always felt that he had the whole of the citizens of this great community behind him when offering a welcome to visitors, may be to strangers, to the city. They did feel very proud indeed that the Institute had chosen Sheffield as the venue for its conference; he was sure that the conference would be very successful and very pleasant, and hoped that the members of the Institute and the visitors would learn much of the great resources of the city, that they would cement old friendships and form new ones, that they would find fresh interests while in Sheffield, and that they would see a good deal of its beautiful surroundings. Mr. Faulkner had rather put the wind up him by his abrupt and unexpected reference to realities. Wise Lord Mayors restricted their speeches on these occasions as far as possible to pleasant generalities, and occasionally indulged in platitudes, but they made as little reference to rates as they possibly could. Therefore, he would get over that point as quickly as possible. (Laughter.) Finally, he expressed the hope that he might have many opportunities of meeting other members of the conference, that their contact might be extremely pleasant to them all, and that they would carry away from the city very pleasant recollections of the nineteen twenty-seven conference.

Mr. Faulkner, inviting the Vice-Chancellor to address the conference, said that foundrymen throughout the world were deeply indebted to the University of Sheffield for the character of the men it had turned out, and also for the uniform excellence of the researches, the results of which it had placed at the disposal of the metallurgical world. The members of the Institute of British Foundrymen appreciated very highly the wonderful research work which was turned out under the ægis of their esteemed fellow member, Professor C. H. Desch (Professor of Metallurgy at the University). He (Mr. Faulkner) knew the Department perhaps as well as anybody; he was one of the students there when it was turned into a University, and he assured the Vice-Chancellor that he had never lost his interest in the work of that Department, which was still recognised as the centre of steel thought throughout the whole world.

Sir Henry Hadow, in his welcome to the members, said it always gave him great pleasure, as a representative of the University, to stand on a public platform with his very good friend, and, if he might say so, his colleague, the Lord Mayor, who represented the City; he was very glad to see representatives of the City and the University side by side on any public platform. The Institute of British Foundrymen, he continued, was specially connected with the University. For one thing, one of the founders of the Institute was Dr. P. Longmuir, whom the University was proud to number among its Graduates. For another thing, one of the chief branches of the Institute was at Glasgow and another was at Sheffield, and if one added the three words "Glasgow," "Sheffield" and "Metallurgy" together, the sum total was "Prof. Desch." Again, the Institute had had very great success; its President, Mr. Faulkner, was a member of the University, and a member whose career was watched with very great interest and pride. The University authorities congratulated him upon his year of office, and they wished all success to Mr. Goodwin; they welcomed the Institute particularly because they were always very glad to see institutes which had a great scientific background and a scientific basis, and because the science of the Institute was one with which the University and the Applied Science Department were specially and intimately concerned. He hoped the visit would be pleasant and profitable, and assured the members that if the University authorities could do anything to aid the conference or make the business more pleasant, they would do their utmost. All the services at the University were at the disposal of the Institute.

Presentation of "Oliver Stubbs" Gold Medal.

The "Oliver Stubbs" Gold Medal, which is provided from funds supplied by the Iron Founding Employers' Federation, and awarded each year for distinguished services to iron founding and to the Institute, was presented by the Lord Mayor to Professor T. Turner (Emeritus Professor of Metallurgy at Birmingham University, and a Past-President of the Institute of Metals).

Mr. Faulkner said that iron founders in particular were indebted to Professor Turner because he had shown the world how silicon influenced the general structure of cast iron. His research, which was done many years ago, had had an enormous influence on every foundry. There were some 3,000 iron foundries in Great Britain and probably 20,000 throughout the world, and they all used the results of the research of Professor Turner—some unwittingly and some knowingly.

Professor Turner, returning thanks, said he had worked for many years in connection with the foundry in various ways, he had formed many friendships and had had many interests; the medal would be a lasting connection and a remembrance to him and his family of work which had been a pleasure whilst it was being performed, and which he trusted had been of some use to others.

Presentation to Mr. John Shaw.

A handsome hall clock was presented to Mr. John Shaw (late manager of the foundry of the Brightside Foundry & Engineering Company, of Sheffield, and who recently retired) by members of the Sheffield Branch and other members of the Institute in recognition of his services to foundrymen. It was intimated by Mr. Faulkner that Mr. Shaw had had a very long and distinguished career, and had placed his experience most generously at the service of foundrymen. During the war he was Controller of Cast Iron at the Ministry of Munitions, and in that capacity had shown a very clear sense of what was just and equitable for the founders.

(The clock, which stood about 5 ft. 6 in. high, was inscribed:—" Presented to Mr. John Shaw by members of the Sheffield Branch and other members of the Institute of British Foundrymen in recognition of his eminent services to the Institute. Sheffield Convention, 1927.")

Mr. Shaw, in expressing his appreciation of the gift, which was a complete surprise to him, generously remarked that anything he had done had been for his own good as well as for the good of the Institute; he owed practically everything to the friendships he had made in the Institute. He also acknowledged the cordial relations which had always existed between himself and his colleagues, and in this connection he mentioned specially Prof. C. H. Desch, Dr. W. H. Hatfield and Dr. T. Swinden. He thanked them all for the help they had extended to him at all times.

Vote of Thanks to Lord Mayor and Vice-Chancellor.

Mr. Faulkner proposed a hearty vote of thanks to the Lord Mayor and Sir Henry Hadow for the charming welcome they had extended to the members, and expressed appreciation of the kindness of the University authorities in placing the facilities of the University at the disposal of the Institute. He hoped that as the result of the Conference the foundry owners, managers and employees throughout Great Britain would learn to know and appreciate Sheffield and its University much better than they had done in the past, although he appreciated, of course, that their reputation was very high throughout the whole metallurgical world.

The vote of thanks was accorded with acclamation, and the Lord Mayor and Vice-Chancellor withdrew.

Annual General Meeting.

The business of the annual general meeting of the Institute was then proceeded with. The minutes of the last annual general meeting were taken as read, and were confirmed and signed and the Annual Report submitted.

Annual Report of the General Council for the Session, 1926-27.

The General Council has pleasure in presenting to the Members of the Institute the Report of the work during the Session 1926-27.

The total number of members on the roll of the Institute on April 30 was 1636. The Council regret to announce the death of 14 members during the year. The distribution of the membership among the various branches is shown in the table on page 7.

The new branch which was opened at Middlesbrough during the spring of last year has now completed a very successful first session and is still adding to its membership.

Junior Sections.—The junior sections in connection with the Newcastle and Lancashire Branches continue to make good progress. The London and Birmingham Branches have also inaugurated successful junior sections and the formation of similar sections is under consideration by other branches.

Membership of the Institute, June, 1927.

	Subscribing Firms.	Members.	Associate Members.	Associates.	Total.
Birmingham, Coventry, and West Midlands ..	2 (1)	68 (71)	106 (122)	16 (22)	192 (216)
East Midlands	—	34 (31)	57 (52)	4 (5)	95 (88)
Lancashire	9 (8)	108 (95)	193 (187)	8 (8)	318 (298)
London	2 (2)	112 (90)	82 (77)	8 (10)	204 (179)
Middlesbrough	4 (2)	26 (17)	27 (19)	8 (7)	65 (45)
Newcastle	10 (10)	67 (66)	60 (72)	72 (88)	209 (236)
Scottish	—	54 (50)	115 (89)	30 (11)	199 (183)
Sheffield	6 (6)	81 (77)	96 (89)	13 (11)	196 (183)
West Riding of Yorkshire	—	25 (28)	53 (45)	2 (2)	80 (75)
Wales and Monmouth ..	—	17 (18)	12 (12)	4 (3)	33 (33)
General	—	32 (26)	12 (3)	1 (—)	45 (29)
Total	33 (29)	624 (569)	813 (794)	166 (186)	1,636 (1,574)

The figures in brackets are for the Session 1925–1926.

Oliver Stubbs Gold Medal.—The fifth medal was awarded to Mr. A. R. Bartlett, of Belvedere, Kent, for meritorious services rendered to the Institute over a period of many years.

Diplomas.—Six diplomas have been awarded for Papers which have been given before the branches. The recipients and the respective branches before which the Papers were given are as follows:—J. Longden, Scottish Branch; Major K. C. Appleyard, Newcastle Branch; J. R. Hyde, Sheffield Branch; A. J. Richman, Lancashire Branch; W. West, Burnley Section of Lancashire Branch; M. J. Cooper, London Branch.

Annual Conference, 1926.—The 1926 Annual Conference was held at the Royal Agricultural Hall, London, in June, and in spite of the unsettled industrial conditions prevailing at that time and of the difficulties of travelling, the Conference was very successful and was largely attended. Simultaneously with the Conference a very comprehensive Foundry and Allied Trades Exhibition was held.

The next Annual Conference will be held on July 5, 6, 7 and 8, 1927, at the University, St. George's Square, Sheffield, by kind permission of the University authorities.

General Council.—Five General Council Meetings have been held at London, Manchester, York, Birmingham and London respectively. All branches have been well represented at these meetings and there has been an average attendance of 34.

In accordance with the bye-laws the following members of the General Council, all of whom are eligible for re-election, retire at the General Meeting:—Messrs. W. T. Evans, A. Firth, J. Haigh, A. Harley and H. Winterton. All these gentlemen offer themselves for re-election. It is necessary to elect five members to complete the ten members elected at general meetings, as provided for in the bye-laws.

Standardisation of Test Bars.—During the year the committee of the British Engineering Standards Association, which is dealing with this matter, completed the drafting of a tentative specification for grey cast iron which followed to a great extent the lines laid down in the original specification issued by the members of your Test

Bar Committee. The whole of the clauses in the B.E.S.A. Tentative Specification were accepted by the various bodies which were represented with the exception of a clause introduced at the final meeting. This clause which relates to a guaranteed time limit before the manufacturers' responsibility ceases, was opposed by your representatives and the settlement awaits a further meeting.

International Tests for Cast Iron.—Your representative, Mr. Shaw, attended an informal International Meeting at Detroit, at which a preliminary discussion on the tests in operation in various countries, took place. Your representative promised to carry out certain tests by a modified "Fremont" method, but he has not yet been able to commence these tests, as up to the present he has not received the drawings of the necessary apparatus.

British Cast-Iron Research Association.—The Institute continues to have very close relations with the British Cast Iron Research Association. In July, 1926, the Association started on its sixth year of activity with the assurance of very generous grants in aid from H.M. Government during the second five-year period of its existence. This support is conditional upon the Association reaching an income of £4,000 per annum, and the support of all ironfounders is earnestly requested, not only to ensure this sum, but to increase it to at least £6,000 per annum, the limit up to which subscriptions will be doubled by means of the grant.

The main development since the last report was issued has been the acquisition of headquarters, offices and laboratories in one building at 24, St Paul's Square, Birmingham, thus combining the offices and laboratories hitherto separately conducted. This has resulted in many advantages and economies in working. All foundrymen interested are cordially invited to pay a visit to the headquarters.

International Relations.—In the autumn of 1926 a number of members and ladies attended the Second International Conference in Detroit, U.S.A., and the thanks of the Institute are due to the American Foundrymen's Association for their hospitality.

The Institute has accepted an invitation on behalf of its members to take part in an International Conference in Paris in September, 1927, and it is hoped that a large number of members and ladies will be present.

The Third International Congress will be organised by this Institute and will be held in London early in June, 1929, and invitations to participate have already been issued to overseas foundry associations.

In December last your President and Secretary attended a meeting in Brussels, and as a result of this meeting an International Committee of Foundry Technical Associations was formed. This Committee will regularise the dates and arrangements for International Conference and will also be concerned with other matters of an International character which are of interest to the various foundry associations. Your General Secretary has been elected Hon. Secretary of this committee.

General Secretary.—It is with great regret that the Council report that in October last Mr. W. G. Hollinworth found it necessary to resign from the Secretaryship of the Institute on account of continued ill-health. The sympathy of the members and thanks for his devoted services have already been expressed to Mr. Hollinworth.

Mr. T. Makemson, Hon. Secretary of the Lancashire Branch, was appointed General Secretary in succession to Mr. Hollinworth, and commenced his duties on December 1, 1926.

General Offices.—The lease of the General Offices at Victoria Street, London, expired on December 25 last, and as the Council was faced with the necessity of engaging other accommodation they decided to transfer the General Offices to the provinces, and the present offices at St. John's Street Chambers, Deansgate, Manchester, were engaged. It is hoped that the removal of the General Offices to the provinces will make for more effective and economical working. By kind permission of Industrial Newspapers, Limited, arrangements have been made for their offices, 49, Wellington Street, Strand, to be the Registered Offices of the Institute.

"*Proceedings.*"—An index to the "Proceedings" from the first volume to the volume 1924-25 has been prepared and will be on sale very shortly at a nominal charge. It is hoped that all members will purchase copies of the Index and thereby enhance the value of their sets of the "Proceedings."

Statement of accounts and balance sheet for the year ended December 31, 1926, follow this report. The Council is of the opinion that the usefulness of the Institute can be largely extended by an increase in the membership, and all members are respectfully urged to impress the advantage of membership upon those engaged in the foundry industry who are not yet members of the Institute.

V. C. Faulkner, *President*.
Tom Makemson, *General Secretary*.

Balance Sheet.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1926.

Expenditure.

				£	s.	d.
Postages				87	13	0
Printing and Stationery, including printing of Proceedings				591	0	3
Council, Finance and Annual Meeting Expenses				47	4	5
Medals for Past-Presidents				36	14	0
Branch Expenses:—						
Lancashire	135	12	8			
Birmingham	74	1	5			
Scottish	102	1	1			
Sheffield	67	10	5			
London	52	5	9			
East Midlands	36	19	1			
Newcastle	100	11	5			
West Riding of Yorkshire	32	18	0			
Wales and Monmouth	19	17	6			
Middlesbrough	11	2	1			
				632	19	5
Audit Fee				6	6	0
Incidental Expenses				32	9	10
Salaries—Secretary and Clerk ...				429	3	4
Rent of Office				100	6	3
Depreciation of Furniture				7	13	8
Removal Expenses				9	7	0
				£1,980	17	2

INCOME.

	£	s.	d.
Subscriptions Received	1,779	12	0
Sale of Proceedings, etc.	10	11	0
Interest on War Loan and Cash on Deposit	34	8	0
	£1,824	11	0
Excess, Expenditure over Income ...	156	6	2
	£1,980	17	2

BALANCE SHEET, DECEMBER 31, 1926.

LIABILITIES.

				£	s.	d.
Subscriptions paid in advance ...				153	12	6
Sundry Creditors				411	16	6
The Oliver Stubbs Medal Fund—						
Balance from Last Account	206	2	0			
Interest to date ...	8	4	4			
	214	6	4			
Less: Cost of Medal ...	9	10	0	204	16	4
Surplus at December 31, 1925	986	5	6			
Less: Excess of Expenditure over Income for the year ended December 31, 1926	156	6	2	829	19	4
				£1,600	4	8

ASSETS.

CASH IN HANDS OF SECRETARIES—	£	s.	d.	£	s.	d.
Lancashire	24	16	6			
Sheffield	85	8	4			
London	70	15	9			
East Midlands	20	15	6			
West Riding of Yorkshire	28	17	6			
Newcastle	4	2	11			
Wales and Monmouth	0	7	4			
Middlesbrough	20	15	11	255	18	9

	£	s.	d.	£	s.	d.
Lloyds Bank, Limited—						
General Account ...	237	16	8			
Deposit Account ...	400	0	0			
				637	16	8
Oliver Stubbs Medal Fund—						
£342 5s. 7d. Local Loan £3 per cent. Stock at cost	200	0	0			
Balance in hands of Lloyds Bank, Limited	4	16	4			
				204	16	4
Investment Account—						
£100 5 per cent. National War Bonds ... ... £350 5 per cent. War Loan at cost				432	10	1
Furniture and Fixtures—						
Per last Account ...	76	16	6			
Less: Depreciation 10 per cent.	7	13	8			
				69	2	10
				£1,600	4	8

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.

On the motion of Mr. Oliver Stubbs (Past-President of the Institute), seconded by Mr. W. B. Lake (President-Elect of the London Branch), the annual report of the General Council for the year 1926-27 was adopted.

On the proposition of Mr. J. T. Goodwin (President-Elect of the Institute), seconded by Mr. J. Haigh (Lancashire Branch), the balance sheet and statement of accounts for the year 1926 were approved and adopted.

Amendment of Bye-Laws.

On the motion of Mr. Wesley Lambert (London Branch), seconded by Mr. S. H. Russell (Vice-President), it was resolved that the bye-laws relating to suspension and expulsion of members be amended in accordance with the circular forwarded to members. The object of the amendments was to simplify the working of the Branches and to enable the Branches to make decisions without reference to the General Council.

Diplomas.

It was announced by the General Secretary (Mr. T. Makemson) that the Institute's Diploma had been awarded to the following for Papers read during the past session:—

Mr. J. E. Hurst (Sheffield Branch): "The Influence of Sulphur in Cast Iron."

Mr. A. E. Peace (East Midlands Branch): "A Comparison of Blackheart and Whiteheart Malleable Cast Iron."

Mr. H. C. Dews (London Branch): "Contraction in Alloy Casting."

Messrs. H. V. Grundy and A. Phillips (Lancashire Branch): "Refractories in the Foundry."

Mr. J. W. Donaldson (Lancashire Branch): "The Heat Treatment and Growth of Cast Iron."

Mr. W. J. Molineux (Newcastle Branch): "The Manufacture of Iron Castings for Petrol Engines."

Mr. H. Field (Birmingham Branch): "Some Experiences in the Production of Malleable Castings."

Election of Officers.

President.

Mr. Faulkner, proposing that Mr. J. T. Goodwin be elected President for the ensuing year, said that the Institute would have had the greatest difficulty in finding a member who had given more whole-hearted attention to its affairs or who had worked so willingly on its behalf as had Mr. Goodwin. Nothing had been too much trouble to him during his twenty or so years' connection with the Institute. The members appreciated very highly the work he had done in the past, and had every confidence that during the next twelve months the affairs of the Institute could not be in better hands than his.

Mr. Oliver Stubbs (Past-President), seconding, said that Mr. Goodwin could have occupied the chair long ago, and it was his own fault that he had not. Mr. Stubbs trusted that Mr. Goodwin, during his year of office, would enjoy good health, and would be supported by the members generally in the manner in which he himself had been supported during his own term of office.

In view of the enthusiasm with which the resolution was received, Mr. Faulkner remarked that it was unnecessary to put it formally to the meeting. He therefore invested Mr. Goodwin with the President's Chain of Office, and the latter formally occupied the chair. The members, standing, gave him a hearty reception.

The President, expressing his appreciation of the honour bestowed upon him, said that he would uphold to the best of his ability the traditions of the Institute and do his utmost to advance its interests. He trusted that throughout his period of office he would carry with him the goodwill of the members, and that at the end of that period—if it were possible—he would have left the Institute in even a more prosperous and more healthy condition than it is at present.

Presentation of Medal to Past-President.

The President then presented to Mr. Faulkner the Medal which it is now the practice to present to Past-Presidents as a memento of their year of office, in substitution for the Diploma which it was previously the practice to present to them. He was very thankful, indeed, he said, that he had been tutored by Mr. Faulkner, who had been more than a father to him and had taught him many things which a President-Elect ought to know before occupying the chair. In a tribute to Mr. Faulkner for the good work he had done for the Institute, he said it had been done very quietly, but very powerfully. The "Journal" of which the members were so proud, as representing the Institute, had done more in the way of propaganda work in every direction than anything else they could possibly think of, and they all knew that Mr. Faulkner's was the guiding hand at the back of it. He was proud to be able to thank Mr. Faulkner most sincerely, on behalf of the members, for the work he had done. What had pleased them perhaps more than anything else was the really sincere and sympathetic manner in which he had met everyone; he had gone out of his way to visit all the Branches, and to get to know the wishes of the Institute as a whole. Finally, the President expressed the members' most sincere wish that Mr. Faulkner would enjoy a long and happy life, and the hope that it would be a very long time before he relinquished his support of the Institute.

Mr. Faulkner, responding, said that the past year had been a very happy one, although it had commenced at a time of very great industrial depression, and he took the opportunity to thank his Vice-Presidents, Members of Council, and the general body of members for the wonderful support they had given him. He also expressed thanks to the American Foundrymen's Association for the hospitality they had extended to the important delegation which had visited America last autumn. His thanks were also due to other societies, and he referred particularly to the Belgian Foundrymen's Association, because Britishers had always received a princely welcome from the Association when they had visited Belgium, and there was a very strong bond of sympathy between Mr. Ropsy, the President of the Belgian Association, and the Institute. The French Association, too, had cemented the already good feelings which existed between it and the Institute by inviting the latter to take part in a conference to be held in September in Paris. Again, during the year the Institute's relationship with the German associations had been cemented, and he was pleased to welcome to the Convention, for the first time since the war, representatives of those associations, namely, Dr. Piwowarsky and Herr Nipper, of Aachen. The Institute had been honoured during the year by invitations to participate in the twenty-first birthday celebrations of the Sheffield University, and Mr. Goodwin and himself had represented the Institute on that occasion. Further, he had been received by the National Federation of Iron and Steel Manufacturers, the Iron and Steel Institute, the London Iron and Steel Exchange, the Institute of Metals, and many other bodies, and he felt that the present occasion offered an opportunity for him to express thanks to those bodies for the many kindnesses which the Institute had received at their hands. Finally, he thanked his directors and colleagues for generously according him facilities to attend to the business of the Institute.

Vice-Presidents.

On the motion of Mr. Oliver Stubbs (Past-President), seconded by Mr. F. J. Cook (Past-President), and supported by Mr. H. Pemberton (President of the East Midlands Branch), Mr. S. H. Russell (of Leicester) was unanimously elected Senior Vice-President.

Mr. Russell, returning thanks for his election, said he felt he had received very much more from the Institute than he could ever put into it, and he could only promise that he would do his very best to carry on its work during his period of office. He also expressed thanks on behalf of the East Midlands Branch, because he felt that his election was more an honour to that Branch than to himself.

On the motion of Mr. W. B. Lake (President-Elect of the London Branch), seconded by Mr. H. Winterton (Scottish Branch), Mr. Wesley Lambert (Past-President of the London Branch) was unanimously elected Junior Vice-President.

Mr. Lambert, who also returned thanks, said that he believed it was his own fault to a very large extent that he had not taken office a few years ago, but the circumstances at that time were such that he was unable to accept. The difficulties which had then stood in the way had now been removed, however, and he looked forward to his year of office in the chair in the future with a very great deal of pleasure, because he had been connected with the foundry industry practically all his life, and, though he belonged to quite a number of institutions, the Institute of British Foundrymen was the one nearest and dearest to his heart. He said that largely because there was a great deal of human nature in the Institute. The class of men one met were really good men, and he had found in the industry that the British working man—the craftsman—when one got to know him, was a real good fellow, and one could always get the information one required from him.

Hon. Treasurer.

On the motion of Mr. Faulkner, seconded by Mr. Lambert, Mr. F. W. Finch was re-elected Hon. Treasurer. Mr. Finch, who has been connected with the Institute since its inception, and at one time carried out the duties of Honorary Secretary, had written to express his regret that he was unable to attend the Convention, owing to the illness of Mrs. Finch. On the suggestion of Mr. Stubbs, it was agreed that a letter be sent to Mr. Finch from the Convention, expressing sympathy and good wishes.

Members of Council.

As the result of the ballot to fill the five vacancies on the General Council, the following were re-elected:—Mr. W. T. Evans (Derby); Mr. A. Firth (Sheffield); Mr. J. Haigh (Wakefield); Mr. A. Harley (Coventry), and Mr. H. Winterton (Milngavie, Dumbartonshire).

Trustees.

On the proposition of Mr. A. Firth (Sheffield), seconded by Mr. E. Stevenson (East Midlands Branch), the following were re-elected Trustees of the Institute:—Mr. F. J. Cook, Mr. Oliver Stubbs and Mr. R. O. Patterson.

Re-Election of Auditors.

On the proposition of the President, seconded by Mr. Faulkner, Messrs. J. & A. W. Sully & Company (chartered accountants) were re-elected auditors.

Welcome to Foreign Delegates.

A telegram was received from Mr. H. Cole Estep (Chairman of the Committee of International Relations of the American Foundrymen's Association) conveying the heartiest and best wishes from that Association for a successful conference.

The PRESIDENT then extended a very hearty welcome to delegates from kindred associations abroad. The Institute, he said, had great pleasure in welcoming Mr. Ropsy, the President of the Belgian Foundrymen's Association and President of the International Foundrymen's Committee. They also were greatly honoured by the presence of Professor Dr. Ing. Piwowarsky and Herr H. Nipper, of the Technical High School, Aachen, Germany; Mr. J. A. Penton, of Cleveland, Ohio, Past-President of the American Foundrymen's Association; and Mr. Earnill, a member of the American Foundrymen's Association. The members of the Institute were most gratified to welcome the visitors on this occasion, inasmuch as they had Papers of very great quality and high standing to offer them.

Mr. Ropsy, who addressed the meeting in French, thanked the Institute very sincerely for its kind invitation to representatives of kindred associations abroad, and expressed the hope that all would derive mutual benefit from the Conference.

Mr. Penton, who also responded, said it always gave him a great deal of pleasure to be in England, and especially to be in the company of foundrymen, because he felt so thoroughly at home with them. His visit was a personal and not an official one. He marvelled at the growth of the Institute and of kindred associations in Great Britain; they were doing wonderful work, and he assured them that those in America were greatly interested in it, and followed their proceedings carefully.

The election of officers having been completed, Mr. Faulkner called upon the newly-elected president to address the meeting. Mr. Goodwin, he said, as manager of a large group of pipe foundries, was in a position to voice the opinions of a very important section of the foundry industry.

PRESIDENTIAL ADDRESS.

Mr. Goodwin then delivered his presidential address, in the course of which he said,

Mr. Faulkner and Gentlemen:

I have the greatest pleasure in welcoming you all to this great city of Sheffield, the centre of the steel industry of this country. On the occasion of your last visit, nine years ago, we were busily engaged in the production of munitions of war in such quantities as made Sheffield the largest arsenal in the country. Since that time we have, in order to meet present requirements, reconstructed our shops, changed our methods of steel manufacture, and produced new classes of goods of such quality and price as to make our competitors as much afraid of us as were our enemies during the terrible years of the war.

Let me now express to you the deep appreciation I feel at the honour you have accorded me in electing me as your President. When I first joined our Institute, then the British Foundrymen's Association, twenty-two years ago, I little anticipated that I should one day be called upon to fill this important office. Later during your visit to Middlesbrough, in 1907, I came into close touch with the work the Council was doing, and was able to appreciate in some measure the responsibilities devolving on the President in guiding the activities of the Institute, and had the possibility of undertaking those duties been presented to my mind it would have appeared remote.

The Work of the B.C.I.R.A.

Perusal of the addresses delivered year by year by successive Presidents impresses me with the desire revealed therein to express the voice of the members as a whole, and with the possibilities which present themselves to the minds of the most far-seeing among our number. The Presidential address offers a very desirable annual opportunity of reviewing the immediate past and the requirements of the present, and of stimulating thought among members on lines likely to lead to necessary courses of action. Nothing in these addresses has impressed me more than the desire expressed for greater technical knowledge of the craft with which we are so closely associated. I was convinced that when the time was ripe the Institute would embark on a scheme for the systematic acquisition of this technical knowledge, and for the advancement of fundamental research. I had made up my mind that when the time arrived I would give all the help within my power to assist in the promotion of this project. In 1921 the opportunity arose, and I am proud to have been associated with those members whose combined efforts have so successfully brought into being the British Cast Iron Research Association, and who have thus fulfilled the desire expressed by you through successive Presidents. This came none too soon. A new organisation takes time and patience to establish, and this particularly applies to one established for undertaking research work. The difficulties to be met have been numerous. Contemplated under very auspicious trade conditions, the new Association actually started as the disastrous slump of 1921 was setting in. From the effects of this the iron and steel industry has not yet recovered, for while consideration of pig-iron and steel output statistics will show that the situation is now as favourable as at any time since then, there is, of course, still an inadequate margin between manufacturing costs and selling prices.

Nevertheless, I repeat that the formation of the British Cast Iron Research Association came none too soon. On every hand we have proof of extensive developments in research on cast iron not only in the United States of America, where industrial conditions are very good, but equally on the Continent, particularly in Germany, Belgium and France, where trade conditions are not dissimilar from our own. Far-reaching results have been obtained, and are being put into practical use in their foundries. A new organisation in this country was necessary not only to ensure that results of work published abroad could be made available here, but also to initiate research work of our own on British irons, melted in cupolas of our type with the fuel and refractory materials we have daily to use.

It is not necessary for those of us who are in the Association to state what measure of success it has achieved. This, fortunately for our modesty, has been done by an impartial authority in the form of an expert committee set up by H.M. Government in 1926. The extent of the appreciation by the Government of the work done is shown by the generous financial support which has been promised during the period 1926-31. This support is conditional on a better response from the industry than is at present being made, and it remains for you to bring your foundries into the co-operative scheme and to undertake to support the Research Association, which is successfully carrying out investigations the results of which are so important to the future of the founding industry. The annual subscription is small enough to be regarded as little more than an insurance premium, and those who wait for a personal approach before joining are seriously prejudicing the whole scheme, particularly in view of the time involved in making such an approach to all founders concerned.

We believe that membership is a matter of business sagacity, for not only does it help on an important national work, but it offers such opportunities of securing information and assistance as to make it a thorough business proposition.

I estimate that the industry could expend, with advantage to itself, and at an annual cost per firm which amounts, as I suggested above, to little more than an insurance premium, a sum of £25,000 per annum. At present one-third of this sum is available, half of which comes from the industry. For the next four years at least we shall continue to have the Government grant. Furthermore, now that the organisation is built up, for every £1 subscribed, £2 can be expended directly on work of assistance to members.

Apprenticeship Recruitment.

The inevitable growth of technical knowledge in the trade will call for men of higher intelligence and skill, and we must prepare to train our apprentices so that they may be ready to fill these positions in due course. Nothing at the moment is harder to fill than a senior position demanding a man with actual practical experience and technical knowledge. Men with this dual qualification have somehow to be produced, and this Institute must take a large part in their training.

Apprentices who show exceptional ability to absorb technical knowledge and to use it in a practical way should be given opportunities to attend *day* technical classes as well as evening schools, for foundry work is fatiguing. A special member of the staff with suitable qualifications should be detailed off to spend, say, an hour each day with the apprentices, instructing them in the correct way to make moulds and castings. Surely this is not impossible even in these days of bad trade and low prices.

We must also encourage to the full the young foreman by giving him opportunities of seeing other works and other methods. He can be encouraged to use a library by being made an associate member of the Research Association. He should be encouraged to experiment and to find out which are the best as distinct from the cheapest materials. An occasional monetary recognition of good work when justified will also be a welcome encouragement.

The shortage of boys entering the trade can be dealt with in various ways. The lack of interest shown is often due to lack of knowledge, and the foremen and men in the shops can do much to encourage their schoolboy sons and their chums to visit the foundry. They will talk about it to their respective mothers and thus the industry may secure useful recruits.

I feel convinced that the Institute has a great part to play in educational developments, and in the not distant future an educational scheme may be worked out. Working in the foundry is often considered a dirty occupation, although it is infinitely to be preferred to certain other occupations which on the surface appear much cleaner. In other trades of a similar character, of which coalmining is an example, the trouble has been met by providing washing accommodation and baths. Recreative facilities and opportunities for further education have also been provided. In the foundry we can do much in the way of better accommodation for clothes, for washing, etc., but even more important are working conditions. Special attention should be given to ventilation. so that it can be regulated to suit climatic conditions. When moulds are dried in the shop, either with open fires or portable furnaces, ventilation must be studied with still greater care. Lighting is also vitally important, and roof lights should be provided with means of easy access for cleaning. A works messroom and canteen is essential, and it should be a rule of the organisation that men who do not go home for meals should use the messroom, or at any rate that they should not take meals in the shop. Space will not permit me to mention other ways of improving the general standard of working conditions, often at very little expense. The question of works accidents deserves notice. Every foundry should encourage the men to join the St. John Ambulance Brigade, and to qualify themselves to attend to accidents. A great deal of unnecessary suffering is avoided by prompt attention to cases, even minor cases, which may become septic. Apart from the desirability of all cases having immediate attention, a matter about which the employee concerned is often careless, complications and possibly compensation cases are avoided.

Meeting Competition by Co-operation.

We have seen recently that the only way to maintain the standard of living in this country is, with the goodwill of the men in the shops, to increase output, and we have learned particularly that an increase in output reduces prices, stimulates demand and hence employment, and thus makes things better all round instead of diminishing the amount of work to be done and causing unemployment. In the foundry this means invariably the introduction of piece-work or contract work, which will have in turn the effect of specialising the foundry and thus centralising the production of a given article in a few foundries.

I would appeal especially, therefore, to those members who are practical men in and about the foundry to consider it their duty to do their utmost to enable their employers to meet competition and thus provide that continuity of employment which is so essential to both employer and employed. This continuity of employment is of great importance to the Institute, for the constant migration of members from one shop to another inevitably results in a number being lost to membership, doubtless owing to the feeling of uncertainty which accompanies a change of this kind. Apart from this the rate of growth has doubtless been lessened on account of the continuance of bad trade. The membership of the Institute in 1919 was 1,544, and the average for the last five years has been 1,567. The membership for 1927 shows a decided increase, and the number now totals 1,636. Similar conditions have applied to the Cast Iron Research Association. In 1921 the number of ordinary full members was 110, and in 1927 is 210, representing many more employees, and but for the conditions mentioned would have been much greater. Now that the period of stagnation appears to have passed, it behoves all of us to consider a plan of campaign to improve the membership of the Institute still further. To this end I make a definite appeal to all members to support me during my presidential year by each pledging himself to obtain one new member. With tne enthusiasm which exists I feel confident that this can be done. We should then have a membership which the Institute would be proud of, and funds with which to carry on its work with greater activity. I might mention, for instance, the Junior Sections, which have been so ably formed and which are in such a flourishing condition. I am sure that these are a guarantee for the future existence of the Institute, and I wish that more such sections could be formed.

Rationalisation.

An important development which I commend to your earnest attention is the movement spread with remarkable rapidity in Europe under the name of "rationalisation." Summarised "rationalisation," literally the making of industry right and reasonable, aims at securing the highest efficiency for the least effort, at eliminating all waste of raw materials, effort and labour in manufacture, transport and distribution, at simplifying designs, patterns, shapes and sizes where variations have no obvious advantage. It will ensure a higher standard of living, lower prices to the consumers and a larger and more certain return to the producers. It involves the goodwill and willing co-operation of employer and employee and joint efforts of scientific and technical institutions and research organisations. It has to be applied and can equally be applied to large and small undertakings, even to the small shopkeeper and to our domestic life. It means for the worker the healthiest, best and most dignified form of labour, for it involves selection for occupations, proper training and also promotion for those fitted for it, and for all the most attractive form of remuneration.

International Relations.

The work of the Institute is being fully appreciated by kindred organisations abroad. We are honoured this year by the award to one of our most esteemed members of a very signal honour. I refer to the John A. Penton medal, presented by the American Foundrymen's Association to Mr. John Shaw, to whom we offer our sincere congratulations.

The strengthening of ties with our friends abroad has always been the desire of the Institute. Through the good work done by your past-President, Mr. V. C. Faulkner, an International Relations Committee has been formed representing Belgium, Czecho-Slovakia, France, Germany, Great Britain, Holland, and the United States. The object of this Committee will be to promote interchange of papers and visits, to prevent overlapping of conferences and exhibitions, and to make arrangements with respect to periodical international conferences to which the members of all the co-operating bodies will be invited. The formation of this Committee has our cordial support, and we trust that it will go far to cement the friendship which already exists between the allied bodies abroad and ourselves. Your General Secretary is acting as honorary secretary to this new body, and in his capable hands the smooth working of the Committee will be assured. The Institute may reflect with pride on the fact that its international relations are probably more extensive than those of any other technical institute in this country, and there is no need for me to emphasise the important part this plays in promoting international understanding.

To attempt fully to review the work of the Institute for the past year in so short a space as is offered by a presidential address would be folly. I should, however, like to refer to one outstanding feature that I know to have been greatly appreciated, namely, the growing number of invitations extended to the Branch members to visit various works and foundries throughout the country. Neither the educational nor the social value of such visits can be too much stressed. To all those firms who have given us such valuable opportunities of extending our knowledge, and who have from time to time entertained us so hospitably, the thanks and appreciation of the Institute as a whole are due.

The honour you have paid me implies very great responsibility, of which I am fully aware, and with your loyal assistance I will endeavour to maintain the high traditions of the Institute throughout my presidential year, trusting at the end to see it in still more flourishing condition.

Gentlemen, I thank you.

Vote of Thanks to the President.

Mr. J. Cameron (Past-President), proposing a vote of thanks to the President for his Address, emphasised how keenly Mr. Goodwin had at heart the interests of the Institute and of the British Cast Iron Research Association. Mr. Goodwin was keen on making progress and finding out new things, and if every member took his words to heart and brought in one new member it would be a very fitting reward to Mr. Goodwin for his excellent Address.

Mr. A. Harley, seconding, expressed the conviction that the President would carry on the work of the Institute in a very efficient and able manner. The President was determined that during his year of office the Institute would make progress, and it was up to the members to support him whole-heartedly in his mission.

The vote of thanks was accorded with acclamation.

The President, in a brief response, said he was unable adequately to express his appreciation of the kind remarks which had been made, and the way in which the resolution had been received, but he again assured the members that he would do his utmost to carry on the work of the Institute in a manner which would give satisfaction to everybody.

The following Papers were then read and discussed.

"The Properties of Coke Affecting the Cupola Melting of Steel" (American Exchange Paper), by J. T. McKenzie.

"The Importance of Air Control in Efficient Cupola Practice," by P. H. Wilson.

"Strains in Non-Ferrous Castings," by Professor C. H. Desch, D.Sc., F.R.S., Member.

During the afternoon parties of members visited each of the following works:—Messrs. Edgar Allen

& Company, Limited, Cammell, Laird & Company, Limited, Vickers, Ltd., and Newton, Chambers & Company, Limited. At the conclusion of each visit the thanks of the Institute was given to the management.

ANNUAL CONVENTION DINNER.

WEDNESDAY, JULY 6.

There was a gathering of some 300 members and guests at the annual Convention dinner, which was held on Wednesday evening, July 6, at the Royal Victoria Hotel, Sheffield. The President was in the chair, and the guests included the Lord Mayor (Alderman J. G. Graves, J.P.) and the Mayoress, the Master and Mistress Cutler (Mr. and Mrs. David Flather), Mr. W. L. Hichens, Mr. A. J. Blanchard, J.P., Sir W. H. Hadow, C.B.E. (Vice-Chancellor of the University), the Mayor of Rotherham, the Mayor of Chesterfield, Mr. Barrington Hooper, C.B.E., Prof. T. Turner, Mr.. W. B. M. Jackson, Mr. J. A. Penton (Past-President, American Foundrymen's Association), Mr. E. J. Fox, Mr. J. Smith, J.P., Prof. C. H. Desch, D.Sc., Ph.D. (Professor of Metallurgy, Sheffield University), Mr. J. M. Allan, Mr. F. W. Bridges, Mr. Ropsy (Belgium), Dr. and Mrs. Piwowarsky and Herr Nipper (Germany), Mr. J. H. Monypenny, Mr. John Oakley, J.P., Mr. H. E. Yerbury, and Mr. T. P. Colclough, M.Sc.

Future of Sheffield's Industries.

The loyal toast having been duly honoured,

Mr. S. H. Russell (Vice-President) proposed the toast of "The City and Commerce of Sheffield," and in the first place expressed appreciation of the kindness and hospitality extended to the Institute by its friends in Sheffield. In a reference to the educational scheme which Sheffield University had launched a few years ago for the benefit of students and apprentices in the foundry trade, he said he hoped that it had flourished, because it was a really good scheme, which had attracted much attention throughout the country, and the Institute was glad to find that Sheffield was so progressive and could organise such a thorough and comprehensive educational scheme. Dealing with the development of Sheffield's industries, he pointed out that, as shown by the handbook which had been prepared for the members of the Institute, one of the largest steelworks in Sheffield, whose pre-war work was almost entirely Government work, had now practically replaced this by commercial work. When he read such names as Vickers, Cammell Laird, Newton Chambers, Edgar Allen, Brown, Firth, Davy, Samuel Osborn, Mappin and Webb, and so on, almost all of which were world-famed, he realised that, just as Sheffield was a leader and pioneer in the past, so Sheffield would again become a leader and a pioneer in the future. He firmly believed that when the present financial stringency, which affected practically the whole world, had passed away, Sheffield would again come into its own. Could one imagine a city which had produced and was still producing the best crucible high-speed steel in the world, and which had developed and still made the best stainless steel in the world, sinking into the background simply because it could not think of anything else to produce? He did not know what Sheffield would bring out of its hat yet, but he was quite sure that it would bring out something good very shortly. In a tribute to Mr. John Shaw, to whom he referred as a typical example of the Sheffield ironfounder, he said, amid laughter, that during his visit last year to America as a member of the delegation from this country Mr. Shaw had been so keen on visiting works that he had visited a works on one day, travelled all night, and visited another next morning. Continuing, Mr. Russell said that the great essential to the return of prosperity to the iron and steel trades was peace in industry, and he urged that that peace must be a just peace. The industry had a very big problem to face. Finally, he coupled with the toast the names of the Lord Mayor and the Master Cutler.

Sheffield Now Making Fine Iron Castings.

The Lord Mayor, in his response, said that a Lord Mayor of Sheffield always felt considerable pride when replying to this toast. He had a good deal of practice, but that in no way detracted from the pride which he felt in representing this great community, for they had not only a past of which they were unreservedly proud, but a vigorous present, and a hopeful outlook for the future. No city in the world had had a harder job to deal with than had Sheffield during the past few years. The difficulties had been formidable and the ordeal severe, but they were emerging and were feeling solid ground under their feet. They had drawn, as they had had to do, upon their reserves of inventiveness, enterprise, self-reliance, pluck and perseverance, and their great industries had adapted themselves in a way which he could only describe—knowing what he did of the conditions of the past six or seven years—as surprising and marvellous. The Institute's own handbook contained a very generous, but perfectly just, appreciation of the inventive ability, enterprise and leadership of the men who had founded Sheffield's great industries, and whose great names were still the signs of firms of world-wide reputation, and all that had been said of them could be said with equal truth and justice of their successors to-day. To Sheffield's workmen, also, the Institute had paid a just tribute. It had said that the Sheffield worker was a craftsman, and experienced non-technical men had shown uncanny knowledge of the steel which they produced, which would shame distinguished academics. He thanked the Institute for its generous appreciation, and for the great compliment it had paid to Sheffield in choosing the city as the meeting-place on this occasion. In a reference to post-war progress in Sheffield, in the course of which he dwelt upon the Corporation's efforts in regard to town planning, and the provision of houses, roads, transport, etc., he said that the foundry branch of the great iron and steel industry had shown versatility, adaptability and enterprise beyond all praise. For example, the progress made in the production of fine castings had come particularly under his notice in connection with his own business. He believed he could say that in pre-war days the Sheffield founders were not No. 1 in the production of extremely fine castings, and when it had become necessary to look around for new sources of supply, those who needed such castings had met with great difficulty. But, instead of going to sleep about it, the Sheffield founders had met their competitors on their own ground, and were now not only producing the equal of the fine castings which for some businesses it had been necessary to import, but had excelled their competitors. He was very pleased and thankful to recognise the international note which had been sounded at this conference. It was to him a matter of the greatest satisfaction to know that there were attending the Conference representatives of the progressive nations of Europe. Sad and painful as were the memories of the past few years, to-day our faces were turned towards the morning once more, and we looked to a better world, to safer, sounder and saner foundations of society than those which had resulted in the shocking catastrophe which we all lamented, and which had so disorganised industry. Great Britain showed how, in one small area, three nations could live together in peace, harmony and helpfulness. As another example he mentioned that along the 3,000 miles of frontier separating the United States and Canada there was not a soldier or a fort. Why should there not be in the future, through the medium of organisations such as the I.B.F., the United States of Europe? What we were longing for was peace in our industrial relations. That would not come through Acts of Parliament; it would come only when each of us did our bit towards it, and we had better not shirk the responsibility. There rested upon each one of us the responsibility to do our part in the building up of a better, safer and a more enlightened society. Finally, the Lord Mayor expressed his earnest and heartiest wishes for the continued success of the Institute.

Multiplicity of Technical Associations.

The Master Cutler, who also responded to the Toast, expressed the very real pleasure which it gave Sheffield to welcome the members of the Institute to the city. They might have a lot of smoke in Sheffield, but not so much as they would like. It was an old saying in Sheffield that "Where there is muck there is money," but they always added "provided it is clean muck." They were not doing enough business, but hoped and believed that the time would come when that deficiency was made good and when they would again flourish and would be able to look the world in the face. Sheffield undoubtedly had played a very great part in the advance of the iron and steel and many other industries and it was proud of that fact; it was proud that it had been able to help, on the technical and scientific side, so many trades and industries in this country. After a reference to the valuable work of the Sheffield University, he said there was another phase of knowledge leading to prosperity which even Universities could not give. By that he meant that only through the association of men who were interested in any particular subject could real progress be made. From the early days of, he believed, the seventeenth century, when the Royal Society was founded, men began to realise that only by combination, by mutual trust and help, could the truth be discovered and knowledge acquired, and as the centuries had rolled on the number of those associations had greatly and steadily increased. It might be that to-day we had too many associations, but the great point about technical associations was that they led men to know one another and to have trust and confidence in their fellows, and although individually they might be competing for the necessities as well as for some little of the luxuries of life their association together was bound to create good in industry, and in municipal, social and national life. Associations such as the I.B.F. tended to promote prosperity and to stabilise our industries. He would to Heaven that that spirit of mutual helpfulness was greater and he prayed that the time might come when the spirit of evil which led men to suspect their fellows of some ulterior motive would be cast out and when we should unite with the common object of improving the relations between man and man, between nation and nation, and when there would be in truth a United States of Europe. In the name of Sheffield and those engaged in its industries he expressed to the Institute the heartiest welcome, congratulated it upon the splendid work it had already done and hoped that it would prosper, to the advantage of its individual members, the Institute itself and to the advantage of the Empire.

How Technical Societies Help Their Members.

Mr. W. L. Hichens (Managing Director of Messrs. Cammell Laird & Company Limited), proposing the Institute of British Foundrymen, emphasised the national importance of the steel industry, of which the foundry trade was an important part. If the steel industry languished, he said, Great Britain would surely languish too, and it was to the interest of everybody to see that not only should the steel industry maintain its previous strength, but that it should increase it and become even greater in the future than it had been in the past. The steel industry had suffered considerable misfortune during the past few years. It had laboured under great difficulties; competition had been very fierce, work had been scarce, prices had been cut to the point which had dismayed all those engaged in the industry, and had delighted correspondingly all those who were not. They were not merely confronted with domestic competition and low prices emanating from a domestic source. They found that foreign competition was even more strenuous, and he believed that as regards foundry work foreign competition was as keen as in any other industry, and prices quoted by foreigners at the present time were sometimes so low as to cause dismay. He was quite convinced, however, that the steel industry could be restored to its former prosperity. Enumerating some of the great benefits which the I.B.F. could and did confer upon the foundry business, he said that in the first place the Institute as he saw it stood for solidarity and good fellowship among all those engaged in this great profession. Solidarity and friendship meant, he supposed, that if A discovered something which was of interest to the industry as a whole, he communicated it at once to B, C, D and the rest; but did he? No! He kept it to himself in the hope that no one else would find it out, and in so acting he behaved very foolishly, because each of us had ways and means, which we thought peculiar to ourselves, but which were in reality common to all, for discovering what he was up to. Therefore, it would really be wiser if A communicated straight away what he had found out instead of allowing everybody to exercise his ingenuity to discover it by devious ways instead of devoting his ingenuity to other and better purposes. Again, solidarity and good friendship meant that if B got into trouble he went to A or to some other who was not in trouble and asked for help to get out of it. But did he go to A or to some other and confess that he was in a hole? Not a bit of it. Therein he acted foolishly, because everybody found out that he was in a bit of a mess—and in the steel industry, from his own experience, everybody got into a mess at times. In such circumstances as he had indicated, B pretended that he was not in a mess at all, everybody else exaggerated the tittle tattle they heard all around, and the gossip was far worse for B than the truth. But supposing that when he got into a mess he did confide his troubles to A, what would A do? He doubted if A would do more than say that in that case B would have to be contented with his heart-felt sympathy. Probably it would not go farther than that. That was a pity, because British A, B and C were not really rivals the one of the other. They were much more the rivals of a foreign X, Y and Z, and what mattered for this country from the broad point of view was that our industry as a whole should be as efficient as possible, and that the weakest member, if there be a weakest member, should be helped by the stronger member so that as a whole we could be strong enough to stand up against foreign competition and that by a united knowledge and competition we should be able to face the strenuous opposition we were met with abroad to-day. He knew that he was regarded as a visionary, but he was quite unrepentant. He always asked for more than he expected to get and perhaps he had done that on this occasion, but surely we should do something more than we had done. For instance, we might, he considered, without the world coming to an end, allow each other freely to visit our works. That would not be going so very far. We might, for instance, compare costs. That was going a little further, but it was the right thing to do if we wanted to have a nationally efficient industry and not an individually efficient industry. We might compare methods with great advantage, and that was one of the directions in which he wished the Institute every success because it stood for the right thing.

Foreign Contacts.

There was another respect in which the Institute could and did perform a great service to the industry, namely, in the promotion of contact with our foreign competitors. He was glad to notice that a number of valuable papers by foreign experts had been read at the meeting and to know that foreign representatives were attending the Conference. That was the right thing because although he felt that in a sense the British were the rivals of the foreigners, yet in a wider and bigger sense they were comrades on the same quest, *i.e.*, the quest of the greatest efficiency in the steel industry for the sake of the whole world, and that was an ideal which was worth something. The Institute had done a great deal also in promoting tours and visits to works in other countries which was most valuable to this country, and, he hoped, useful to the countries visited, and he trusted that the Institute would be able to extend that. Discussing finally the development of education, he said there was a time—he did not know whether it had altogether gone by—when people used to say that foundry work was a rough kind of work and therefore it was not the kind of work that an educated man was likely to do. That was all wrong, for all experience went to show that the steel industry was becoming more and more dependent upon science, and the more we could attract men of eminent scientific attainments to take up work in our foundries and in the steel industry as a whole, the better it would be. But that was not all. It was even more important that we should encourage education among apprentices in the foundry business. He could not help believing that one of the great advantages that the Americans and Germans had over us in industry was that there was such a high standard of education in those countries amongst men engaged in industry. Finally, Mr. Hichens paid a tribute to Mr. Goodwin, whose valuable work was recognised and whose year of office would add lustre to the Institute of which he was so distinguished a President.

Results Achieved by the Institute.

The President responded, and, in thanking Mr. Hichens for the manner in which he had proposed the toast, said that the members of the Institute who had visited the works of Messrs. Cammell Laird & Company that day had been very much impressed with the great changes which had been made to meet present-day competition. The re-organisation of those works seemed to him to be the greatest monument to industry that he had seen lately. Not only was it apparent that the staff had worked exceptionally hard, but also that what had been effected was the result of round-table co-operation. The happy feeling which he had recognised among the staff of Messrs. Cammell Laird twenty years ago, when he had first visited their works, still existed, and had brought about the alteration of the works which everyone was so gratified to see. Referring to the Institute, he was happy to say that it was on the fringe of the work which Mr. Hichens had outlined. One result was the formation of the International Committee, in connection with which the immediate Past-President, Mr. Faulkner, had been to the Continent, and had worked very hard indeed on behalf of the Institute to cement that friendship with other countries which they all so much desired, and which they knew would be ultimately to the good of everybody in this country. He was also pleased to be able to tell Mr. Hichens that the friendship amongst the foundrymen of this country, to which reference had also been made, did exist. Barriers were being broken down yearly by the Institute, and nothing but good could result. The President then went on to deal with the development of the Institute since it was founded in 1904, at Birmingham, when the late Mr. R. Buchanan was elected President. Since that time the Institute had held Conventions in most of the large cities of the country, and the last Convention in Sheffield was held in 1918, under the Presidency of the late Mr. T. H. Firth. With regard to membership, he said that as the foundry trade was one that had suffered the most during the last five years of trade depression, it would be understood that membership had not increased as rapidly as had been hoped. However, from past experience it was found that as soon as there was the least improvement in trade the Institute obtained an increase in membership. At the moment the number was low in comparison, namely, 1,700. At the same time, one must not overlook the fact that the Institute now had an offshoot in the form of the British Cast Iron Research Association, the membership of which included a number of the Institute's members, and also that there were a number of would-be members who could not afford to be members of both. The 1,700 included trade members, each of whom represented a large number of employees, so that the information the Institute was able to send out was transmitted to a larger number than 1,700. In a reference to the ten branches, all of which were in a flourishing condition, he made special mention of the manner in which the London Branch had worked, as the result of which it had nearly doubled its membership. He did not know of any Institute which arranged for so many works visits as did the I.B.F., and he believed the Institute was doing more educational work amongst the practical men in the foundry than any other body was doing in a like manner for the membership represented. The junior sections of the Branches were also in a most flourishing condition, and it would be appreciated that the members of these junior sections would be the backbone of the Institute in the future. In regard to the Institute's charter, he was pleased to say that Sheffield had figured largely in obtaining it; it was due to the indefatigable energy and generosity of the late Mr. T. H. Firth that the Institute had become a chartered Institute.

The Cast Iron Research Association.

The formation of the British Cast Iron Research Association by members of the Institute was another matter to which the President referred. The programme before that Association, he said, was such that it would necessitate the expenditure of not less than £8,000 per year, to which the Government were contributing approximately 30 per cent. The Association had been formed in most difficult times, but it was in times such as these, when trade was bad and foreign competition was keen, that research work of the kind that the Association had undertaken was most needed. Unfortuately, also, it was at times such as these that an employer was least able and most unwilling to pursue them. Nevertheless, the Association was being favourably supported, not only by employers, who were fully alive to the fact that on every hand we had proof of extensive developments in research in cast iron abroad—in the United States, where trade had been good, and on the Continent, where conditions of trade were similar to our own —but also by employees, who were anxious that England should continue to produce "more perfect work, more finished work, more honest work, than any other nation in the world." He felt that good trade was coming. From past experience he knew that this meant increased prosperity to the Institute, both financially and numerically, and in order to maintain our trade he urged the adoption of the slogan, "All-British goods for British people," and support for the good work done by the greatest commercial travellers this country had ever known, and of whom we were so justly proud—the Prince of Wales and the Duke and Duchess of York.

Mr. Oliver Stubbs (Past-President), in the absence of Sir Robert Hadfield, Bart., F.R.S., who was unable to attend, and who had conveyed by telegram his good wishes for the success of the Conference, proposed "Our Guests and Kindred Associations." After expressing gratitude for the kind reception which Sheffield had accorded the members, he said the members were proud of the Institute because it was the only body which took a man out of the shop and brought him among others connected with the industry. In welcoming the Institute's guests from abroad, he emphasised that the more closely we were able to co-operate with those other countries the better should we be able to establish and maintain industrial peace. He coupled with the toast the name of Mr. J. A. Penton (Past-President of the American Foundrymen's Association).

Anglo-American Relations.

Mr. J. A. Penton, responding, said that although his visit to this country was partly a personal one, he had been anxious to pay his respects to this wonderful Institute of British Foundrymen. Americans, he said, were very deeply concerned with regard to the position of the iron and steel business in Europe, and not for selfish reasons. America was a prosperous nation, and there was market enough in their own country—the home market constituted over 90 per cent. of their business—without going abroad. They were deeply concerned sentimentally regarding the conditions of the iron and steel industry in Europe, and they realised fully the terrible strain that had been put upon all the nations of Europe in connection with the war, which had profited none, but had meant great loss to all. They considered that the greatest accomplishment and the greatest victory of the whole war was that of the nation which, beset with a great debt and heavy taxation, had put its currency on par. Americans took their hats off and bowed their heads to that nation for having made a serious effort to get on to her feet. Emphasising the importance of constant contact as a means of preserving peace between the nations, he said that the excellent relations which existed between the United States and Canada, with their contiguous frontiers, was largely due to the fact that they spoke the same language and knew each other as the result of constant association. Industrial peace was all very well, but international peace was a more vital factor. The one great power and the greatest influence of all in preventing conflicts in the future would be an affiliation between the English-speaking peoples of the world such as there was between Canada and the United States. These thoughts were also those of a great multitude of thinkers in his own country. He felt that the time was not far distant when the United States and Great Britain should so understand themselves and each other that they would both agree to march step by step for ever to the music of a band playing "Peace on earth and good will to men."

Mr. V. C. Faulkner (Past-President) proposed the toast of "The University of Sheffield." Owing to the late hour he curtailed his speech considerably, but he did take the opportunity to compliment the University authorities upon their astuteness and broadmindedness. He coupled with the toast the name of Sir Henry Hadow (the Vice-Chancellor).

Prizes for Practical Discovery.

Sir Henry Hadow (Vice-Chancellor of the University), who on rising to respond was greeted with enthusiasm, said that the University authorities were very glad indeed to join with the Lord Mayor and the Master Cutler and others in Sheffield in welcoming the Institute on this occasion. He stood, he said, as a representative of education, and education, he was glad to say, was one of the subjects upon which more nonsense was talked than any other in this country. He was glad because it was one of the symptoms of becoming a public institution in England that people should blame, criticise or discuss it when they had not devoted any great attention to the subject. A man who one would not ask to direct one to the Post Office was perfectly prepared to say what this country ought to do about China, but if one asked him if China was in Africa or South America he would shift the conversation to Ireland. (Laughter.) That was exactly what was happening on the topic of education. He was told on all hands and he read in all quarters that there were two kinds of education, the academic and the practical, and that not only had they different kinds of method, but different kinds of truth; that colleges and universities and such-like taught theoretical and truth that would not work out in practice. He was told that practical education was that which dealt with the truth by which people could live and by which they could work—with which the academic principle had nothing to do. There was no greater nonsense in the world than that. If Universities taught academic truth which would not work out in practice they would be merely the depositories of useless knowledge, and the sooner they shut up shop the better. If the members of the I.B.F. and their forbears had always tried to do without theory they would be sitting together that evening enjoying a banquet of raw wild beasts and very imperfectly distilled water. There was no education in the world worth the name which did not comprise both sides and co-ordinate both sides. The University authorities were fully aware of that, and because they were fully aware of it they were particularly glad to welcome the co-operation of those who were engaged on the practical side, who could learn something from the University and from whom in turn the University could learn something. Discussing the importance of pooling information, which had been mentioned by Mr. Hichens, Sir Henry drew attention to the fact that a short time ago the Company of Armourers and Braziers, which had been a very good friend to the University, had devoted an annual sum, which had been presented to the Master Cutler (who had kindly called in the co-operation of the University to administer it) for the purpose of encouraging research in the practical trades of Sheffield, of which the foundry trade was one. Prizes would be given, not on literary merit, but on practical discovery, and would be open to all workmen and members of the trade, and the prize-winning Papers would, if of sufficient merit, be printed and circulated for the common use. That was a very important step in the direction of that general co-operation which Mr. Hichens had so strongly desiderated. Referring to the advantages of providing facilities for visits to works, he recalled a conversation he had had with the head of one of the Great American firms some time ago whilst crossing the Atlantic. The American had told him that one of the principles which had always inspired and animated his work was to allow all his competitors entirely free access to his works, to show them everything, to explain everything and keep nothing back. When he (Sir Henry) had replied that other people to whom he had spoken on the subject had expressed misgivings and had said that possibly others might take away their secrets and use them to their detriment, the American had reflected for a moment, and he replied, "That's silly." That, continued Sir Henry, was a man with a life-long experience in the matter, and who knew what he was talking about. It had very much impressed him (Sir Henry), and he passed it on as a word of wisdom which he believed had its real educational value. Finally he paid a tribute to Mr. Faulkner, whom he said the University was proud to have as an old member.

During the evening the members and visitors were each presented with a Sheffield stainless-steel pocket knife as a memento of the Convention. It being remarked by the President that the recipients would probably like to cut their luck, they were invited to contribute towards the funds of the Sheffield Works Convalescent Homes. There was a liberal response, and the proceeds, which amounted to £13 15s., were handed to the Mistress Cutler, who is interested in the homes and who briefly expressed her gratitude.

THURSDAY, JULY 7.

The Thursday morning session commenced with a continuation of the discussion on Professor Desch's Paper, and the following Papers were then read and discussed.

" Note on the Making of Steam Engine Cylinders and Piston Rings " (French Exchange Paper), by M. Audo.

" The Influence of Chromium and Nickel on High Quality and Heat Treated Cast Irons," by Professor E. Piwowarsky.

" The Strength of Cast Iron," by J. E. Fletcher (Member).

" The Effect of Manganese and Manganese Sulphide in Whiteheart Malleable," by E. R. Taylor (Associate Member).

After adjournment for luncheon, which was provided at the University Western Bank, the Conference again resumed and the following Paper was read and discussed.

" The Manufacture of a Large Steel Casting," by F. A. Melmoth (Member) and T. Brown (Associate Member).

At the conclusion of the discussion, Mr. F. J. Cook, Past-President, proposed that the sincere thanks of the Institute be accorded to all who had helped with the Conference. Included in the resolution were the University of Sheffield the Lord Mayor and Lady Mayoress the Master and Mistress

Cutler the authors of Papers the firms who had allowed their works to be inspected, the subscribers to the Convention Fund and the Sheffield Conference Committee. The motion was carried with acclamation.

While the technical discussion was proceeding, the ladies visited the printing works of the "Sheffield Telegraph."

Later in the afternoon the members and ladies attended a Civic reception at the Town Hall, offered by the Lord Mayor and Corporation. In the evening a variety entertainment was visited by invitation of the Reception Committee.

FRIDAY, JULY 8.

On the morning of Friday, July 8, parties of members visited each of the following works:—Messrs. Davy Bros., Limited, Darnall; the Brown Firth Research Laboratories; and Messrs. Samuel Osborn & Company, Limited. At the conclusion of each of the visits the thanks of the Institute were tendered to the respective managements for their courtesy.

At a luncheon held at the Grand Hotel, at which a large number of members and ladies were present, Mr. J. T. Goodwin, the President, presided, and again voiced the thanks of the Institute to the various firms who had permitted the members to inspect their respective works. He particularly referred to the courtesy of Dr. W. H. Hatfield, who had personally conducted a party of members around the Brown Firth Research Laboratories that morning.

In reply, Dr. W. H. Hatfield, Director of the Brown Firth Research Laboratories and Past-President of the Sheffield Branch, expressed the pleasure of his directors and of himself at the opportunity of meeting the members of the Institute. He referred to the rapid growth of the Institute, both in numbers and in influence, and he also stressed the importance of the rapid developments in the metallurgy of cast iron which had taken place in recent years.

Visit to Buxton.

On the afternoon of Friday, July 8, the final event of the Conference took place in the form of a motor excursion through the Derbyshire Dales, a halt being made for dinner at Buxton. About 90 members and ladies participated, and, in spite of the somewhat showery weather, the party had a very enjoyable outing.

Mr. J. T. Goodwin, President of the Institute, presided over the dinner, which was held at the Palace Hotel, Buxton.

After the loyal toast had been honoured, Mr. G. H. Oxley, Vice-President of the Sheffield Branch, proposed the toast of "The Visitors," and referred to the pleasure which the members had in entertaining their guests, particularly those from other countries.

Prof. Piwowarsky replied on behalf of the guests, and thanked the members for the very cordial reception which the visitors had received throughout the Conference. He stated that the presence of overseas delegates at Conferences such as this would go far to cement the friendship between the various countries. He concluded by proposing the health of the President, which was drunk with considerable enthusiasm.

The President thanked the company, and referred to the work which had been done by the Sheffield local Committee in organising the Conference. He said that the success of the Conference was largely due to the hard work which had been done during the previous few months by the local Committee, and he also expressed the thanks of the members to the Ladies' Committee, and to their convener, Mrs. Frank Russell, for their work in connection with the ladies' social programme, and for the manner in which they had arranged for the welcome of the lady visitors to the Conference. He said that they were specially indebted to Mr. Firth and Mr. Edginton, respectively Past-President and President of the Sheffield Branch, and also to Mr. W. A. Macdonald, the Convention Secretary. On behalf of the Committee he had pleasure in presenting a fountain pen to Mr. Macdonald as a token of their esteem, and also a wallet of notes to Mrs. Macdonald.

Mr. Macdonald was accorded an enthusiastic reception upon rising to reply. He said that as soon as it became known that the Conference would be held in Sheffield he felt that it was his duty to assist in every possible way, and he had been loyally supported by every member of the Executive Committee and of the Branch Council.

He tendered his thanks to Mr. Makemson, the General Secretary, and his assistant, for the invaluable help which they had rendered. He said that anything which he had been able to do had been done with a good heart, and he hoped that when the members and ladies went back to their own cities and towns they would take with them pleasant memories of the few days they had spent in Sheffield.

THE PROPERTIES OF COKE AFFECTING THE CUPOLA MELTING OF STEEL.

By James T. MacKenzie, Chief Chemist, American Cast Iron Pipe Company, Birmingham, Ala.

[American Exchange Paper.]

Steel scrap in cupola mixtures has challenged the attention of foundrymen everywhere for a number of years. Many papers have been presented in the technical Press and before the various technical societies dealing with the strength of irons obtained from such mixtures, and it is almost universally accepted that steel scrap does increase the strength of the iron quite out of proportion to its effect on the chemical analysis. The recent work of Piwowarski on the influence of graphite nuclei has provided a valuable theory as a basis for future investigation and may serve to assist in the interpretation of some heretofore anomalous results. Accurate thermal data may be expected in the foundry literature of the future, because the development of the optical pyrometer has placed within the reach of everyone the means of observing and recording temperature. Recent investigation has shown that the disappearing filament type of pyrometer is accurate, within very small limits, for all types of foundry irons and the quickness with which readings may be made, even by an inexperienced observer, is remarkable. Many of the conflicting results obtained by the use of steel scrap are due undoubtedly to differences in melting conditions, of which the temperature is probably the most important. " Hot iron " is an indefinite term and may mean one thing when spoken by the stove-plate founder and something entirely different when spoken by the manufacturer of heavy castings.

Another cause of misunderstanding in discussions of steel has been the confusion of test bar and casting. The iron that will make the strongest test bar of say 1.25 in. dia. and 15 in. length will certainly make a poor radiator, if it will make it at all, and will be almost as unsuitable for a very heavy casting. This is one of the reasons why various statements exist as to the maximum permissible percentage of steel scrap in the charge, which, if memory fails not, varies from zero to 100 per cent.

Inextricably associated with the temperature of melting and the chemical composition of the melt, is the problem of oxidation. With steel in the mixture, the lower the melting temperature, the greater the oxidation, the lower will be the carbon, silicon, and manganese, and the higher will be the freezing point and the gas content. Consequently the practical fluidity, or "coulabilite" as Guillet and Portevin call it, is rapidly reduced.

This paper is concerned chiefly with the total carbon absorbed by steel scrap when melted with the various cokes of an unusual collection, not complete, but well representative and containing the extremes likely to be encountered. The cupola used was a Number 0 Whiting with a 27-in. shell, lined to 18 in. with clay brick, with 2 tuyeres 17 in. above the mantel plate and 70 in. below the charging door. The lining was straight from mantel to charging door. The tuyeres measured 9 in. by 3 in. at the lining; and the blast, supplied by a fan, was fairly constant at 4 oz. per sq. in. In some of the early heats the volume increased as the stock fell in the stack, but the practice was changed as soon as this was noted and thereafter the stack was kept full of coke throughout the melting period. None of the heats reported here was affected by this to a great extent, though in several heats a slight drop in carbon on the last tap or so may be noted. The cupola was lighted in the usual way and the wood allowed to burn away by natural draft, coke being put on to have the bed at 30 in. above the tuyeres when this was accomplished. The wind was then put on for five minutes to heat the tap hole and basin, after which the bed was built to 40 in. with fresh coke, the breast stopped in, the charges quickly put in and the blast put on as soon as the stack was filled (about 5 min.). The first tap was made in 25 min., when usually 25 to 75 lb. of iron were obtained, after which melting proceeded at the rate of approximately 1,000 lb. per hr. A shank ladle of 200 lb. capacity was used for handling the molten iron which was poured into pigs on the first two or three taps and then into well blacked and dried test moulds, giving the 2 x 1 x 28-in. bars cast vertically. Charges were 100 lb. with sufficient 50 per cent. ferro-silicon and 80 per cent. ferro-manganese to give the indicated composition. These were placed on top of the steel in the centre of the cupola. The coke charge was kept constant at 25 lb., except in the case of the high volatile petroleum cokes, Parco, Wichita Falls, and Shell. No fluxing was attempted, but there was usually a thin liquid slag which was allowed to run into the ladle and was skimmed off before pouring. The amount of this slag varied practically with the ash content of the coke, for it seems that the higher the ash the greater the oxidation of the steel and the proportion of ferrous oxide to silicon dioxide is thus automatically maintained. There was very little cutting of the lining except in the melts with the very high-ash cokes.

Table I shows the results for total carbon which are calculated from the detailed data of Table II. The base was taken as 2.00 silicon; 0.10 phosphorus; and 0.50 per cent. manganese. Pure iron holds 4.3 per cent. carbon in solution; 80 per cent. manganese, about 6.7 per cent. carbon; and 21 per cent. silicon (Fe_2Si), or 15.6 per cent. phosphorus (Fe_3P), throw the carbon to zero. Therefore the corrections are as follows:—

For each per cent. variation in manganese (3.4/80), 0.04 per cent. C.

For each per cent. variation in silicon (4.3/21), 0.21 per cent. C.

For each per cent. variation in phosphorus (4.3/15.6), 0.28 per cent. C.

The calculations are admittedly doubtful, but the sum of all three corrections is less than 0.20 per cent. in nearly all cases, and it seems the only hope of reducing all the melts to a common basis. Table II is given to enable anyone to make a detailed study of the actual results obtained undisturbed by the assumption of the author.

Turning again to Table I, it seems that in the beehive cokes the carbon rises as the ash falls, but in no regular way; while in the pure cokes the same thing is noted in regard to volatile matter. It is at once apparent that the structure of the coke is of fundamental importance and

TABLE II.

			Actual analysis.							
Coke.	Date.	Bar.	C.	Si.	P.	Mn.	S.	Calculated Carbon	Breaking load.	Defl.
Dayton	3/27/24	124	1.72	2.02	0.09	0.94	0.228	1.70	4,780	0.36
		125	1.70	1.76	0.07	1.08	0.184	1.63	5,000	0.35
	4/30/25	219	2.04	1.13	0.16	0.36	0.192	1.86	4,300	0.28
		220	1.96	0.88	0.11	0.38	0.173	1.73	3,250	0.21
	5/4/25*	225	1.89	3.39	0.13	0.67	0.236	2.18	3,600	0.29
	(4/30/25)	226	1.99	3.42	0.13	0.42	0.254	2.29	4,230	0.34
Sewanee	5/5/25	227	1.96	1.88	0.13	1.04	0.105	1.91	5,100	0.34
		228	1.73	1.71	0.12	0.30	0.102	1.68	5,100	0.34
	5/8/25*	233	2.62	1.95	0.14	0.73	0.156	2.60	3,700	0.32
	(5/5/25)	234	2.56	1.86	0.14	0.37	0.155	2.53	3,000	0.22
Fire Creek ..	8/14/25	316	2.09	2.22	0.10	0.33	0.102	2.13	3,700	0.31
		317	2.18	1.45	0.10	0.45	0.098	2.06	4,600	0.28
Bradford	7/30/25	300	2.78	2.55	0.09	0.38	0.119	2.90	3,650	0.35
		301	2.75	1.89	0.05	0.29	0.107	2.73	3,680	0.33
	8/1/25*	304	3.45	1.71	0.12	0.33	0.140	3.39	3,180	0.40
	(7/30/25)	305	3.25	2.04	0.11	0.34	0.134	3.26	3,000	0.35
A.B.C.	3/19/24	113	2.48	2.94	0.05	1.52	0.111	2.64	3,090	0.28
		114	2.74	2.05	0.05	1.24	0.121	2.72	4,570	0.41
	5/1/25	221	2.34	1.64	0.11	0.40	0.126	2.26	3,800	0.26
		222	2.23	1.40	0.10	0.27	0.113	2.11	3,250	0.21
	5/6/25*	229	2.85	2.46	0.12	0.51	0.173	2.95	3,500	0.34
	(5/1/25)	230	2.85	2.30	0.14	0.67	0.156	2.90	3,600	0.37
	7/17/25	288	1.45	0.04	6.46	0.26	0.161	2.80	1,050	0.09
	(20%Fe_3P)	289	1.81	0.04	4.80	0.24	0.124	2.70	920	0.07
	7/20/25	292	1.91	4.35	0.08	0.50	0.140	2.35	3,500	0.32
	(20% Fe_2Si)	293	2.15	3.60	0.15	0.48	0.132	2.49	3,300	0.30
		294	1.98	3.51	0.15	0.49	0.131	2.30	3,200	0.27
A.B.C. Bed ..	7/21/25	295	2.58	2.22	0.11	0.29	0.160	2.63	3,450	0.37
With 40% ..	(10%Fe_2Si)	296	2.65	1.75	0.16	0.28	0.149	2.61	3,400	0.37
Barrett Above ..										
(Steel from Shell	8/5/25	308	2.50	2.83	0.06	0.27	0.188	2.68	3,450	0.29
Coke Experiment)		309	2.72	0.69	0.08	0.20	0.154	2.44	3,000	0.21
A.B.C. 50 per cent.	8/29/25	336	3.09	1.95	0.08	0.38	0.189	3.10	3,400	0.34
W. Falls, 50 ,,		337	3.21	0.80	0.12	0.26	0.192	2.97	3,060	0.22
AB.C.	1/21/27	402	2.17	1.04	0.09	0.39	0.062†	1.97	3,690	0.27
Unbroken (Steel ..	3¼″	403	2.12	1.52	0.11	0.47	0.077	2.02	4,290	0.27
Round)		404	2.16	1.95	0.08	0.47	0.066	2.15	4,970	0.44
		405	2.26	1.00	0.12	0.25	0.070	2.16	3,360	0.25
(Steel, ¾ in.	1/22/27	406	2.30	1.52	0.07	1.29	0.110	2.20	4,700	0.31
Round)		407	2.30	1.50	0.06	0.29	0.122	2.20	4,200	0.29
		408	2.27	1.85	0.09	0.36	0.104	2.24	4,240	0.28
		409	2.52	0.95	0.05	0.41	0.102	2.30	4,100	0.28
		410	2.31	2.32	0.08	0.28	0.080	2.38	3,740	0.29
(Steel, ⅛ in.	1/29/27	411	2.00	2.26	0.07	0.32	0.115	2.05	3,730	0.27
to ¼ in. thick)										
		412	2.14	2.14	0.08	0.28	0.118†	2.17	3,510	0.24
Barrett	3/13/24	107	3.37	2.25	0.02	0.61	0.092	3.42	3,200	0.46
		108	3.27	3.28	0.04	1.32	0.080	3.52	1,950	0.42
	3/31/24	129	3.47	1.20	0.18	0.52	0.266	3.30	3.120	0.39
		130	3.28	1.70	0.17	0.48	0.130	3.22	3,320	0.43
	4/2/24	131	3.11	1.96	0.89	0.40	0.119	3.32	3,660	0.34
	5/2/25	223	4.05	1.50	0.09	0.44	0.106	3.95	2,100	0.49
(Coke, 35 lbs.)		224	3.92	1.17	0.11	0.29	0.104	3.75	2,600	0.41
	5/7/25*	231	4.18	2.36	0.12	0.54	0.097	4.26	1,930	0.57
	(5/2/25)	332	4.09	2.70	0.12	0.38	0.095	4.23	1,750	0.51
Bayonne	6/11/25	240	3.75	1.36	0.05	0.61	0.122	3.62	2,600	0.36
		241	3.68	0.90	0.06	0.55	0.170	3.45	2,490	0.23
Parco	8/6/25	310	4.42	1.16	0.09	0.82	0.141	4.24	1,920	0.54
		311	4.33	1.70	0.10	0.66	0.125	4.27	1,700	0.46
W. Falls	6/11/25	No melt	—	—	—	—	—	—	—	—
Shell	8/4/25	No melt	—	—	—	—	—	—	—	—

* Remelts of heat in parentheses. † Evolution Sulphurs on bars 402 to 412 inclusive. All others oxidation.

TABLE I.

Coke.	Oven.	Ash.	Volatile.	S.	Porosity.	Shatter.	S. G.	C.	Appearance of coke.
Dayton	Bee Hive	17.0	0.4	1.7	59	70	1.94	1.73	Dull grey, overburned.
Sewanee	Bee Hive	16.9	0.7	0.6	—	80	—	1.80	Silver bright.
Fire Creek	Bee Hive	5.8	0.6	0.5	59	93	1.94	2.10	Dull, light grey.
Bradford	Bee Hive	3.9	0.5	0.5	50	50	1.80	2.81	Silver bright.
A.B.C.	By product	10.0	0.7	0.6	46	68	1.92	2.50	Dull, dark grey.
A.B.C.	Unbroken	—	—	—	—	—	—	2.17	Dull, dark grey.
Barrett	Bee Hive	1.1*	0.9	0.4	47	88	1.85	3.38	Dull black.
Bayonne	Unknown	0.1	5.0	1.2	—	75	—	3.54	Dull black.
Parco	Still residue	0.2	15.0	0.5	—	55	—	4.27	Shiny black.
Wichita Falls	Still residue	0.3	14.0	1.4	51	52	1.92	No melt	Dull black.
Shell	Still residue	1.4	18.0	1.4	—	—	—	No melt	Dull black, badly broken.

* Largely dust from long storage—the new coke runs about 0.4 per cent. ash. This extraneous excess would not affect the properties of the coke.

Carbons calculated to basis of 2.00 per cent. Si, 0.10 per cent. P, and 0.50 per cent. Mn.

Shatter is amount remaining on 2 in. screen after 4 drops from 6 feet.

Porosity (or cell space) determined according to A. S. T. M. standard method.

may counteract to a considerable extent the effect of the composition. The two high-ash cokes have little difference in structure and little in carbon absorption. The Bradford is much softer than the Fire Creek (which is extraordinarily hard and dense), and so carburises to an extent not warranted by the difference in ash. Coming to the pure cokes, the Barrett is hard and dense (really a true coke), the Bayonne quite cellular, and the others highly cellular. In fact, the Wichita Falls burned along the cell walls so rapidly that small pieces were blown out of the stack in a veritable shower, which no doubt accounted for its failure to melt. The Parco was much better, and gave few sparks of this nature, but required an inordinately long time to begin melting, and then melted very slowly. The furnace was 70 minutes in blast before any iron melted, and then it came slowly but hot, throwing out great quantities of "kish" as it was being poured. The Shell coke was so broken up in its long journey in bags from the Pacific Coast that it was almost useless to try it, but under the heat it melted down to a soft, gummy mass, so no deductions could be made from its original structure. While it is not thought that the volatile matter has any influence *per se*, on escaping it probably leaves the coke in a more porous condition than originally.

In an able paper published by Mr. F. Hudson in The Foundry Trade Journal, December 11, 1924, entitled "The Melting and Casting of High Duty Irons," the four points influencing the absorption of carbon are stated as follows:—(1) Temperature in the melting zone; (2) time in the melting zone; (3) atmosphere of combustion; and (4) initial analysis of material melted. That these are true there is no doubt, for the first two and last are special statements of the fundamental laws of solution, viz., temperature, time of contact, and concentration. The third, based on the known chemistry of the iron-carbon-oxygen system, is probably better fixed in the minds of foundrymen than the other three. The author would, however, question the restriction implied in the words "melting zone," for he is convinced that absorption can and often does continue in the hearth following exactly the laws stated above. Running only 15 per cent. steel on A B C coke he has observed a constant difference in total carbon of 0.10 per cent. when tapping intermittently as against continuous flow, the latter being about 3.50 per cent. and the former 3.60 per cent.; this on the large foundry cupolas running heats of 10 hours.

Since only the melting of steel scrap is being considered, where the original material is nearly the same in all cases, these principles may be restated as:—(1) Temperature; (2) time of contact *with carbon;* and (3) atmosphere of combustion. Looking at the problem solely from the standpoint of the coke, the case may be stated:—That the temperature depends on the purity, reactivity and size of the coke in the melting zone and below; that the time of contact depends on the purity and size of the coke, for the higher the ash the more will be the tendency to cover up the carbon by slag and prevent contact with the metal; and that the atmosphere of combustion depends on the purity, reactivity, and size of the coke. Since the reactivity depends on the purity and physical structure, and since the effective size of the coke depends on the structure, one may assume that the extent of carburisation depends on the purity and structure of the coke.

Unfortunately, the testing of coke has not reached the plane of true science, and, although it can be taken for granted that the reactivity is a function of structure, no one is yet sure of a test that will indicate the right structure for maximum reactivity. It would appear that for carburisation, coke should not be either extremely dense or extremely porous; that it should be neither too hard nor too soft; and that it should be neither very heavy nor very light. A hard, dense, heavy coke will tend to allow oxygen to persist a long distance above the tuyeres, and the molten metal will flow over a comparatively small surface of coke on its way through the melting zone, where most of the carburisation takes place.

Just as rock candy is harder to dissolve than loaf sugar, so is the dense carbon more difficult to dissolve than the light, though time of contact is probably the explanation of both. On the other hand, a soft, porous, light coke will burn almost entirely to carbon monoxide close to the tuyeres, with consequently low temperature, and it will easily crush down and either shut off the blast or blow out of the stack as did the Wichita Falls. Undoubtedly, if high temperature can be obtained with a soft, pure coke, the metal can easily be saturated beyond the eutectic. A medium structure would appear in general to give the maximum carburisation, even if temperature is somewhat sacrificed, for the highest temperatures obtained were with the Fire Creek and Barrett cokes, but neither gives the best carburisation for its class. By increasing the amount of Barrett to 35 lbs. per charge, or the same ratio as the Parco heat of 5/2/25, carbons of nearly 4 per cent. were obtained at temperatures approximating 1,600 deg.

This is not truly comparative, since 35 lbs. of Parco coke contained only 30 lbs. of carbon, and the Barrett contained almost 35 lbs., but the test is illuminating as an illustration of the effect of higher temperature and greater time of contact using the same coke thus eliminating the effect of all other variables.

The melts with unbroken A B C coke show clearly the effect of the coke size on the carbon absorption. For all other tests on this cupola, the coke was carefully broken up so that no piece would stay on a two-inch screen; but in these three tests large lumps of coke, none of which would pass a two-inch screen, were used throughout and the carbon dropped 0.3 per cent. from the average for the broken coke in spite of the same temperature obtained under both conditions (1,500 deg. C.).

The experiment with Wichita Falls and A B C, 50 per cent. each, above a bed of A B C is interesting, Table II—heat of 8/29/25. Here a corrected carbon of 3.04 per cent. was obtained from the mixture, though the temperature given was rather low (1,450 deg. C.). Thus by mixing a coke (or probably pitch would be more accurate) of high reactivity with one of good structure, results may be obtained not possible with either alone.

As most of these melts were made on mild steel scrap of nondescript character and with a considerable variation in size from that desired (1 in. round), it appeared worth while to run some tests to see if ordinary variations in size had any effect on the carbon absorption. A 500 lb. length of 3.25 in. round mild steel (0.16 per cent. C, 0.06 per cent. P, 0.43 per cent. Mn, and 0.038 per cent. S) was cut into 8-in. lengths and melted (heat of 1/21/27). The next day a similar test was run with 0.75 in. round of the same analysis cut to 8 ins. The heat of 1/29/27 was run on thin strips of the same steel, varying in thickness from ⅛ to ¼ in., and in width from 1 to 2 ins., as there was not sufficient of one particular size in stock to make up a complete melt. The large steel was heavier than anything used in these tests, and the thin strips were lighter than anything used in them, while the ¾ in. round would almost represent the average. It is evident that the carbon absorption does not depend on the size, for the average of the large bars and the thin strips is the same. For some reason the temperature of the ¾ in. round melt was fully 50 deg. higher than the other two, and the carbon is 15 points higher. These tests prove that carbon is not absorbed to any appreciable extent by the solid steel though the reverse may be noted on the sulphur, which seems to be absorbed much more readily by the small stuff. Another interesting confirmation of this is the melt of 8/5/25. This steel had been in the cupola for over an hour under blast, trying to melt it with the Shell coke. When the test was abandoned and the bottom dropped, the whole body of the steel was somewhere between 900 and 1,200 deg. C., but only a few pieces showed the slightest signs of melting. To test the question of carbon absorption, the author examined several of these under the microscope, finding the merest film of carbon, so it was decided to melt it with A B C coke as a further test on this point. The carbon on the melt, 2.56 per cent., is just 0.06 per cent. above the average for this coke on new steel, and is well below some other melts, so it is thought there is no doubt of the accuracy of the generalisation, which was also made by Mr. Hudson (loc. cit.).

Table III shows the equalised carbons on five melts which were remelted with slight additions of silicon and manganese, using the same coke. The metal from the first melt was largely in pigs, and therefore considerably heavier in section than the steel. The average was approximately 2 × 3 × 8 ins. with some few pieces as large as 4 × 4 ins

TABLE. III.

Coke.	Carbon, 1st melt.	Carbon, 2nd melt.	Carbon absorption, 2nd melt.
Dayton ..	1.80	2.23*	0.43
Sewanee ..	1.80	2.57	0.77
Bradford ..	2.81	3.33	0.52
A B C ..	2.18†	2.93	0.75
Barrett ..	3.85	4.25	0.40

* Cold melt. † Scaffolded.

The original A B C heat scaffolded after the second tap, because of some rods a little too long in the charge, so that it is not truly representative of the melts of this coke, but the remelt went off in great shape. The remelt on the Dayton coke was sluggish, probably due to oxidation and high sulphur, though the silicon was abnormally increased in anticipation of this result. It was difficult to get an accurate reading on it, but it was estimated that the temperature was about 1.400 deg. from the cupola, which is close to the liquidus for such a low carbon.

This set of tests is to be extended for a discussion of the equilibrium point of carbon in the cupola. For this, sufficient quantitative data are not yet available, but the writer trusts they will be completed and published in the near future. There has been, perhaps, sufficient work to show that each coke tends to produce a certain definite carbon content in the melt. For a given coke this is affected by the elements other than carbon—particularly phosphorus, silicon, and manganese, and by the proportion of coke to iron and coke to blast. For the same iron and blast ratio, and the same iron composition, it will vary as the purity and structure of the coke. Thus on A B C coke, the remelt of steel 0.2 per cent. carbon reaches 2.93 per cent. and the remelt of the 4.15 per cent. pig shows 3.55 per cent. carbon (first melt 3.78

per cent.). The result from a synthetic pig of 2.95 per cent. carbon (first melt 3.30 per cent.) showed 3.46 per cent. carbon. Undoubtedly if the steel had again been remelted, the carbon would have risen again. The above values are plotted in Fig. 1 with similar results for the Barrett coke. The diagrams clearly indicate equilibrium points of 3.55 per cent. C and 4.20 per cent. C for these respective conditions. It is evident that under repeated melting the time of contact will cease to be of importance, as time equilibrium will be reached, and that the temperature and atmosphere of combustion will be the controlling factors. Aside from the effects of phosphorus, silicon, and manganese on the solubility of carbon in iron, all fairly well established, the equilibrium point for carbon will depend on the deoxidising constituents of the melt—manganese, silicon, titanium, etc.; the oxygen, carbon dioxide, and carbon monoxide content of the gas; and the temperature of the whole system. As the temperature and composition of the gas phase depend on the purity and structure of the coke, the amount of the coke, and

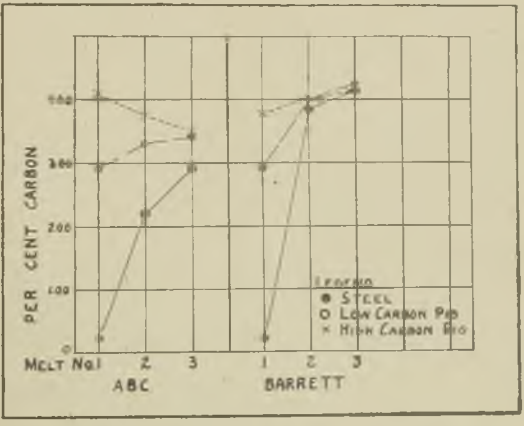

FIG. 1.—SHOWING TENDENCY FOR ALL MATERIAL TO COME TO SAME CARBON CONTENT ON REPEATED MELTING, THIS POINT BEING DEPENDENT ON COKE AND BLAST.

the velocity of the blast, it is hoped that suitable tests for coke can be devised whereby the equilibrium point for the particular coke can be predetermined with fair accuracy for any given set of conditions.

In conclusion it is our privilege and pleasure to extend to the Institute of British Foundrymen the cordial greetings and best wishes of the American Foundrymen's Association, and to express the hope that we may be drawn closer and closer together by these annual exchanges of thought which are the very pledges of international goodwill.

THE IMPORTANCE OF AIR CONTROL IN EFFICIENT CUPOLA PRACTICE.

By P. H. Wilson, M.I.Mech.E. (Stanton Ironworks Company, Limited).

Efficiency and economy are the two essentials in the successful operation of any process. As the cupola is often referred to as the heart of the foundry, it is essential that it should not be considered merely as a shaft into which so much iron and coke is dumped, and air blown through to produce iron in a molten state. This used to be the case years ago, but to-day most foundrymen realise the importance of more scientific control in the process of melting iron.

In the production of any class of casting it is, in the first place, important that the molten iron is of the correct composition and at a suitable temperature for casting. It is false economy to attempt to reduce coke consumption at the expense of a high percentage of waster castings. To produce suitable molten iron economically many factors must be dealt with. These will be treated in their proper sequence.

The real efficiency of a cupola may be measured by the ratio of the heat in the molten metal to the heat generated in the cupola. Thermal balance-sheets have been published in Papers by many writers on this subject during the last few years. The conclusions arrived at from these balance-sheets show that it is chiefly the value of the perceptible and latent heat lost in the gases which decides the thermal efficiency of a cupola furnace. In other words, the cooler the escaping gases, the higher the percentage of carbon dioxide, or conversely, the lower the carbon monoxide in the gases, the greater the heat efficiency of the cupola. Many ideas have been tried to utilise the waste heat passing up the cupola stack, but very little success has been attained in this direction.

Many cupolas operating successfully to-day vary very little in design from those in use fifty years ago. Whilst the results obtained depend on certain principles in the design of a cupola, it is not the writer's intention to deal in this Paper with these details, apart from the construction which directly affects the air supply and distribution of the products of combustion.

The composition of the molten metal is more or less determined by the analysis of the materials charged into the cupola, but inefficient working has a serious effect on certain elements in the iron during the melting operation. Silicon and manganese may be considerably reduced due to excessive oxidation. Further, the absorption of detrimental gases affects the temperature and fluidity of the molten metal; also its physical and mechanical properties.

The efficient working of any cupola depends primarily on the quantity of air supplied at a suitable pressure according to its capacity. The melting capacity of a cupola is determined by its effective diameter at the melting zone. It has been proved that good results are obtained in practice by burning 1 lb. of good coke per hour per sq. in. of cross-sectional area at this point. This is equivalent to from 10 to 12.5 lbs. of iron melted per sq. in. of area per hour. Therefore, a cupola with a diameter of, say, 4 ft. 6 in. is capable of melting economically approximately 10 to 12.5 tons per hour.

By this it will be seen that the figures given for the melting capacity of a cupola relative to its cross-sectional area at the melting zone vary to the extent of 25 per cent. This is dependent on the percentage of coke consumption to iron melted, and also the percentage of carbon in the coke.

The melting rate per hour can be calculated for any sized cupola given the coke consumption per ton of iron and the diameter, as follows:—

M = Melting rate in tons per hour.
D = Diameter of cupola in inches.
P = Percentage of coke to iron (by weight).

$$M = \frac{\pi D^2 \times 1 \times 100}{4 \times P \times 2240} = \frac{D^2 \times 100}{2851\,P} = \frac{0.0351 \times D^2}{P}$$

For example, in a 4 ft. 6 in. dia. cupola with a coke consumption of 8 per cent. the melting capacity would be:—

$$M = \frac{0.0351 \times 54^2}{8} = 12.78 \text{ tons per hour.}$$

If the coke ratio is 1 to 10, or 10 per cent., the melting rate would be 10.2 tons per hour. From the above it will be seen that the higher the coke to iron ratio the greater the melting capacity of the cupola per hour.

Having determined the output of the cupola, the amount of air required can be arrived at from the equation :

$$\begin{gathered} C + O_2 = CO_2 \\ 12 + 32 = 44 \end{gathered}$$

That is to say, to combust 12 lbs. of carbon completely to CO_2, 32 lbs. of oxygen are required. This is equivalent to 11.6 lbs. of air or 152.4 cub. ft. per lb. of carbon.

As the quality of coke varies, the carbon content must be taken into consideration in calculating the volume of air required per lb. of coke. Further, the volume of air per ton of iron melted will vary with the quantity of coke used per ton of iron.

This can be estimated for different diameters of cupolas for any given coke ratio of a known carbon content, as follows :—

V = Vol. of air per hr. in cub. ft.
v = Vol. of air per ton of iron melted.
D = Dia. of cupola in inches.
P = Percentage of coke to iron charge (by weight).
C = Percentage of carbon in the coke.

$$\therefore V = \frac{\pi D^2 \times 1 \times 152.4 \times C}{4 \qquad\qquad 100}$$

$$v = \frac{V}{M} = 34.54\ C.P.$$

This gives the theoretical volume of air necessary, but in actual practice allowance must be made for loss through various causes. This amount of loss will depend on the position of the blast-indicating instrument relative to the tuyères. Usually it is placed on the air main leading to the wind belt, and in a position convenient to the operator. The actual loss between the blast gauge and the tuyeres can be estimated for any cupola according to the general arrangement of the piping, etc.

Having obtained this, the actual volume required at the point at which the blast indicator is fixed can be calculated as follows :—

L = The percentage loss.
V_m = Actual volume of air per min.

$$V_m = \left(\frac{\pi D^2 \times 1 \times 152.4 \times C}{4 \times 60 \times 100}\right) \times \left(1 + \frac{L}{100}\right)$$

$$V_m = 0.01994\, D^2 C \times \left(1 + \frac{L}{100}\right)$$

The method of introducing the air into the furnaces is the next consideration. Various types of tuyères are in use, being circular, square, rectangular and oval shaped, both parallel and flared. In some cases a single row and in others two or more rows are used.

The number and shape of tuyères has long been a debatable point. The main point, however, is that they should be sufficeintly large to admit the correct quantity of air, at a pressure not higher than necessary for the air to penetrate the coke bed and distribute it uniformly at the melting zone.

Having found the pressure necessary, and knowing the volume of air to be passed, allowing for loss in friction, etc., the correct tuyère area can be calculated to give the necessary result for any size of cupola. Therefore, the ratio of the area of the tuyères to that of the cupola will vary according to the area of the cupola.

The 4 ft. 6 in.-cupola under consideration, in which most of the tests reported in this Paper were carried out, has a staggered row of tuyères oval in shape, the area being 18 per cent. of the cupola area, and it has been found that a pressure of 18 in. w.g. is adequate to give a proper distribution of the air.

Another important detail in tuyère design is that each tuyère should be fitted with auxiliary valves, so that when working dirty they can be shut off and burned clear. Poking of tuyères should not be necessary, but it is advisable to provide hinged site holes, through which a bar may be inserted to remove any obstruction. Such an arrangement is shown in Fig. 1.

The effective height of the cupolas (that is, the distance from the top of the tuyères to the charging door) is important. The depth of the well is not so important, this depending on the requirements of the foundry. As the effective height determines the time contact between the hot gases and the burden, the higher this is the more heat is taken from the gases by the descending charge. There is, of course, a limit to the carrying capacity of the coke. A height equivalent to from four or five times the diameter at the tuyere level has been found to give good results.

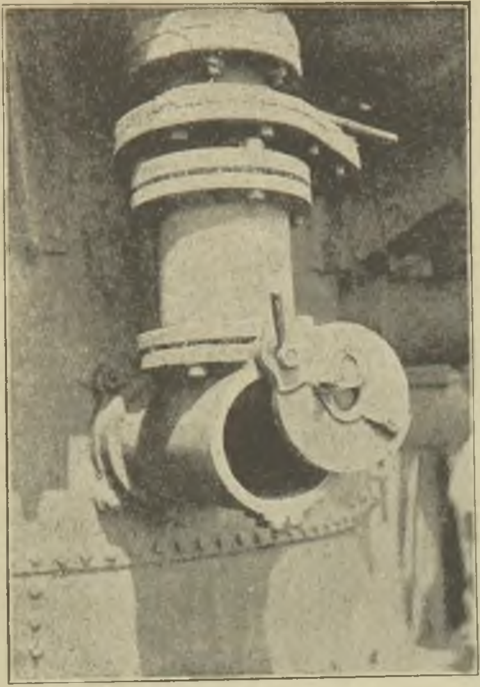

Fig. 1.—Hinged Site Hole for Removing Obstructions.

In mechanically-charged cupolas these may be greater to allow a level deposition of the charges below the charging doors. To prove how the "effective height" of a cupola affects the temperature of the rising gases, temperatures of the gases were taken simultaneously at different heights up the stack on two cupolas. The figures obtained were as follows:—

	Cupola A	Cupola B
Effective height	21 ft.	12 ft. 6 in.
Diameter at tuyères ..	4 ft.	4 ft. 6 in.
Ratio (height ÷ diameter)	5.25	2.77

The temperatures obtained in deg. C. were:—

Cupola A.		Cupola B.	
At charging door ..	280	At charging door ..	450
9 ft. below ..	440	2 ft. 6 in. below ..	600
13 ft. ,, ..	900	6 ft. below	900
16 ft. ,, ..	1,160	8 ft. 6 in. below ..	1,220
At tuyères	1,600	At tuyères	1,650

Blast volume per min. (cupola A) .. .. 5,000 cub. ft
,, ,, ,, (cupola B) .. .. 5,400 cub. ft.

Blast pressure w.g. in inches (cupola A) 19
,, ,, ,, ,, (cupola B) 18

It is obvious from the above figures that the effective height of cupola B is too low compared with A, the loss in perceptible heat being high, escaping gases being much cooler in the higher cupola. These results are shown in graphical form in Fig. 2. The temperatures were taken with thermo-couples of various types. For the higher temperatures these were enclosed in nichrome steel sheaths, which melted immediately after the readings had been taken. The temperature at the tuyères was taken with a "Disappearing Filament Pyrometer."

It is interesting to note that the cupola A melted during the one heat 250 tons of metal, and very little variation in temperature was noted during that period. Thompson and Becker point out in their Paper* on "The Chemistry of the Cupola" that when in equilibrium a mixture of CO and CO_2 tends as the temperature falls to change its composition so that a definite amount of each gas is present at a definite temperature. This would tend to cause in the stack a gradual disappearance of CO and its conversion into CO_2.

This is a slight argument in favour of cooling of the gases. Of course, this reaction will be greatly minimised owing to the high velocity of

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* Proceedings, Inst. Brit. Foundrymen, Vol. xix., p. 156.

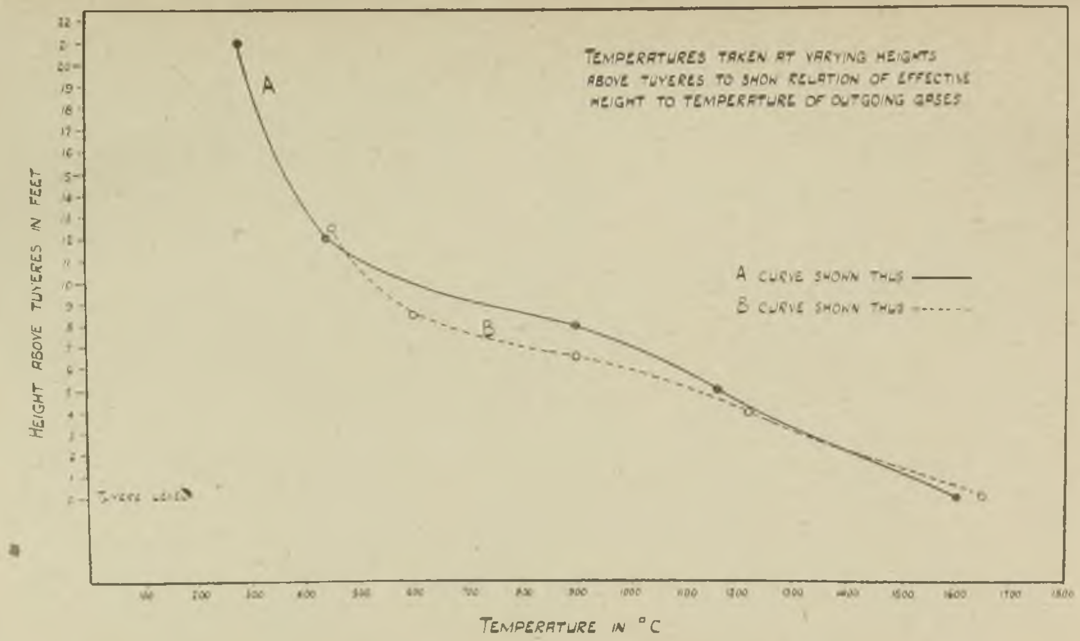


FIG. 2.—TEMPERATURES OF THE GASES TAKEN SIMULTANEOUSLY AT DIFFERENT HEIGHTS ON TWO CUPOLAS.

the ascending stream of gases, but may be further aided by reducing the speed of the gas stream—that is, the blast pressure. Also, to assist in this reaction, the area of the stack may be enlarged above the melting zone. This has been found to be effective and to increase the melting rate owing to preheating of the descending charge. The more slowly the gases rise, the more complete the heat transference, and the lower the CO in the escaping gases, the cooler the top of the cupola and the better the conditions for charging.

Another important factor in cupola practice is the charging of the materials. Pig-iron, scrap, coke and fluxing material should be properly weighed, and to obtain the necessary result in the resultant metal the iron should be charged according to analysis. The weight and distribution of the charges will vary according to the size of the cupola. It is of vital importance that the layers of materials should be deposited in a level plane.

The weight of iron charge suitable for any size of cupola can be estimated from the weight of the coke layer. The depth of the coke layer should be sufficient to fill completely the cross section of the furnace with a minimum thickness. No accurate figures can be given for this relative to the area of the cupola, as the physical condition of different brands vary, also the carbon content. To obtain the weight of this volume of coke, the common practice is to construct a ring of bricks corresponding with the diameter of the cupola lining, into which the coke is placed.

Limestone, or other fluxing material, should be of uniform size, and charged in proper quantities according to the amount of sand and foreign material adhering to the pig-iron and scrap; 35 lbs. to 50 lbs. of limestone per ton of iron should be sufficient. An excess of limestone increases the coke consumption and causes a greater wear on the lining. A further point is the height of the coke bed above the tuyères. The effect of this on the quality and temperature of molten metal, also the coke consumption, is important in cupola practice.

In many cupola plants known to the writer insufficient attention is paid to the periods of slagging. It is bad practice to hold the slag in the cupola too long, as it tends to blanket the metal from the heat. Cupolas not tapping continuously should be slagged at intervals of not longer than two hours. Further, periodical analyses of the slag should be made to check the iron losses. With iron charges fairly free from rust, the FeO content of the slag should not exceed 3.0 per cent.

Having dealt briefly with some of the conditions which affect the working of a cupola, the points which, in the writer's opinion, are of vital importance will be detailed.

To melt iron, the two principal materials required are fuel (coke) and blast (air). It is in the correct distribution of these two factors that the efficient working of the cupola depends, particularly the air supply. The oxygen in the air is capable of combining with the carbon of the coke to form two oxides of carbon, carbon dioxide CO_2 and carbon monoxide CO. Carbon dioxide is formed where there is excess of oxygen, and carbon monoxide when there is an excess of carbon. The thermal value of these reactions varies greatly. Carbon burning to CO_2 generates 14,500 B.Th.U. per lb. of carbon. Carbon burning to CO generates only 4,500 B.Th.U. per lb. of carbon.

It is obvious, therefore, that the maximum thermal efficiency is obtained when the carbon is burned to CO_2 in one stage. If the carbon is burned to CO, and is further oxidised to CO_2, the thermal efficiency is reduced by approximately 38 per cent. To obtain maximum efficiency the percentage of CO formed must be kept at a minimum. When the air is forced into the layer of incandescent coke above the tuyères, combustion takes place. If the coke layer is uniform in size, shape and disposition, and the air is supplied at the correct velocity and volume, then combustion would be uniform across the coke layer. If these conditions in the cupola are not sufficiently uniform, and the air admitted at too low a pressure, it will not penetrate sufficiently to the centre of the fuel, consequently the combustion does not take place evenly across the section. It tends to be greatest near the lining of the cupola, and the combustion takes the form of an inverted cone.

On the other hand, if the blast pressure is high, then there is a tendency for the combustion to be greater at the centre and the cone to be reversed.

In order to determine the amount of air penetrating to different points in the area at the melting zone, an experiment was made on a 4 ft. 6 in. dia. cupola. Primarily, a series of tubes equally spaced were placed across the cupola, the lower ends of which were perforated and rested on the top of the coke bed, the upper

FIG. 3.—DETERMINING THE AMOUNT OF AIR PENETRATING TO DIFFERENT POINTS IN THE AREA AT THE MELTING ZONE.

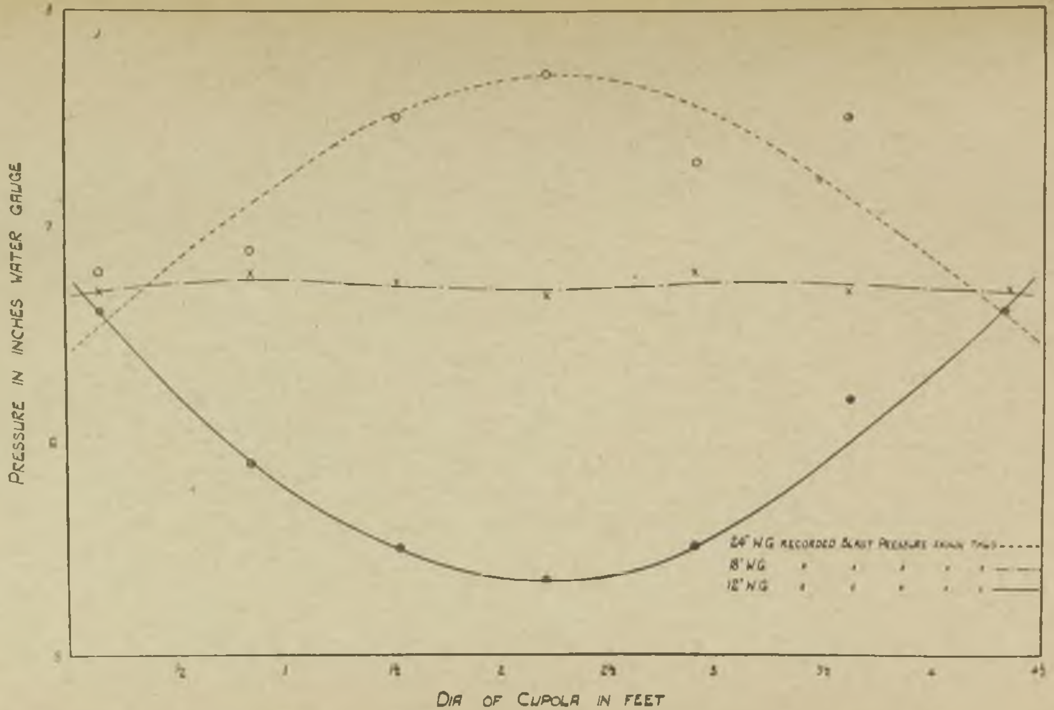


FIG. 4.—DIAGRAM SHOWING PRESSURE OBTAINED AT EACH TUBE IN EXPERIMENT DETERMINING AMOUNT OF AIR PENETRATING TO DIFFERENT POINTS AT THE MELTING ZONE.

ends being connected to water-pressure gauges. A photograph taken at the time of the experiment is shown in Fig. 3.

The cupola was carefully charged and blown in in the usual way, provision being made to maintain the correct spacing of the tubes during the test. The pressures obtained at each tube indicated the volume of air passing at that point. Arrangements were made to maintain an approximately constant volume of air with varying pressures. In the first place, the air was admitted at a pressure of 12 in. w.g. This was increased to 24 in. w.g. The pressures obtained from each tube were plotted and are shown on diagram, Fig. 4, from which it will be noted that in the former case the curve forms a distinct inverted cone, whereas the curve obtained from the higher pressure is directly opposite.

The depth of the cone formed by the higher pressure is not so intensive as that of the lower pressures. This may account for the trouble experienced with dirty tuyeres (referred to previously) when the tuyere area is large compared with the diameter of the cupola, or the velocity of the air is insufficient to penetrate the charges fully, the tendency being for the slag and iron to flow through an outer ring of the melting zone, the pressure of air at the tuyeres being insufficient to prevent scaffolding at the tuyeres, caused by local chilling. This emphasises the fact that a correct combination of pressure and volume is necessary to obtain an ideal melting condition.

This experiment was repeated, maintaining the same volume at a pressure of 18 in. w.g., which had been found to be the correct working pressure of this particular cupola. The result obtained gave a fairly level distribution of the air across the melting zone.

To check the uniformity of the combustion under what was considered ideal conditions, namely, 5,500 cub. ft. of air per min. at a pressure of 18 in. w.g.—coke ratio 12.3 to 1, gas samples were taken at three levels up the cupola at points 4 ft., 6 ft. 6 in. and 9 ft. 6 in. above the tuyeres. These samples were taken from the centre and the sides of the cupola simultaneously, with the following results:—

	Centre of cupola.	Side of cupola.
4 ft. above the tuyère.		
CO_2	18.8%	17.6%
O	nil.	nil.
CO	1.2%	3.2%
6 ft. 6 in. above the tuyère.		
CO_2	18.0%	14.8%
O	nil.	nil.
CO	2.2%	5.2%
9 ft. 6 in. above the tuyère.		
CO_2	17.2%	14.8%
O	nil.	nil.
CO	6.0%	8.8%

These analyses prove that, under the conditions of correct air volume and pressure, the combustion is fairly uniform across the furnace. All the figures show a high CO_2, absence of oxygen, and the presence of sufficient CO to give a reducing and not an oxidising atmosphere in the cupola.

In addition to proving the above, these figures show that under correct working conditions the method of taking the samples for gas analysis from the side of the cupola gives an approximate indication of the average composition of the gases across the zone.

Further tests were made to find the effect on the resulting gases at different heights using varying coke ratios, the volume and pressure of air remaining constant. These results showed that with a large coke ratio—8 to 1—a high percentage of CO was formed in the gases at a point 4 ft. above the tuyeres, and this CO tended to persist up the cupola; with a 10 to 1 ratio there was less CO and more CO_2, showing that the combustion was better, the outgoing gases containing very little CO; and with a 12 to 1 ratio, the CO tends to increase slightly and the CO_2 to decrease.

At each test the analyses were taken simultaneously, and the average results obtained from four tests were as shown in Table I:—

TABLE I.—*Percentage Composition at Varying Heights and Coke Ratios.*

Coke ratio.	8 : 1	10 : 1	12 : 1	Height above tuyères.
CO_2 ..	9.6	14.4	15.2	4 ft. 0 in.
O ..	—	—	0.4	
CO ..	18.0	7.6	8.4	
CO_2 ..	12·0	14.0	17.0	6 ft. 6 in.
O ..	—	0.4	0.2	
CO ..	14.2	9.6	6.2	
CO_2 ..	12.0	18.0	17.6	14 ft. 6 in.
O ..	—	—	—	
CO ..	15.2	4.8	5.2	

It will be seen from the above analyses that with a 12 to 1 ratio there is a slight excess of CO in the outgoing gases as compared with the 10 to 1 coke ratio. The loss in latent heat due to this excess CO is more than compensated for by the saving in fuel effected by using the higher ratio. It was found that the temperature of the resultant iron was unaffected by this reduction in coke.

In taking samples of gas for analysis, at a point of, say, 4 ft. above the tuyères, it is obvious that there is a tendency for the CO_2 to vary according to the position of the coke layer above the tuyère.

When the coke charge is just on the melting zone, then the full CO_2 reaction takes place. As the iron charge melts, the next layer of coke descends, the CO_2 reacts with this, and CO is formed, increasing as the coke descends. Then, as this coke reaches just above the melting zone, the full CO_2 reaction recurs.

It is necessary, therefore, to take frequent samples over a period of time required to melt completely one charge. The following analysis illustrates this point, the samples being taken at intervals of two minutes:—

Sample No.	1.	2.	3.	4.
CO_2..	18.8	8.4	14.4	17.5
CO	1.2	18.0	7.6	5.2

Tuyère Ratios.

There seems to be a difference of opinion amongst cupola designers as to the correct ratio of tuyère area to cupola area. A mistaken idea is that large tuyères are difficult to keep clean and free from slag. This is not the case where the correct volume of air is used at a suitable pressure. As stated above, the 4-ft. 6-in. cupola on which most of the tests referred to in this Paper were made has a tuyère area of 18 per cent. To find the effect of different tuyère areas, various sizes were tried by inserting liners into the existing tuyères. The results proved that a reduced tuyère area considerably decreased the thermal efficiency of the cupola, and reduced the melting rate. With a 10 per cent. area the output of the cupola was reduced by 20 per cent.

Further, to maintain the correct volume of air with the smaller tuyères it was necessary to increase the pressure, and although, as stated, the melting rate was reduced, the power consumption on the fan motor increased 40 per cent. The following figures give the results of gas analysis taken during one of these experiments. In Test No. 1 the tuyères were arranged to admit low volume at a high pressure. Test No. 2 was taken under normal working conditions.

Test No.	Pressure. Ins. w.g.	Volume. Cub. ft. per min.	Percentage.	
			CO_2.	CO.
1.. ..	28	3,600	8.2	21.2
2.. ..	18	5,400	16.4	6.0

It has been stated that the volume of air can be regulated, knowing the pressure in the wind belt and the power absorbed by the blower. The writer disagrees with this theory. It is well known that the resistance in a cupola is not constant, therefore it is possible that an increase in pressure may indicate a decrease in volume, or *vice versa*. This applies to both fans and positive blowers. On the one hand, if the resistance is increased, either by choking of the tuyères from slagging or poor quality of coke, or the blast-valve is insufficiently open, the pressure will increase, but the quantity of air delivered will be less, since a

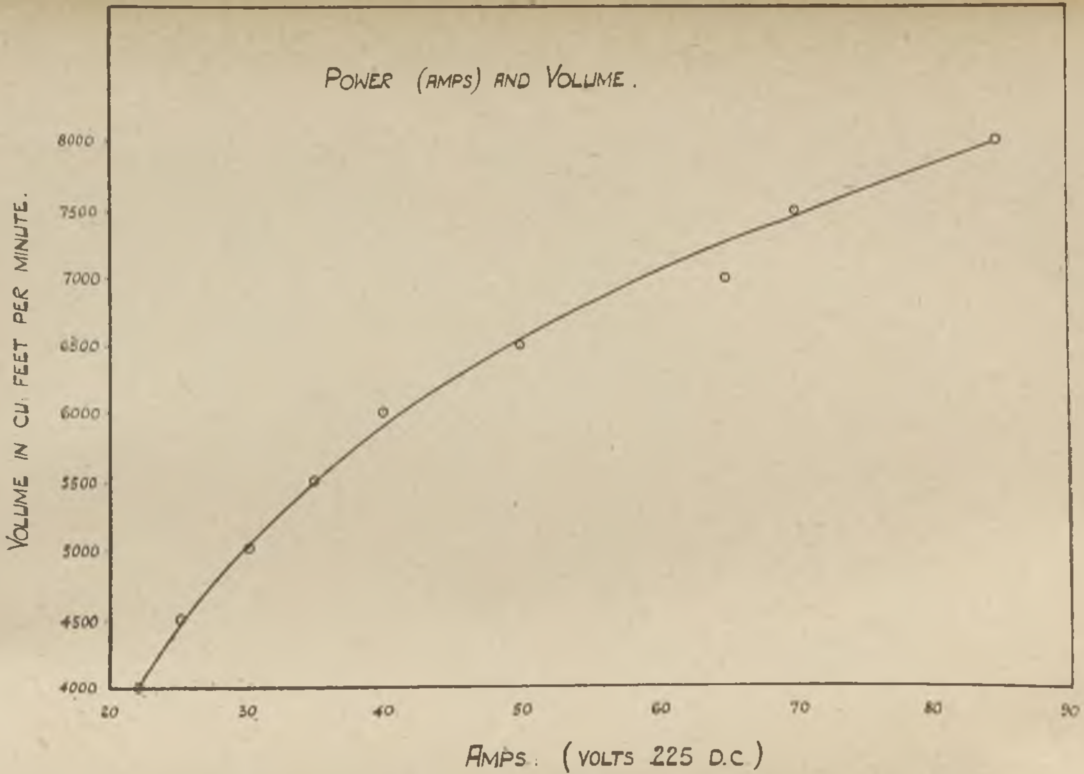


FIG. 5.—TEST SHOWING THAT THE VOLUME OF AIR PASSING INTO THE CUPOLA IS NOT DIRECTLY PROPORTIONAL TO THE POWER ABSORPTION AND THE PRESSURE.

higher resistance causes a drop in the fan capacity.

Consider again, towards the end of the blow, when the charge is low, small resistance is offered to the blast, the pressure drops, and a greater flow of air is obtained. If the blast is not properly controlled during the blowing-down period, apart from the oxidising effect on the metal, it is at this period when serious damage is done to

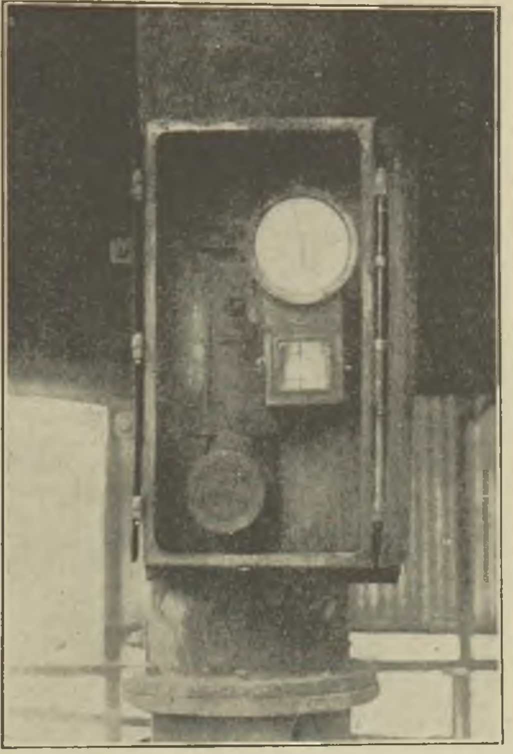


Fig. 6.—Instrument for Recording Volume and Pressure of Blast.

the lining. In the case of a positive blower, if the resistance is increased beyond a certain point, the blast is exhausted through a relief valve fitted between the blower and the cupola, which is loaded above the normal working pressure, so that more than the normal power is absorbed and energy wasted.

Tests made with both types of blowers on several cupolas definitely prove that the volume of air passing into the cupola is not directly proportional to the power absorption and the pressure. Several results have been tabulated, and most irregular figures were obtained. One is shown in graphical form in Fig. 5.

As previously mentioned, constant volume of air for a given cupola is essential to good cupola practice, therefore to obtain efficient and economical working conditions, it is necessary that the tenter should have before him a meter showing the volume and pressure of air delivered to the cupola, so that he can regulate his valve accordingly. It is also desirable that this meter should be of the recording type, so that the manager of the plant can check the working of the cupola throughout the heat. Many blast-indicating instruments are actuated on the Pitot tube principle, but many users have found these to be unreliable, due to dust (which is prevalent in most foundries) lodging in the small tubes, which tends to give readings which are misleading. Fig. 6 shows an instrument which simultaneously indicates both volume and pressure. It is also fitted with a recording apparatus, which supplies an accurate chart showing both volume and pressure during the blowing period, also all stoppages.

Fig. 7 is a copy of the chart taken from a day's run on a cupola when no attempt was made to regulate the volume of air. From this it will be seen that the pressure at blowing-in was 16 in., and when blowing down as low as 14 in. During the other part of the melt the pressure varied between 17 in. and 20 in., whilst the volume (apart from the beginning and end of the blow, which reached 8,000 cub. ft. per min) varied from 4,500 to 6,000 cub. ft. per min. On this occasion the operator was unaware that the recorder,

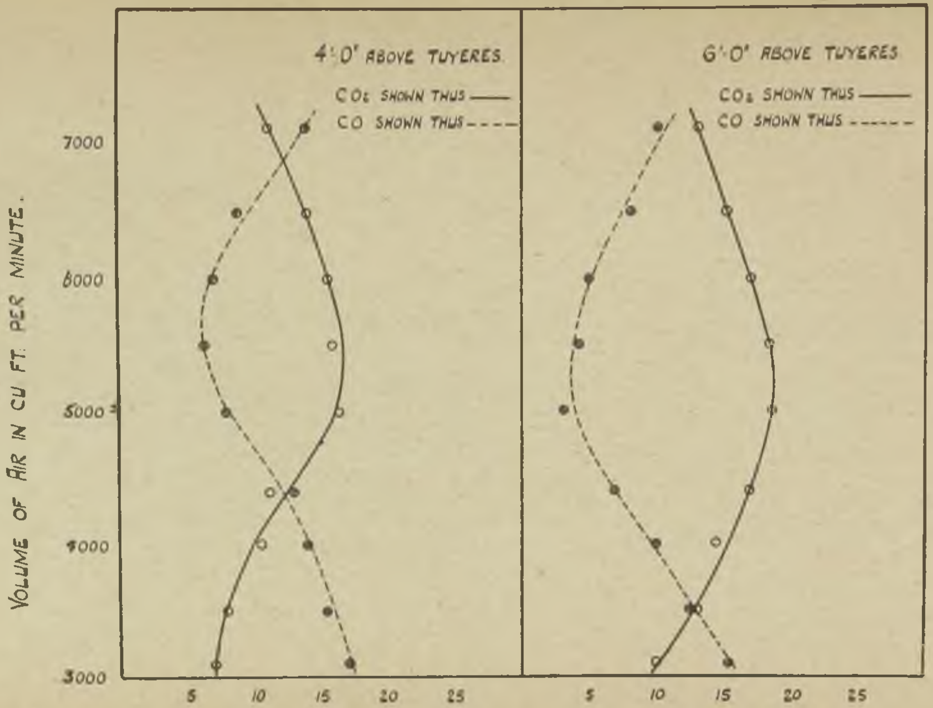


FIG. 8.—CHART SHOWING RELATION OF CO_2 AND CO FOR VARYING VOLUMES OF BLAST; PERCENTAGE OF CO AND CO_2 PRESENT.

which was locked up and could not be seen, was working. His instructions were to maintain as far as possible a regular pressure, as indicated on an ordinary mercury gauge fixed in the wind belt.

To ascertain the effect of varying volumes of air in a 4-ft. 6-in. dia. cupola, tests were made in which the quantity of air was increased from 3,000 cub ft. per min. to 7,000 cub. ft. per min. by stages of 500 cub. ft. The iron and coke charges remained constant throughout. These consisted of 60 per cent. pig-iron and 40 per cent. scrap. The total iron in each charge was 37½ cwts. and coke 3 cwts., the coke ratio being 12.5 to 1, or 8 per cent. The weight of coke in the bed was 27 cwts. The actual coke ratio, including bed charge and not allowing for coke recovered, being 1:10.8, equal to 9 per cent. of coke.

Before changing the blast supply at each test, which lasted one hour, the cupola was drained of metal, and samples of iron were taken for analysis and physical tests. During these tests the following observations were made: (1) Vol. of air per min.; (2) pressure of blast in in. w.g.; (3) power consumption; (4) gas analyses at points 4 ft. and 6 ft. above the tuyeres. (The CO_2 was recorded every two minutes in the middle of each test to obtain a fair average.) This was checked at regular intervals from spot samples, from which the CO and oxygen contents were estimated; (5) temperatures were taken at these two points, also at the tuyeres; (6) temperatures of the slag and the metal at the spouts; (7) transverse and tensile test bars were run from each test, also bars triangular in section 10 in. long were cast in a special apparatus to obtain the expansion and contraction of the metal; (8) samples were taken for analysis from the test bars, and compared with the analysis of the iron charged; and (9) slag analysis at each test. The whole of the figures obtained in these experiments are too extensive for insertion in this Paper.

The conclusions arrived at prove that volumes below and above the normal give a low thermal efficiency. The average CO_2 and CO gases are given in Table II:—

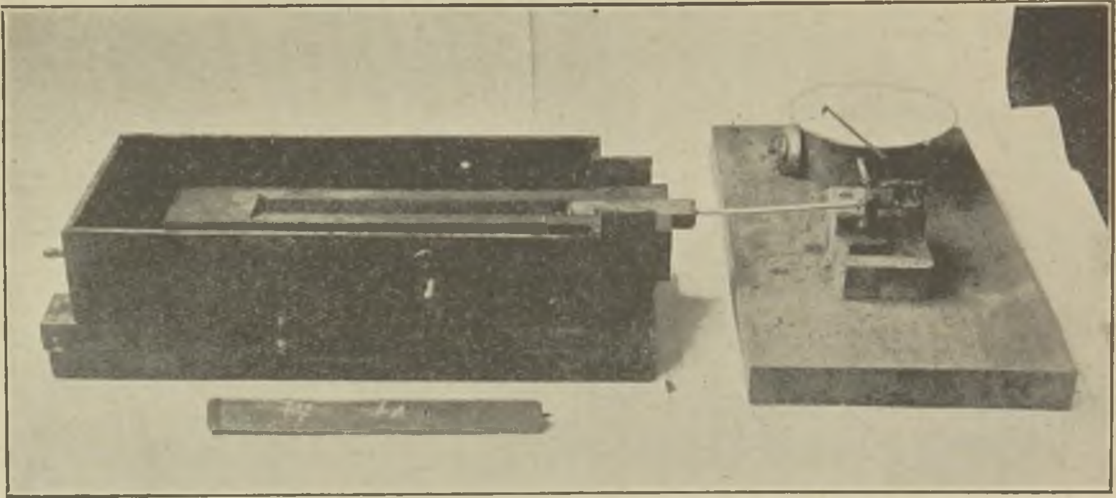


FIG. 10.—APPARATUS FOR RECORDING EXPANSION AND CONTRACTION IN THE METAL.

TABLE II.—*Gas Analyses with Increasing Blast Volume.*

	4 feet above tuyères.		6 feet above tuyères.	
Volume.	CO_2.	CO.	CO_2.	CO.
7,000	11.0	14.0	13.0	10.0
6,500	14.0	9.0	15.2	8.0
6,000	15.6	7.0	17.0	5.0
5,500	16.0	6.5	18.4	4.2
5,000	16.5	8.0	18.5	3.1
4,500	11.0	13.0	16.0	7.0
4,000	10.5	14.0	14.5	10.0
3,500	8.0	15.5	13.0	12.4
3,000	7.0	17.2	10.0	15.5

These results are shown in graphical form in Fig. 8, from which it will be seen that the combustion was distinctly most complete when the volume of air was between 5,000 and 6,000 cub. ft. per min., measured at the meter. At lower volumes, whilst the temperature of the iron was not appreciably low compared with the maximum obtained at 5,500 cub. ft. per min., it was found that, as the volumes and correspondingly the pressure increased above this point, the temperature of the furnace and the metal began to fall at a much greater rate. Although the chemical analysis of the iron varied little at each test (the loss in silicon and manganese gradually increased up to 7,000 cub. ft. per min.), the effect on the physical strength of the iron was appreciable.

The average result of the transverse bars 2 in. × 1 in. section tested on supports 3 ft. apart, taken from the cast at 3,000 cub. ft. per min., was 24¾ cwts., with a deflection of 0.32 in. The average tensile result from this cast was 8.7 tons per sq. in.

The physical result gradually increased up to 5,500 cub. ft. per min., the transverse bars from the test giving a result of 30 cwt. with a deflection of 0.371 in. The corresponding tensile bars broke at 12.68 tons per sq. in. At higher volumes the strength of the iron decreased, and most of the bars showed slight defects, and at the lower volumes the slag analysis revealed low FeO content. At 5,000 it was 2.3, whilst at 7,000 cub. ft. per min. the FeO was as high as 6.6 per cent.

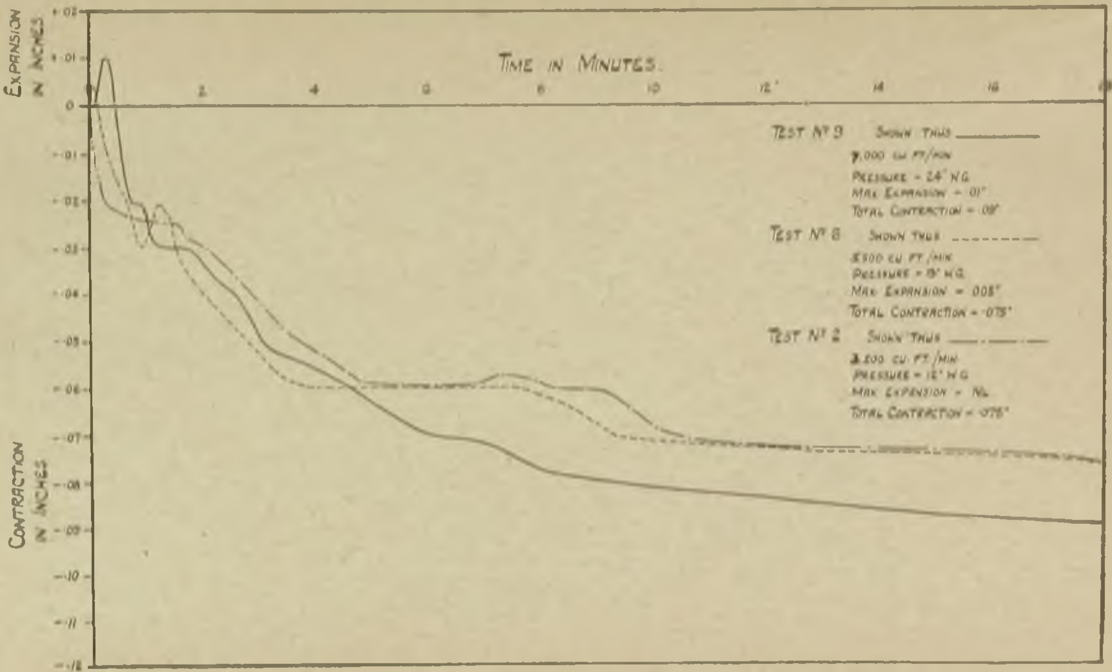


FIG. 11.—EXPANSION AND CONTRACTION OF THREE BARS RECORDED BY THE APPARATUS SHOWN IN FIG. 10.

The average analyses of the materials taken at this test are:—

Resultant Metal taken from Test Bars.—Si, 2.68 per cent.; S, 0.068; P, 1.08; Mn, 0.36; G.C., 2.89; C.C., 0.44; and T.C., 3.33 per cent.

Coke:—

	As received.	Dry.
Water ..	1.52 per cent.	—
Ash.. ..	8.20 ,,	8.32 per cent.
Volatile ..	1.60 ,,	1.64 ,,
Sulphur ..	0.72 ,,	0.73 ,,
Carbon ..	87.96 ,,	

Average Slag Analysis.—SiO_2, 47.4; Al_2O_3, 17.72; FeO, 3.78; MnO, 0.65; CaO, 28.6; and MgO, 1.88 per cent.

The blast recorder chart taken during this test is shown in Fig. 9.

A further interesting experiment was made during this test. Samples of each cast were run into a triangular-shaped chilled mould, one end of which was closed by a block, shaped to suit the mould, but capable of sliding freely in the mould. Fixed in the inside surface of the block at each cast was a screw, the head of which was cast into the metal of the test piece. The other end of the mould was shaped to prevent any movement at this end. The block was fitted to a lever mechanism which operated a pen on a chart fixed to a clock, which revolved at one complete revolution in six minutes. The movement of the pen relative to that of the block was magnified eight times. A photograph of the apparatus is shown in Fig. 10. It was found that, with high volumes and pressures, an appreciable expansion takes place in the metal, accompanied by a high contraction, whereas with low volumes the expansion is nil and the contraction normal.

The results of three bars obtained in this series of tests are shown on graph (Fig. 11). An enlarged diagram over a period of two minutes is shown on Fig. 12. It will be noticed from these that no expansion takes place at 3,500 cub. ft. per min., whilst at 7,000 cub. ft. per min. the expansion is prominent. At 5,500 cub. ft. per min. the expansion is very slight and the contraction normal. The length of the test piece was 10 in.

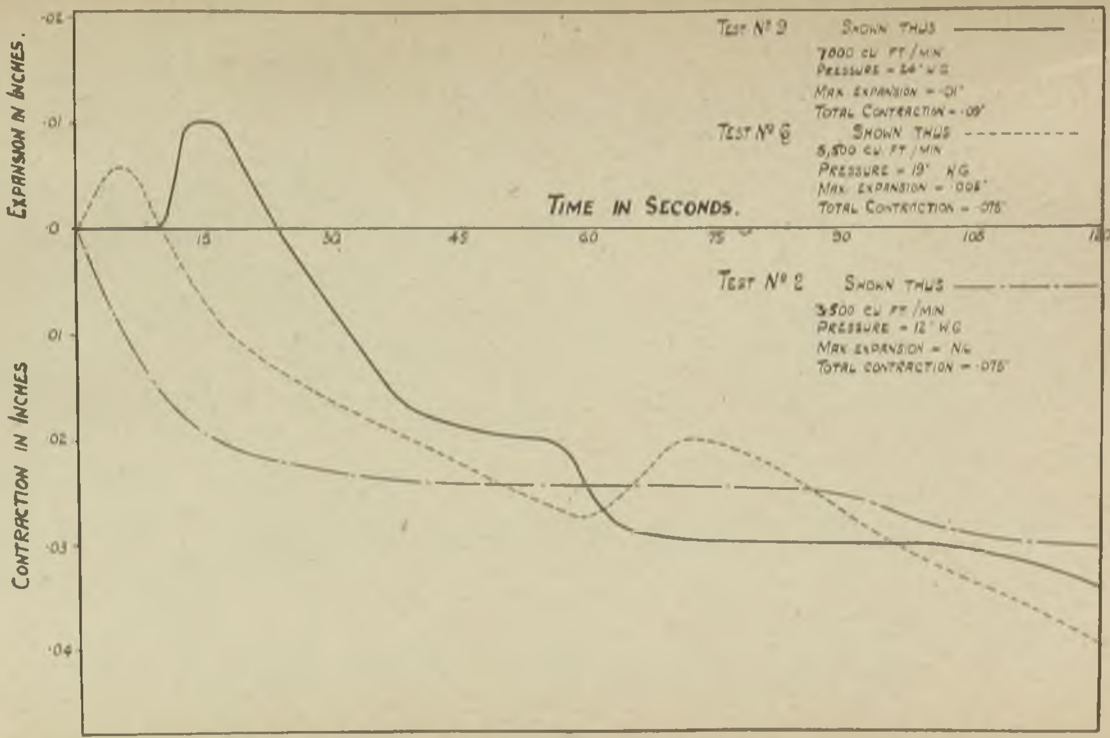


FIG. 12.—AN ENLARGED DIAGRAM SHOWING EXPANSION AND CONTRACTION OF TEST BARS OVER PERIOD OF 2 MINUTES.

Cupola No. No. 1.

STANTON IRONWORKS COMPANY, LIMITED.

Stanton Works June 8th 1927

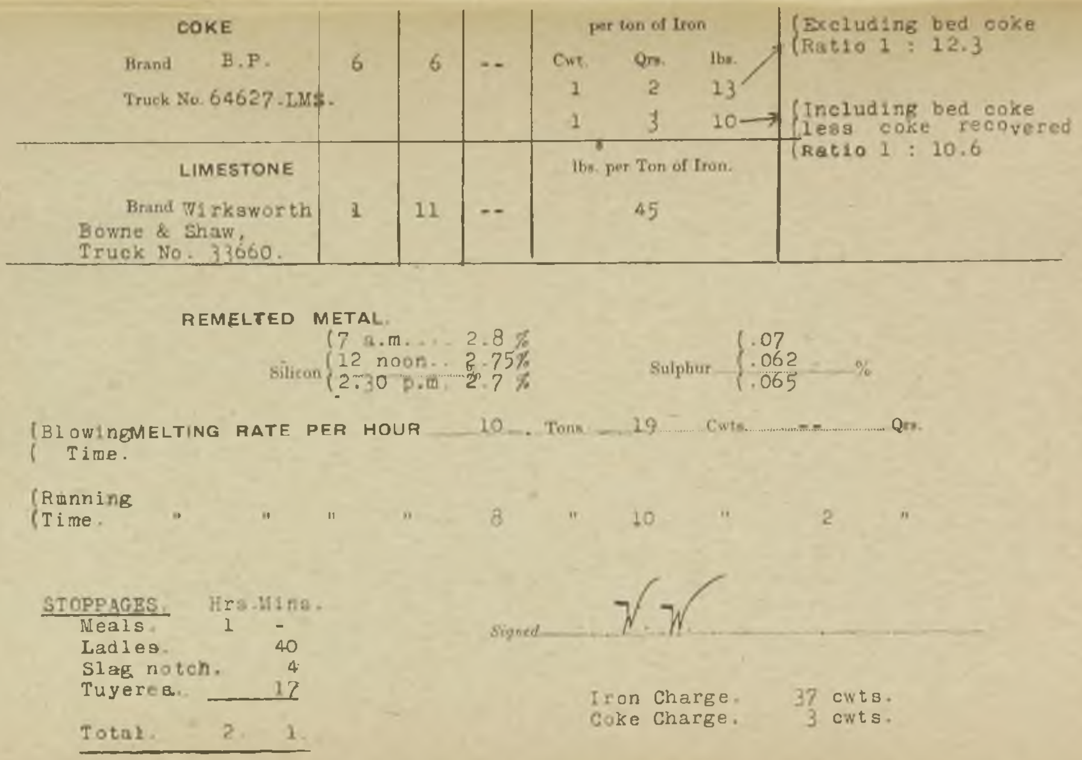
DAILY CUPOLA CHARGE SHEET.

Time Blast on 6 a.m. Last Tap. 3.6 p.m. Raked out 3.36 p.m.

Coke Bed Charge 24 Cwts.

Hours run 9 hrs. 6 mins.

Material Charged.	Weight Charged			Per cent. of charge.	Remarks
	Tons	Cwts.	Qrs.		
PIG IRON **Grade** No. 3. **Brand** Stanton. **Truck Nos.** 112.246 1129. 26. 5634. 92	62	14	--	80%	Average Silicon 3.2
SCRAP **Quality** Circulating. **Truck Nos.** 9. 12. 1350.	15	10	--	20%	Average Silicon 2.7
				Average Consumption	



COKE				per ton of Iron			
Brand B.P.	6	6	--	Cwt.	Qrs.	lbs.	(Excluding bed coke (Ratio 1 : 12.3
Truck No. 64627.LMS.				1	2	13	
				1	3	10	(Including bed coke (less coke recovered (Ratio 1 : 10.6
LIMESTONE				lbs. per Ton of Iron.			
Brand Wirksworth Bowne & Shaw, Truck No. 33660.	1	11	--	45			

REMELTED METAL.

Silicon (7 a.m. 2.8 % (12 noon 2.75% (2.30 p.m. 2.7 %

Sulphur (.07 (.062 (.065 %

(Blowing MELTING RATE PER HOUR 10 Tons 19 Cwts. -- Qrs.
(Time.

(Running
(Time. " " " " 8 " 10 " 2 "

STOPPAGES.	Hrs.	Mins.
Meals.	1	-
Ladles.		40
Slag notch.		4
Tuyeres.		17
Total.	2	1.

Signed V. W.

Iron Charge. 37 cwts.
Coke Charge. 3 cwts.

FIG. 13.—REPRODUCTION OF DAILY CHARGE SHEET OF TYPICAL MELT IN 4 FT. 6 IN. DIA. CUPOLA.

The writer has seen the result of a similar test (made in another country, where it is the practice to work cupolas at a high blast) in which a bar 10 in. long expanded 0.06 in., the metal remaining in this condition nearly 60 seconds. From the same cupola with a lower blast, using a similar mixture of iron, the expansion was reduced to 0.015 in.

Table III shows the result of an average day's melt in a 4-ft. 6-in. dia. cupola, which may be considered typical of good practice. Fig. 13 is a reproduction of the works daily charge sheet, whilst Fig. 14 shows the blast recorder chart.

TABLE III.—*A normal day's run in a 4 ft. 6 in. dia. cupola.*

	Tons	cwts.	qrs.	lb.
Total pig-iron charged (80 per cent.)	62	4	0	0
Total scrap charged (20 per cent.)	15	10	0	0
Total metal charged	77	14	0	0
Coke bed	1	4	0	0
Coke charged	6	6	0	0
Coke consumption per ton excluding bed charge	0	1	2	13
Coke consumption per ton including bed charge and allowing for coke recovered	0	1	3	10
Total limestone charged	1	11	0	0
Limestone per ton			0	45

	hrs.	mins.
Hours run	9	6
Stoppages:		
Dinner	1	0
Ladles		40
Slag notch		4
Tuyères		17
Total stoppages	2	1
Hours blowing time	7	5

	Tons	cwts.	qrs.	lb.
Melting rate per hour running time	8	10	2	0
,, ,, ,, blowing ,,	10	19	0	0

	Bed coke included.	Bed coke excluded.
Coke ratio	1 : 10.6	1 : 12.3
Coke per cent.	9.4	8

Iron charges	37 cwts.
Coke	3 cwts.
Time lighting up	12 midnight.
,, cupola charged	4.0 a.m.
,, blast on	6.0 a.m.
,, first metal past tuyères	8 minutes.
,, first tap	6.37 a.m.
,, slagging	Every 2 hrs.
Duration of slagging	10 to 15 mins.
Volume of blast at recorder	5,500 cub. ft. per min.
Pressure of blast at recorder	18 in. w.g.
Average temperature of metal	1,400 deg. C.
,, ,, ,, slag	1,425 deg. C.
Slag per ton of iron	110 lbs.

Slag Analysis :

Time.	Flush.	Iron.	Ferrous oxide.
8 a.m.	1	2.6 per cent.	3.33 per cent.
10 a.m.	2	2.3 ,,	3.0 ,,
12 noon	3	1.86 ,,	2.38 ,,
2.30 p.m.	4	1.86 ,,	2.38 ,,

Analysis of Average Sample of Slag :

SiO_2	50.0 per cent.
Al_2O_3	13.0 ,,
FeO	2.7 ,,
MnO	1.3 ,,
CaO	29.2 ,,
MgO	3.6 ,,
Iron	2.1 ,,

Gas Analyses :

Time sampled	9 a.m.		11.30 a.m.		1.30 p.m.	
Where sampled above tuyère	ft. in. 4 0	ft. in. 6 6	ft. in. 4 0	ft. in. 6 6	ft. in. 4 0	ft. in. 6 6
	Per cent.		Per cent.		Per cent.	
CO_2	15.0	17.0	16.0	18.0	16.2	18.6
O	—	—	0.4	—	—	—
CO	8.0	7.0	7.0	5.0	5.6	1.8

Analyses of :

	Pig Iron.	Scrap.	Remelt metal.		
			7.0 a.m.	12 noon.	2.30 p.m.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silicon	3.2	2.7	2.8	2.75	2.7
Sulphur	0.03	0.06	0.07	0.062	0.065
Phosphorus	1.0	0.99	1.0	0.99	1.0
Manganese	0.4	0.35	0.32	0.35	0.36
Graphitic Carbon	3.1	2.8	2.8	2.9	2.85
Combined Carbon	0.3	0.5	0.5	0.45	0.51
Total Carbon	3.4	3.3	3.3	3.35	3.36

Coke recovered from bed	6¾ cwts.
Temperature at tuyères	1,640 deg. C.
Diameter of melting zone before melting	4 ft. 6 in.
,, ,, ,, ,, after ,,	5 ft. 2 in.
Depth of melting zone	1 ft. 10 in.

Experience has proved that the scientific control of the air blast at the cupola does pay, from the point of view of: (1) Economy in fuel; (2) reduction in waster castings, and (3) saving in iron losses. All cupolas, however small, should be fitted with a volume indicator in addition to the usual pressure gauge. Many writers on cupola

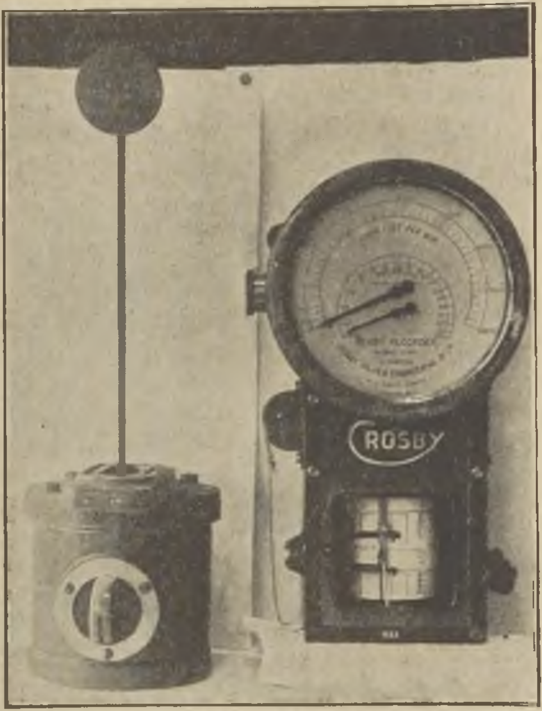


Fig. 15.—Volume Pressure Gauge.

practice have emphasised the importance of measuring the air supply. Recently one writer expressed the opinion that: "Whilst volume pressure gauges are a valuable appliance for cupola correction, they are not suitable for being permanently fixed to the cupola for daily use; but the real reason why they are not in more general use is that the cost is more than the average foundry proprietor is prepared to pay."

It is within the writer's knowledge that the installation of one of the instruments illustrated in Fig. 15 at a certain cupola plant was the means of saving approximately £100 per week in coke consumption alone, apart from a reduction in waster castings and savings in other directions. In this instance the instrument paid for itself in a few days.

The possible saving in fuel and waste is just as important to the small foundry as to large producers, whatever class of castings they turn out. In some cases the iron represents a high percentage of the total cost. In others, where large, intricate castings are involved, the preparation of the mould is an expensive item. Yet, if the iron poured into this mould is not correct, due probably to inefficient cupola practice, the loss is considerably higher than in the former case. In the foundries under the writer's control one-quarter of a cwt. of coke per ton of iron melted represents a sum of £10,000 per annum, and 1 per cent. loss in iron a similar figure.

In conclusion, the writer desires to record his thanks to Mr. W. Woodhouse, chief chemist to the Stanton Ironworks Company, Limited, for his assistance in conducting the various tests referred to in this Paper.

JOINT DISCUSSION ON MR. MACKENZIE'S PAPER AND MR. WILSON'S PAPER.

Mr. John Shaw, who opened the discussion, said that Mr. MacKenzie's Paper was of interest because of its bearing on the production of low-carbon iron from the cupola. He wished Mr. MacKenzie could bring home to the American Foundrymen's Association Test-Bar Committee that iron suitable for a $1\frac{1}{4}$-in. diameter bar was most unsuitable for thin or thick castings. Dealing with the experiments, he said one was surprised at the heavy coke ratios of 1 : 4, and also that a bed should be 40 in. above the tuyères. The true melting zone for a cupola of the size dealt with, with a 4-oz. pressure, would be about 12 in. above the tuyères. In his view this fact, taken together with the purity and varying shatter of the coke, accounted for the wide divergence in the carbon increase. With the poor high-ash cokes it might be necessary to increase the coke ratio, but with the pure cokes it was defeating the object in view. Jennings (A.F.A. Paper), in melting from 20 to 30 tons of all steel per day, had found that he could obtain no result at all when using a coke of 84 per cent. C, irrespective of the amount employed. With a coke containing over 90 per cent. C and a low ash he had experienced no difficulty, and had obtained about 2 per cent. C in the resultant metal. He (Mr. Shaw) used a ratio of about 1 : 7.5, with a coke containing carbon of 88 per cent., and obtained a metal of approximately 2.3 per cent. C. Mr. MacKenzie had made a point of "Time in contact with coke." It took 25 minutes to obtain 50 lbs. of metal, even with the poor coke, but in the only example given of a pure coke (Parco), 70 minutes had elapsed before any metal was melted, and then it had come slowly, throwing out great quantities of kish.

Sulphur in Metal Unrelated to S Content in Coke.

Continuing, Mr. Shaw said that, although he had spent a good few hours studying Table II, he must confess that, without personal explanations by Mr. MacKenzie, he had not found it possible to arrive at many conclusions. Were we to understand that, with the exceptions mentioned, a uniform analysis was aimed at in all the experiments? If so, there was a great variation in every element, which variation was difficult to understand. One thing was clear, namely, that additions of high-percentage material, such as FeMn or FeSi, were very difficult to control unless one took out the whole of the charges in one ladle. As examples, he referred to Nos. 227 and 228, both from one melt, with Mn 0.04 per cent. in the first ladle and 0.30 per cent. in the second; and to

Nos. 316 and 317, with Si 2.22 and 1.45 per cent. respectively. He could confirm the author's conclusion with regard to the importance of the size of coke and its influence on the final composition of the iron. During the coal strike he had bought some foreign coke with 0.8 per cent. S, which corresponded to his usual specification. On the first day's melt with this coke he not only had a sluggish iron, but he had ascertained from the chill test before casting that the iron was too hard for the work. On analysis he had found an increased reduction in the C, Mn and Si. The loss of Mn was nearly double the normal, while the S content went up from 0.034 to 0.06. By decreasing the size of the coke to about the normal size the discrepancies disappeared, except in the case of the S. From subsequent investigations, and from information obtained from outside sources, he had come to the conclusion that the S in the coke was in two forms, one of which united with the iron more freely than the other, hence the gain of 0.06 per cent., which persisted while this coke was used. Certainly the usual S analysis gave no clue. He could not attain the temperature of 1,600 deg. C., reached by Mr. MacKenzie, his highest being 1,475 deg. C., and he asked whether Mr. MacKenzie's figure was correct.

Influence of Increased Pressure in Loss of Elements.

Discussing Mr. Wilson's Paper, he said that the majority of the points raised did tend towards good cupola practice, and Mr. Wilson had proved that a self-registering chart did tend to ensure better attention on the part of the cupola tenter, if only because there was a visible record. With regard to the test on a 4 ft. 6 in. diameter cupola, with a series of tubes placed across it, he said he gathered that the cupola was charged in the ordinary way, but not lit. If it were lighted, it was difficult to understand how the tubes were kept in position, having in view the continually falling charge. If, on the other hand, it were not lighted, the test was not quite a true one. Discussing the test with varying air pressures, he said that if Mr. Wilson continued blowing without lifting the bed at the end of the 3,000 cub. ft. per min. experiment, and increased his pressure to 5,000 cub. ft.

per min., he automatically raised the melting zone, and no doubt oxidised the metal slightly, with a further loss of Mn and Si. As the strength of the bars was on the low side in the first case, this would account for the increase of the breaking load in the second experiment. The raising of the blast to 7,000 cub. ft. per min. without raising the bed would lead to severe oxidation at once, and would account for the cool metal and lower test results. He (Mr. Shaw) could not accept that a reduced blast volume accounted for the disappearance of the two recalescence points usually found in a high-phosphorus iron, and he suggested that it was due to the quick cooling resulting from pouring into a cold chill, which at once carried the temperature below the change points. In the second and third tests the chill was hot, as the result of the previous cast, and the arrests usually found in this metal had had time to develop.

Calculation of Oxygen in Blast Supplied.

Mr. F. J. Cook (Past-President) agreed with Mr. Wilson when he said that many people who presented Papers on cupola practice probably only guessed, or had very poor methods of determining, the actual volume of air going into the cupola. In a Paper published in the Institute's Proceedings for 1913-14 very great stress was laid on that point. He felt, however, that Mr. Wilson had similarly erred. Anyone who had to deal with the measurement of compressed air had to employ a great deal of mathematical calculation, as evidenced by the Paper, and if one were going to deal on a mathematical basis with the measurement of air, it was essential that the methods adopted should be accurate. The melting efficiency of a cupola was dependent on the amount of oxygen put into it by the air. Early in the Paper there was a formula for the purpose of arriving at the correct amount of air. In the formula the author had dealt with air in volume, and had assumed that there was a definite quantity of oxygen in every cub. ft. of air, but that was quite wrong. the quantity of oxygen per cub. ft. of air would vary almost every minute of the day, and there would be very wide differences over longer periods.

It was better to deal with the quantity of oxygen in a given weight of air, because then one took into account the density due to height of barometer, and so on, so that if the author would alter the formula to deal with oxygen per lb. of air, it would be more correct mathematically. That might appear to be a very small point, but he could assure his hearers that that was not the case. He had had something over 25 years' experience of the measurement of air, and had known differences of as much as 19 per cent. in the amount of oxygen in cub. ft. of air. Very often a cupola man would report that a cupola was not working so well on one day as on another, and that might be due entirely to the variation in the amount of oxygen one was putting into the cupola. With regard to tuyères, if the author would give the formula which he arrived at the correct size and shape of tuyères it would add to the value of his Paper. He had assumed that the correct tuyère area was well known, but that was not the case. No doubt his formula was on the basis of mean velocity. Discussing the diagrammatic measurement of volume and pressure, he said he believed he could claim to have been the first to apply diagrammatic results to cupola working. At that time, however —about 26 years ago—he had had a gauge which would measure only pressure, and he was very interested to know that there was now available a gauge which would measure and give a diagram of both volume and pressure. He asked, however, whether the gauge used by Mr. Wilson had been calibrated, what were the means of calibration, and what density of air it had been calibrated on, because without some correction to take care of differences in the height of the barometer, and in temperature, etc., the amount of oxygen actually going into the cupola might be very different from the amount one thought one was using.

Quantity of Air Admitted should Vary with Coke Charge.

Mr. A. Campion (Scottish Branch), referring to Mr. MacKenzie's paper, said he had intended to raise the points which had already been raised by Mr. Shaw with regard to coke, and he considered that the value of the paper was minimised by the very heavy coke ratios. Coming to Mr. Wilson's paper, he was particularly glad to see that the author had emphasised the necessity for measuring the quantity of air. For many years he had hammered into cupola men the fact that it was necessary to measure the air as well as the other materials. Efficient working depended on the concentration of heat, and one wanted to develop the heat of coke as rapidly as possible in a limited space so as to get it transferred to the metal with the minimum of loss. The author had pointed out that the variation in the carbon content of the coke must be taken into account in arriving at the quantity of air to be admitted. That reminded him (Mr. Campion) that the air required for a cupola was generally stated to be a certain quantity per ton of metal melted. It always seemed to him that that was wrong, however, because the air was admitted for the purpose of burning the coke; therefore, the amount of air should be adjusted to the amount of coke to be burned, and one should state the quantity of air per unit of coke rather than the quantity of air per ton of metal. In that way one would dispose of some of the anomalies which arose in connection with the quantity of air admitted to a cupola. The correct method was to arrive at the quantity of air, and then to put in the tuyeres to suit, but he was afraid that in some cupolas the tuyeres were put in in a more or less haphazard way, and the air admitted depended upon the capacity of the tuyeres and pressure of blast. It was better to measure air by weight than by volume, but measurement by volume was much simpler in practice. In measuring by volume one did introduce inaccuracies, unless there were corrections not only for variations in the height of the barometer and in temperature, but also in humidity. The difference in the condition of air as between a frosty day and a warm day was very important; one was putting in a different weight of air on a frosty day, with each revolution of the blower, than on a warm day, so that there was a different concentration in the melting zone. All these factors had to be considered, and until we got down more to the fundamentals of these important points we should not make the cupola the exact instrument which we all desired.

He had used with much success a modified Pitot tube instrument, which being simple to use and instal, was also sufficiently robust for every-day foundry use.

Where Cupola Exhibits Maximum Temperature.

Mr. Colin Gresty (Newcastle) said he was glad that Mr. Campion had raised the question of humidity. Practically all foundrymen were aware that cupolas worked differently on wet and dry days, although apparently all other conditions were exactly similar, and he would be glad if Mr. Wilson could quote actual experiences in this connection. Discussing Fig. 2 in Mr. Wilson's Paper, showing the temperatures of the gases at different heights in the two cupolas, he said that from the curve as drawn it would appear that the highest temperature was at the tuyere level. He had never actually and seriously tried to take cupola temperatures at, say, the melting zone, but was it to be assumed from the curve that Mr. Wilson considered that the highest temperature in the cupola was at the tuyere level, and that there should not be a peak in the curve between the readings at 4 ft. up and those at the tuyere level? He mentioned the point because the curve was one which was likely to go into history as a record of actual temperatures in the cupola. With regard to the absence of expansion, which Mr. Wilson had attributed to low volume, he said that, with Mr. Shaw, he did not believe for a moment that the simple melting of the iron with a much lower volume was going to remove what was one of the fundamental properties of cast iron, namely, expansion almost immediately after solidification. Referring to Fig. 14, he confessed that he was surprised at the wonderful regularity of the pressure and the volume. He presumed that the cupola was run at a constant volume, and he would have expected a considerable change in the pressure during the last half-hour of the blow, and also some variations in the pressure during the course of such a long run.

Reliability of Measuring Apparatus.

A Member, dealing with Mr. Wilson's Paper, asked what was the shape and number of the tuyeres used in the furnaces, and also what was the height of the bed above the top of the tuyeres before charging proceeded. Those who were handling cupolas melting large quantities of metal were always endeavouring to attain, as far as possible, standard conditions, although there were difficulties in that connection, and the proposal to use blast gauges measuring both volume and pressure was a step in the right direction. It had to be borne in mind that founding conditions were very difficult, very dirty, and not particularly suitable for the regular operation of delicate instruments, and he asked Mr. Wilson whether the instrument he had referred to would stand rough usage. If Mr. Wilson could give an assurance that the instrument to which he had referred could be so used, he was satisfied that a considerable advance had been made.

Mr. V. C. Faulkner (Past-President) exhibited a diagram handed to him by Professor Piwowarsky, which showed that if the amount of blast put into a cupola were progressively increased from 5,000 to 20,000 cub. ft. per min., the temperature would go up in a straight line form, and that the tensile strength of the metal would go up parallel with it, ranging from, say, 6 tons per sq. in. at something like 1,000 or 1,100 deg., up to 14 tons at 20,000 cub. ft. per min. Professor Piwowarsky had pointed out that the average cupola was incapable of introducing 20,000 cub. ft. per min., but that with suitable modifications that amount could be admitted, and a hotter and stronger metal could be produced.

Mr. J. E. Fletcher (Consultant, B.C.I.R.A.), speaking on behalf of Mr. MacKenzie, said that if the members, in discussing the Paper, would take notice of the kind of work which Mr. MacKenzie had done generally—and it had been of a most valuable character—they would find that he had put an immense array of figures before them, representing various types of practice, and had put them forward generally, without reserve, in order

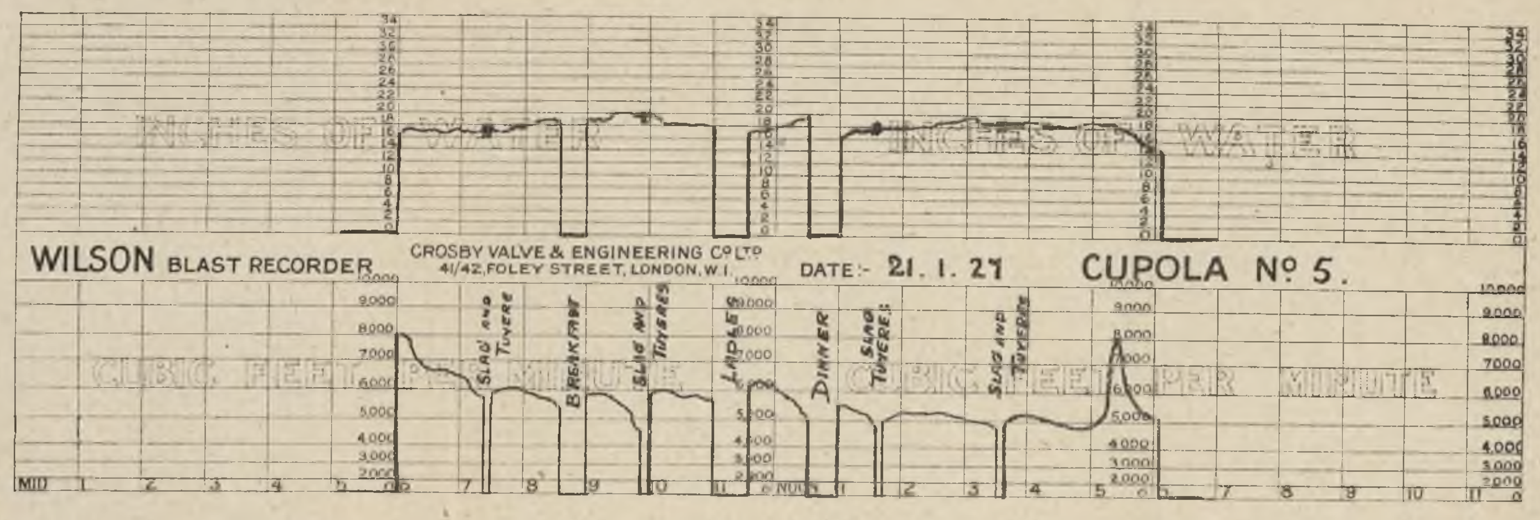


Fig. 7.—Copy of Chart taken from a Day's Run on a Cupola without Regulating Volume of Air.

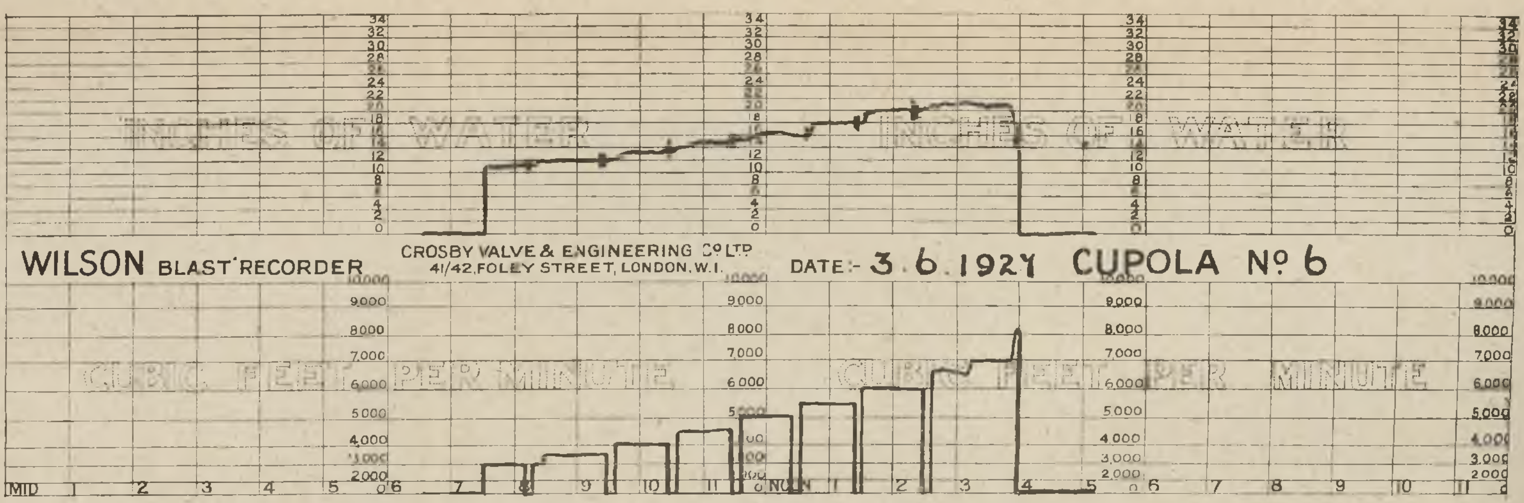


Fig. 9.—Blast Recorder Chart from Test in which Volume of Air was Increased from 3,000 cub. ft. to 7,000 cub. ft. per min., by Stages of 500 cub. ft.

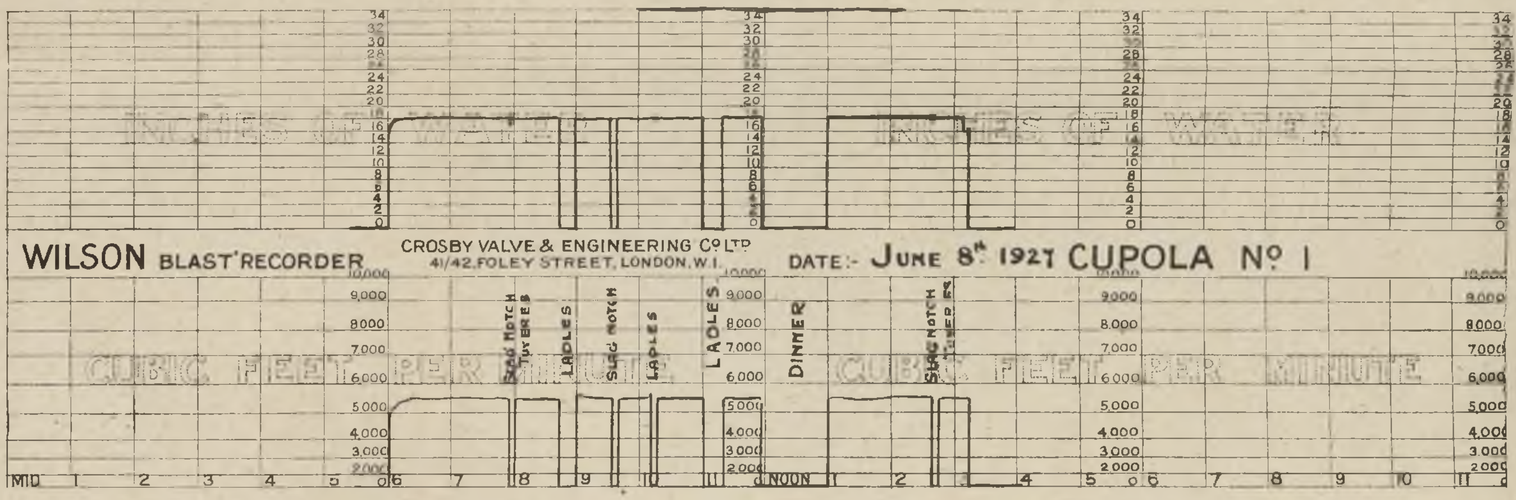


Fig. 14.—Blast Recorder Chart from an Average Day's Melt Typical of Good Practice.

that they might be studied. In this particular case he had done the same thing. Those who had tried to melt all-steel charges knew that it was very difficult to do so without modifications in blast-pressure, and so on. Those modifications, in a small cupola, under such circumstances as those obtaining in this case, had to be so small that one could scarcely record them. Emphasising the value of Table II, he said that if the younger and more scientific members who were taking an active interest in the technical side of the subject would study that Table and the Paper very critically they would find there some very valuable information. Mr. MacKenzie had brought forward a subject which had not been sufficiently touched upon in the Institute's Proceedings, it was the character of the coke which influenced melting conditions, and Mr. MacKenzie had given information which would enable one to follow up this subject very advantageously by examining domestic conditions, the cokes used, and the results obtained. It was recognised in every foundry where any notice was taken of cupola conditions that variations in the coke produced important variations in the melting results, and we were not yet quite certain whether the trouble was in the air supply, or the texture of the coke, or in the combination of quite a number of circumstances, depending largely on the rate at which the metal was running through the coke in the coke bed. That was a condition which required a good deal of examination. He did not wish to criticise any of the points in Mr. MacKenzie's Paper, because he believed it was written primarily so that it might be read carefully and critically, and so that one might form one's own opinion upon it from actual practice. Inasmuch as it dealt with the melting of all-steel charges, a subject on which there was very little information available, it furnished a basis for a great deal of useful study.

Cleanliness an Essential.

Discussing Mr. Wilson's Paper, he congratulated the author upon having obtained such uniformly regular result with a cupola working under what might be called good standard conditions, with regular metal supplies, and, he gathered, almost regular coke supplies. It must be borne in mind, however, that the author was dealing with one class of metal—a fairly high-phosphorus iron—and under very favourable cupola conditions, so that one could get good results without a great deal of difficulty; it was in the production of higher-class irons that the difficulties and the variations arose. The same cupola did not function equally efficiently when melting an iron with 1.5 per cent. silicon and a very low phosphorus content as when melting high-phosphorus irons, but, at the same time, it was a great advantage to have a Paper of this description, showing what could be done under regular conditions with a well-designed cupola. Referring to coke ratios, which, after all, was a question of the carbon in the coke; again, air ratios were really a question of oxygen per lb. of carbon turned into CO_2 finally, and it was upon the regulation of that that everything depended. He hoped foundrymen would bear in mind the value of being able to co-relate pressure and volume, and that the instrument Mr. Wilson had brought forward was really the reliable instrument that was so much needed in the foundry. The importance of cleanliness of plants in connection with which such instruments were used was of importance. He knew of blast-furnace plants which were kept wonderfully clean and in perfect good order, but he would not like to mention the percentage of foundries in which such conditions prevailed. Foundrymen could not expect to get such results as Mr. Wilson had referred to unless they began to mend their ways, cleaned things around the cupola, and made the atmosphere and surroundings good enough to warrant the use of a modern instrument.

Dr. Maurice L. Becker, referring to Mr. MacKenzie's Paper, confessed to a lack of knowledge concerning the relative merits and characteristics of the various American cokes mentioned in it. In order to make comparisons it was important that the measurable properties of the materials should be stated. To a certain extent this information had been given in the Paper, but there seemed to be very little connection between any reported property and the total carbon increase in the metal tapped. A test which did not appear to be reported was that for reactivity or combustibility. This test was quite well known, and the values obtained by it would be extremely useful in studying the relative effects of these various cokes in the cupola. Rather more data as to the rate of melting with each charge would also be useful, if the author were able to include it. The results plotted in Fig. 1 were of particular interest, and showed very clearly the importance of coke control where it was desired to limit as much as possible the carbon pick-up during melting.

Mr. A. Logan said they would all be in agreement with the statement in Mr. Wilson's Paper that inefficient working had a serious effect on certain elements in the iron during the melting operation, and that silicon and manganese might be considerably reduced due to excessive oxidation. A further statement following that, however, to the effect that absorption of detrimental gases affected the temperature and fluidity of the molten metal, also its physical and mechanical properties, was rather a bold one. He asked whether Mr. Wilson had carried out any work on that point, what were the detrimental gases, and to what extent were they absorbed.

Coke Ratios Melting Capacity.

Mr. Ben Hird asked Mr. Wilson to explain more fully his statement that in a 4 ft. 6 in. diameter cupola with a coke consumption of 8 per cent. the melting capacity would be 12.78 tons per hour; that if the coke ratio were 1 : 10, or 10 per cent., the melting rate would be 10.2 tons per hour; so that the higher the coke to iron ratio the greater the melting capacity of the cupola per hour.

Mr. Horace J. Young, in a written communication of Mr. Wilson's Paper, said that most ordinary foundries in this country could save coke and iron, but in his experience it could not be done by the installation of an intricate apparatus. Moreover, no apparatus was better or cheaper than a simple pressure gauge—home-made if possible—and a Pitot tube properly installed. These, in the hands of somebody who knew how a cupola worked, were all sufficient, and no instrument in any other hands was much good at all. He could not agree that the expansion of any one iron could be reduced from 0.06 to 0.015 in. by reduction of the blast. There must be more than one factor operating to account for it, and it was not due to the blast alone. If one worked a cupola at a certain pressure, the coke bed must be made to suit that pressure; if one worked it at a certain volume, the coke charges must be made to suit that volume. Given these obvious rules of working, he did not believe that the metal would be affected hardly at all by either volume or pressure within reasonable limits. The greatest mystery about cupola practice was the mystery made about it; if it were as intricate as was suggested, half the cupolas in the country would not make castings, but they did produce them, and all that was necessary was to introduce a little economy for ordinary foundries and a little science for those on special work.

Some Interesting Experiments.

Mr. R. A. Mott (Sheffield University) wrote that it may be of interest to foundrymen to know that experiments are being carried out at Sheffield University to study the manner of burning of metallurgical cokes under standardised conditions. The experiments are performed in a small cupola of 1 sq. ft. grate area, to which the air (which is measured by means of a Venturi meter) is blown in at the bottom. Gas samples are taken at each 1½ in. interval above the grate level, and the temperatures are noted at the same points by means of a disappearing type of optical pyrometer. By using specified rates of air supply with measured weights (and sizes) of coke, it is possible to compare for different cokes, the distance from the grate at which the oxygen of the blast disappears (reactivity with air), and also the extent of the reduction of the CO_2 to CO in the higher levels of the furnace (reactivity with CO_2), as well as the temperatures developed. It is hoped that by the use of cokes of known cupola performances in such experiments, the significance of "combustibility" and "reactivity" of coke may be made clearer. Further tests are carried out to measure the resistance of coke to breakage by impact or dropping (the shatter test), and by attrition (abrasion tests), and the porous structure of coke is studied by Rose's method.

Structure of Coke and Combustibility.

Mr. F. Hudson, discussing Mr. MacKenzie's Paper, emphasised that the question of the properties of coke was of vast importance to the foundry industry, and said that the trend of modern progress lay in rigid specifications. He was disappointed that the author had omitted to give the volume of blast employed in his experiments, together with actual temperature determinations of the resulting metal in Table I, for the various cokes tested. These would have been well worth studying in conjunction with the text of the Paper. Mr. A. Thau, the Superintendent of the Dueben Coke Plant, at Halle, Germany, had published an excellent series of articles in "Chemical and Metallurgical Engineering," dated February 11, February 25, and March 3, 1924, regarding the formation, structure and combustibility of coke. He had pointed out that the combustibility and reactivity of coke depended upon its surface structure as well as its general physical structure, and, as proof, he had given some very excellent photographs. He had illustrated a specimen of sponge coke which, on an ordinary grate, had behaved like firebrick, and a seemingly dense coke which had behaved in an exactly opposite manner; the latter coke was made by the low-temperature carbonisation process. Coke produced by a modification of the low-temperature carbonisation process had given a combustibility exceeding that of the best beehive or bye-product brands, but the structure by fracture did not appear to have an open texture at all; it looked almost like black granite, and the largest of its cells could be discovered only with a strong magnifying glass. As yet, of course, this material was not suitable for cupola melting conditions, but he mentioned it in order further to illustrate that the structure of a coke alone did not seem a reliable index even when considered with chemical analysis as to the reactivity of coke. This should be borne in mind when considering suitable coke tests whereby the equilibrium point for any particular coke could be determined, as shown by Mr. MacKenzie. In conclusion, Mr. Hudson said that his personal work in the melting of all-steel charges gave results which were in agreement with those obtained by Mr. MacKenzie. With regard to the suggestion in Mr. Wilson's Paper as to slagging every two hours, he said that many firms in this country and abroad had an open slag hole all the time, and he would like to know what was the effect of the leakage of air through the slag hole upon the position and shape of the melting zone.

MR. WILSON'S REPLY.

Before replying to the points raised in the discussion on this Paper, Mr. Wilson pointed out that he had tried to make it as practical as possible, for the reason that quite a number of foundrymen who were keen on bringing their plant up to a high state of efficiency, desired to have results based on actual practice rather than too much theory. The average man asked for something which would help him to produce better and cheaper castings.

Replying to Mr. Shaw, Mr. Wilson stated, with regard to the test mentioned at the bottom of page 4 of the Paper, that the pressures were taken directly after the cupola was blown in. Special arrangements were made to allow for the tubes to descend with the charge, but it was only possible to continue this test for a period of fifteen minutes, due to the flexible connecting tubes burning after that time.

Referring to the tests in which varying volumes were used, several tests not published in the Paper had been made for a long period with different volumes, but the object of taking this particular test on one day was to ensure that the conditions remained the same. The cupola was not blown down at each change of volume. The volumes were changed at intervals of one hour.

He had already explained in the Paper the periods at which the various samples were taken, and particular care was taken to keep the condition of the cupola and the height of the bed, etc., as near constant as possible.

With reference to the expansion points, as shown in the diagram, on bars obtained from iron cast in chills melted at varying volumes, the chilled mould in which these bars were cast was water cooled, with an arrangement for maintaining a constant temperature at the time of casting.

Replying to Mr. Cook, he expressed the view that, although it was well known that the percentage of oxygen in the air varied under different climatic conditions, the measurement of air by weight instead of volume would be a complicated arrangement. The measurement of air by weight was an excellent method, but he was afraid that under ordinary foundry conditions this was impracticable.

Wilson Blast Meter is Standardised.

The instrument referred to in the Paper is specially designed to withstand the conditions usually found round and about a cupola. In other words, it is not affected by dust and grit contained in the air. As to the accuracy of the instrument, he said that each instrument was calibrated with a Pitot tube under standard conditions.

He agreed with Mr. Campion that the quantity of air should be referred to in terms of "Coke Consumed," and not "Per ton of Iron Melted." It is obvious that this is more correct, as the coke ratio varies considerably, and for this reason the formulæ referred to in the Paper are based on, not only the amount of coke, but also their carbon content.

Replying to Mr. Gresty's remarks as to the temperature of gases at varying heights, as shown in Fig. 2, he said the temperature was taken at the tuyere level at a point a few inches inside the cupola. He believed that the maximum temperature was not obtained at this point. It would naturally be greater at the melting zone, but it would be very difficult to obtain the temperature at that point, so that undoubtedly the curve as shown in Fig. 2 would have a kink in it at some point above the tuyere level.

The object of this test was not to obtain the maximum temperature at the melting zone, but to show the variation in temperature due to the height of the cupola. In other words, to prove that in the case of cupolas with a charging door too low, the loss in sensible heat was more excessive than in the case of higher cupolas.

With regard to the increased expansion obtained on bars cast from iron melted with a high blast, a large number of experiments made in course of investigations in connection with casting in permanent moulds prove that a higher expansion is obtained with oxidised iron. Referring to Fig. 14, the regularity of the pressure and volume curve proved that the cupola was working efficiently, the tuyeres remaining clean throughout the melt.

Tuyere Details.

Replying to Mr. Hudson, it is found that with an open slag hole and continuous slagging, there is slight reduction in temperature, and also a higher percentage of iron shot in the slag. Replying to another member with regard to the shape and number of tuyeres used in the cupola, he said that in the particular cupola referred to in the Paper the number of tuyeres used was eight. These were oval in shape, and the tuyere area was 18 per cent. of the cross sectional area at the melting zone. The height of the coke bed above the upper tuyere was 18 in.

He agreed with Mr. Fletcher that with iron having a high phosphorus content one could work with a lower coke consumption, but with a cupola properly constructed, with means of regulating the blast supplies, this could efficiently deal with the production of high-class irons without any difficulty. In the latter case it is more important to have some method of blast control than when using common irons.

With regard to detrimental gases, mentioned by Mr. Logan, it is well known that molten metal can contain in varying degrees—oxygen, hydrogen, nitrogen, carbon monoxide and carbon dioxide. An excess of any of these gases produces unsound castings and affects the physical strength of the metal. Castings produced from hot metal are less liable to be affected by absorbed gases than are castings produced from cold sluggish metal.

Factors Governing Melting Rates.

Replying to Mr. Hird's question with regard to increasing the output of the cupola by increasing the coke ratio, he said that what he meant to convey was that the lower the percentage of coke, or the higher the ratio of iron to coke, the greater the melting rate.

With regard to Mr. Young's written communication stating that a Pitot tube was all that was necessary, Mr. Wilson pointed out that, taking into consideration the collection of dust under ordinary working conditions, this must affect the reading of the Pitot tube, and unless these tubes were kept clean the results must be unreliable.

With regard to the expansion of the iron referred to, the object of quoting these figures was to show that this condition can arise where iron is highly oxidised, producing a great expansion. The particular case mentioned by him was not obtained within reasonable limits, but was only given to show the possible results under very abnormal conditions. The figures given were not obtained in this country, but in a cupola abroad where very high blast was used.

MR. MACKENZIE'S REPLY.

Mr. MacKenzie replied to the discussion on his Paper in the following written communication :—

Replying to Mr. Shaw, the author states that it was not the idea to obtain from each ladle exactly the same amounts of silicon, manganese, etc. In fact, it was felt that the information would be better if some variation in these were allowed, and, therefore, small taps were taken. It is well known that in using high percentage alloys and taking out small amounts, as was done in these experiments, the variations are likely to be very serious. In fact, in using ordinary materials, it is common practice to use a receiving ladle so that better mixtures may be obtained. It should also be borne in mind that the small cupola used was only 18 in. in diameter with a very low stack, so that an excess coke had to take the place of the stack, to some extent, in heating. We have tried ratios of 6 to 1 of coke in all steel melts in this cupola, and were very successful in getting good temperatures, but with 17 per cent. ash coke the iron could not have been handled in the ladle if such coke ratios were used. Also, considering the fact that the surface of the cupola varies with the first power of the diameter, and the area varies with the square of the diameter, it can be readily seen that more coke is usually necessary in a small cupola than in a medium size. In larger cupolas other factors obtain, and this does not go to the other extreme. The same is the argument for the higher bed. With high ash coke it is necessary to push air through a very long column of coke to get the maximum temperature and carbon dioxide. If the right bed had been used for the Barrett coke we would not have been able to melt with the high ash beehive coke, and in order to keep the conditions the same, the bed was put at a point where it would work with these cokes, not with any idea that if we used Barrett coke in a cupola consistently we would ever dream of sticking to a 40-in. bed. Our personal opinion is that if we had to use Dayton coke we would go to a 60-in. bed.

The temperatures obtained have been recently checked with the U.S. Bureau of Standards, and the results will be published by the American Foundrymen's Association. The work done by the Grey Iron Research Committee of the American Foundrymen's Association on comparative temperatures between the optical pyrometer and the thermo-couple shows that steam temperatures give approximately theoretical correction for all mixtures, and the author entertains no doubt of the approximate accuracy of these figures.

About the heavy coke ratios, which were also mentioned by Mr. Campion, it is not felt that this high amount of coke which was selected as a mere convenience in handling the metal in small quantities because it gave such excessive high temperatures would change the ratio of the different cokes whatsoever if the amount was cut to, say 6 to 1. In one case we were able to handle all of the melt, but at 6 to 1 we would not be able to handle the high ash coke at all. It is not believed that the relation between the different cokes would be changed at all by the absolute amount of coke used.

Replying to Dr. Becker's remarks, the author regrets that no figures were available for reactivity. In fact, there is very little unanimity of opinion as to the correct tests. A recent Paper by Prof. Parr, of the University of Illinois, seems to give a very useful test which can be carried out on a laboratory scale. We shall await Mr. Mott's experiments with considerable interest. This test would seem to be a larger scale modification of Prof. Bähr's, published in "Stahl und Eisen," volume 44, pages 1 to 9 and 39 to 48. It is hoped that the University of Sheffield will obtain some of the more reactive cokes to supplement charcoal, which is the upper limit of Prof. Bahr's experiments. The author would be glad to ship Mr. Mott a sample of the Barrett coke, and probably could obtain for him one of the lighter petroleum pitches, if it is not available in England.

In conclusion, the author would thank Mr. J. E. Fletcher for abstracting the Paper, and also for his kindly remarks. A great deal of this work was done before the idea of a complete series came into being, and a great deal of information which would have been obtained had the programme been carefully made, was not obtained in the earlier melts. As it was not possible to repeat these, on account of the exhaustion of the coke supplies, some data which were obtained on the last of the melts were not put into the table.

STRESSES IN NON-FERROUS CASTINGS.

By Professor Cecil H. Desch, D.Sc., F.R.S. (Member)·

The existence of internal stress in castings is a frequent cause of failure, giving rise to defects which are familiar to every foundryman. All metals are liable to internal stresses when cast into shapes which allow of the cooling of different parts at unequal rates, but the trouble is apt to present itself in a more acute form in the non-ferrous foundry than in the iron foundry, owing to the conditions of solidification. The greater the change of volume during solidification, and the greater the solid contraction during cooling, the more severe the stresses which will be developed. Cast iron contracts on freezing, but very shortly afterwards an expansion occurs, owing to the liberation of graphite, and this expansion partly neutralises the effect of the contraction, so that stress is to that extent relieved. Steel, on the other hand, does not undergo an expansion, and as its casting temperature is very high, there is a long range of temperature over which contraction is occurring in the solid state, and the liability to internal stress is therefore great. Cooling stresses of this kind will obviously be in greater proportion, as the reduction of volume on freezing and the solid contraction are greater, but other factors are also involved. A very soft metal, such as lead, will yield to stress so that the casting will deform more or less, but will not crack. On the other hand, a hard bronze or nickel alloy, with a high elastic limit, even at temperatures above that of the atmosphere, will be unable to yield, and is likely to develop cracks. Table I gives the contraction on freezing and the mean coefficient of linear contraction in the solid state of the principal pure metals, but few data as to their yield when hot are available.

Simple shrinkage is in itself able to account for quite considerable stresses, but in some metals and alloys the effect is accentuated by the crystalline nature of the material. Metals such as copper, silver, iron, lead and aluminium crystallise in the cubic system, and their contraction is the same in all directions, but others, such as zinc, bismuth, antimony and cadmium, crystallise in less simple forms, and contract more in one direction than in another. For instance, the coefficient of expansion (or contraction) of bismuth is 16.2 × 10^{-6} parallel to the axis and only 12.0 × 10^{-6} perpendicular to the axis, and although accurate determinations of this kind have not been made for other metals, it is certain that all metals and alloys which do not crystallise in the cubic system must show similar differences. Such metals, for example zinc, usually form crystals which are much longer in one direction than in any other, and the high contraction in the direction of greatest length sets up stresses which may be considerable. Moreover, such crystals grow most rapidly along the axis, and exert a measurable thrust in so doing. A consequence of this is that when a casting, such as a long bar, begins to freeze, the outer shell, which first solidifies, consists of long crystals, thrusting against one another and causing an apparent expansion, leaving small cavities in the interior. For this reason, many brasses and other alloys have been recorded as expanding during freezing, whilst a determination of the density proves that no real expansion has taken place, but that the cast bar is minutely porous. An outer shell which has solidified in this way is in a state of stress, which is greater the greater the

TABLE I.

Metal.	Coefficient of linear expansion. $\beta \times 10^6$.	Change of volume on melting. Per cent.
Aluminium ..	27.4	6.4
Antimony ..	10	1.4
Bismuth ..	13	3.2
Cadmium ..	31	4.7
Copper ..	16.5	4.0
Gold	14.5	5.2
Lead	29	3.4
Magnesium ..	29	—
Nickel	16	—
Silver	24	5.0
Tin	22	2.8
Zinc	26	6.5

difference in the coefficients of expansion of the crystals in two directions at right-angles to one another.

It follows that a mere knowledge of the coefficients of expansion of metals and alloys counts for little in deciding how much shrinkage will be found in a casting, and empirical measurements of actual castings of simple form are of greater value. The shrinkage observed in this way is the net result of a number of separate changes, which may partly neutralise one another. As an example, the values of the shrinkage of light alloys of aluminium may be considered. Various writers have given figures, which differ remarkably little from one another, as the composition is varied within wide limits, although every foundryman knows that the differences in actual shrinkage are very large, and that this accounts in large measure for the popularity of the alloys with silicon which show a smaller shrinkage than most alloys of the kind.

When an alloy consists of two constituents of very different physical properties, stresses may easily be set up. The gun-metal and similar alloys mostly contain the eutectoid of copper and tin, a hard, brittle material. The difference in contraction between this and the adjoining solid solution is so great that small cracks often start from the patches of eutectoid. Rapid cooling will diminish the size of any such inclusions, and thus lessen the concentration of stress. Although rapid cooling might be expected to cause thermal stresses, this is often more than compensated for by the smaller size of the crystals and by their less regular arrangement, causing a more even distribution of the small residual stresses. It is for this reason that chill castings may be more free from stress than sand castings, although at a first glance the contrary might be expected to be the case. When the chill is very severe, as in pressure die-casting, there may be great shrinkage stresses, and this has been observed with aluminium alloys. Pistons, when die-cast under pressure, have been known to separate into two concentric shells, completely distinct from one another, owing to sharp contraction stresses between the two rapidly-chilled surfaces. Ordinarily, when the feeding of the die-casting is properly provided for, the metal obtained is comparatively free from internal stress, unless the alloy is of such a kind that a transformation may continue in the solid state after solidification. Such a condition appears to be responsible for the warping of some zinc base die-castings in the course of time. The alloys of aluminium with zinc contain an unstable phase, and the gradual change to the stable condition sets up stress. As an example, die-cast tensile test pieces of an alloy of 93 per cent. zinc, 4 per cent. aluminium, and 3 per cent. copper, showed a distinct falling off of tensile strength after one year, but the resistance to shock was very greatly reduced, falling in the same time from 76 to 8 ft.-lb. sq. in., although chemical action was prevented. This effect must be attributed to internal stress.

Many alloys pass through a brittle range during the process of cooling, and within certain limits of temperature they are easily fractured. All alloys of copper and zinc have this property. For cast brasses of the alpha-beta type this range lies in the neighbourhood of 300 to 500 deg C., and a similar range is found in the tin bronzes. Advantage is taken of this fact in knocking off the runners of castings, but it is obviously dangerous to shake or handle castings while within this range of temperature.

Any local heating subsequently to casting is liable to set up stresses. Burning-on at defective places is a prolific source of trouble. It may happen that the burnt-on portion may appear to be quite sound, and that cracking will occur at a later stage. Monel-metal castings which have been treated in this way sometimes crack violently some ten minutes after making the weld. Such trouble can only be avoided by annealing, taking care that the metal cools from the welding temperature slowly enough to allow of the gradual relief of stress. Large castings have sometimes split suddenly without known cause, and the presence of dissolved gases has been suspected as being responsible. Much work is now in progress on the removal of gas from casting metal, and it remains to be seen whether the measures which are recommended will lead to the production of castings which are less liable to crack as the result of internal tension.

A remarkable case of cracking of castings through internal stress is that of the valve castings used in the construction of the Catskill Aqueduct for a supply of water to New York, an account of which was published in 1915. These castings were of the alloy usually called manganese bronze, and were very large, sometimes up to 10 tons in weight. Although they had been subjected to hydraulic test pressures of 200 or 300 lb. per sq. in. for half an hour or more, they developed leaks some months later under very small pressures, and these leaks became larger in course of time. An analysis of one of the castings gave:—Copper, 58.5; zinc, 39.1; tin, 1.0; iron, 1.4 per cent.; lead, trace, and manganese, none. The structure was that of an approximately 60 : 40 brass, composed of beta crystals containing numerous isolated alpha crystals. Many of the valves and other objects had been repaired by "burning-in," cracks and other defects being filled by melting in some of the same material. Sound welds were obtained in this way, and the castings had every appearance of being in good condition. It was only after an interval of time that failure occurred. The matter was investigated by the U.S. Bureau of Standards in 1916, and experiments were made by casting frames of the shape shown in Fig. 1, cutting through at the point A, and burning in a supply of the same metal, making a weld. By

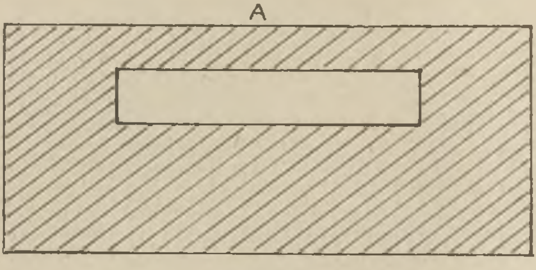


Fig. 1.

sawing through this arm of the frame, after having removed the pouring gate, it was possible to measure the stress in the casting by measuring the change in distance between two gauge points previously marked. Tensile stresses ranging from 2.8 to 4.3 tons per sq. in. were found to exist. Calculations showed that a stress four times as great might have been expected theoretically, so that in all probability there had been some plastic yielding of the alloy, the elastic limit being exceeded. This would leave the other parts of the casting near to the repair in a state of severe internal stress, similar to that which is found in a severely cold-worked metal.

Fig. 2.

The subsequent cracking would then be of exactly the same kind as the "season-cracking" of cold drawn tubes and rods. It would not occur immediately, but after an interval, as in season-cracking. The failure was not in any way due to the weld metal itself, which gave normal tests and structure, but to internal stress, which could not be removed by subsequent annealing, owing to the large size of the castings.

A more obscure condition of stress, in which the writer has taken particular interest, is that which manifests itself between the individual crystal grains of a cast metal. It is well known to all who have been concerned with the casting of marine propellers in manganese bronze or similar alloys that occasionally a brittle casting is obtained, which may fracture on a blow, invariably showing a coarse intercrystalline fracture. A fragment of a broken propeller of this kind is shown in Fig. 2. In this case fracture occurred when a blade of the propeller happened to strike a floating plank. The crystal grains of such castings are occasionally of enormous size, the shape of one, which was of the size of a turkey's egg, being shown in Fig. 3. In the writer's experience, castings which have behaved in this way have always consisted either of the beta constituent only, or of beta with a relatively small proportion of alpha, and they have contained a high proportion of aluminium. The late Prof. Huntington noticed that very coarse crystalline alloys of this kind would disintegrate if placed in mercury, and this test has proved useful. The fragment of propeller in question, if immersed in mercury, will break up in the course of thirty seconds into a loose mass like sand, each particle being a single crystal grain. Other specimens disintegrate more slowly, and the process may take minutes or hours. Others, again, although with grains as

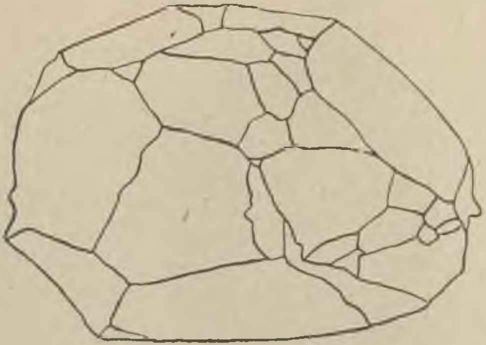


FIG. 3.

coarse as the specimens in question, are not loosened by the action of mercury, but are evenly amalgamated without penetration along the grain boundaries. The effect strongly recalls the use of mercury or of mercuric salts as a test for season-cracking. Cold-worked brasses are sometimes in a condition in which spontaneous cracking may occur, perhaps months after manufacture, on exposure to corrosive fumes or by a change of temperature. The mercury test produces sudden cracking, which is evidence of internal stress. Reasoning from analogy, it may be supposed that the castings which respond to the action of mercury in this way are also in a condition of stress, and this conclusion is almost certainly justified. A comparison may be made with the action of tin or solder on brasses at high temperatures, to which attention was first directed by Dickenson, who described a beta brass (so-called manganese bronze) of the following composition:—

Copper, 55.75; zinc, 36.77; manganese, 3.87; and aluminium, 2.56 per cent., which cracked owing to the penetration of molten solder between the grains. It was shown that the solder could only penetrate while the brass was under tensile stress, and the alloy could be brought into contact with liquid solder when the specimen was under compression or on the compression side of a bent bar without producing any effect. Failure under tension was obtained in a number of brasses, and in most instances the penetration could be seen to follow the boundaries of the beta grains. The more regular the polyhedral structure of the brasses the more readily such failure occurred. A very similar kind of fracture is seen when gases penetrate into metals, as for example, when hydrogen is forced by electrolysis into copper or iron. The gases penetrate along the grain boundaries and may readily cause rupture. Brasses which on slow cooling give an alpha and beta structure fracture more readily in contact with mercury or with molten metals when quenched from a sufficiently high temperature to give them the structure of a homogeneous beta alloy. The writer has made a large number of experiments for the purpose of discovering the exact conditions under which disintegration could be brought about by mercury. A complete beta structure is the most favourable, and it appears that the presence of some metal other than zinc is usually necessary. In one series of experiments brasses were made to have a simple beta structure by varying the zinc and adding a sufficient quantity of aluminium, manganese or silicon. It was found that 2 per cent. of aluminium was necessary to produce disintegration, but this might be replaced by a rather larger quantity, perhaps 3 per cent. of silicon. On the other hand, manganese did not tend to develop this type of brittleness, and it is of interest to notice that in the Japanese navy much attention has been given to alloys containing as much as 4 per cent.

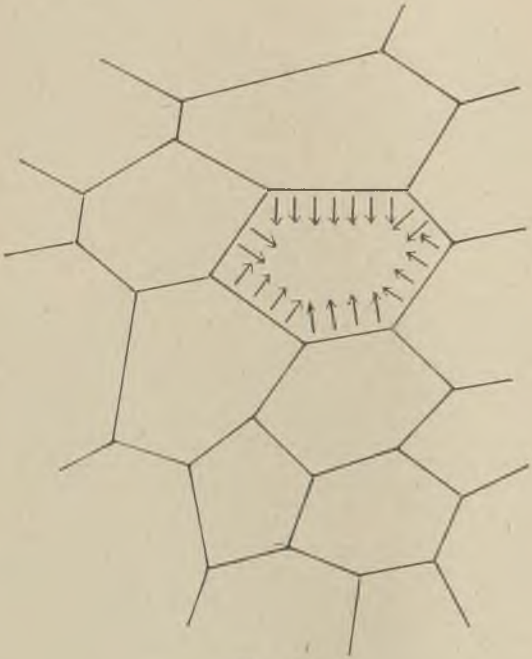


FIG. 4.

manganese for the castings of propellers, and it is understood that these are not so liable to exhibit great brittleness. That the question is not merely one of chemical composition is shown by the behaviour of a casting which was examined recently. The analysis of this casting was:—Copper, 64.40; zinc, 26.55; iron, 1.55; manganese, 1.84; and aluminium, 5.30 per cent., with only minute quantities of other metals. The structure was that of a beta brass and the mechanical properties in the cold were excellent, although it was possible to produce a brittle intercrystalline fracture by moderate heating. Mercury did not cause disintegration unless the surface to which the mercury was applied was in tension. The aluminium in this alloy is remarkably high, and nevertheless direct disintegration by mercury without stress was not produced. When the surface of an alloy of this kind is amalgamated and a section is cut through and examined by means of the microscope (special precautions being necessary to avoid the smearing of the amalgam) it is seen that amalgamation has advanced along the grain boundaries, whilst the crystals as a whole are unchanged. The behaviour of castings having the simple polygonal grain structure of beta brass may be illustrated by Fig. 4. These polygonal masses contract in cooling, and there is, therefore, a tendency for each grain to pull away from its neighbours, the stress in one such grain being indicated by arrows. The more simple the form of the boundaries the more likely is rupture to occur, and this is in accordance with the fact that such brittle fractures are almost always accompanied by a simple polygonal structure. Whether it is considered that an amorphous material exists between the grains or not, it is certain that chemical action, including amalgamation by mercury, can proceed most readily along the boundaries, and when considerable stresses are present at those boundaries the material may break up. It seems very probable from analogy with season cracking that rupture by chemical means does not occur unless a state of stress exists in the region to which the reagent penetrates. Why there should be so much difference between different castings remains unexplained.

DISCUSSION.

Largest Crystal Grains Absent in High-Grade Manganese-Bronze Propellers.

Mr. Wesley Lambert (Vice-President) commented on the author's statement regarding the very large crystal grain structure to be found in some large marine-propeller castings. As one who had had a very considerable experience in the manufacture of heavy manganese-bronze castings, weighing up to 30 tons apiece, he pointed out that it would be a most alarming thing were the Paper to be allowed to be published broadcast without a correction being made. He felt sure that the purchasers of marine propellers and of other heavy manganese-bronze castings would be extremely chary about ordering these castings if there was even a likelihood of the crystal grain size in any part of a casting even approaching that shown in Fig. 3, which represented a single crystal grain of several centimetres diameter. He believed he recognised in Fig. 3 a crystal grain which he himself had loaned to Professor Desch. Professor Desch had published a Paper on the isolation of metal grains, and at the conclusion of that Paper had written that he hoped in the near future to succeed in isolating larger grains. He (Mr. Lambert) had sent Professor Desch the grain illustrated, and he could only surmise that, seeing it came from a propeller manufacturer, Professor Desch had concluded that it must have resulted from a very large casting, presumably a propeller.

Original Chill and Large Grains.

As a matter of fact the large grain in question came from a small bulk of metal weighing only about 200 lbs. Explaining the circumstances under which the large grain was obtained, he said that on a certain Monday morning manganese bronze was being extruded, and a chill-cast billet had fallen to pieces while being removed from the reheating furnace. Among the pieces of metal was found the large single crystal grain shown in Fig. 3. He was sent for and informed that there was something radically wrong with the metal as evidenced by the large grain structure exposed on the fractured surfaces of the billet. Inquiring as to when the billet was put into the reheating furnace, he was told that it was put in that morning. He came to the conclusion, however, that the billet had been put into the furnace on the previous Saturday morning, and that when the whistle to cease work had blown the men had not troubled to extrude the last remaining billet, but had allowed it to remain in the furnace until the Monday. Then, when the furnace had been fired on the Monday morning, the billet had been left at the back of the furnace, until at last it was brought forward for extrusion and had fallen to pieces as it was handled.

It is practically impossible, when following the ordinary routine practice, so to cast a propeller, even when weighing say 30 tons, as to produce a crystal grain of the size shown in Fig. 3. He had examined many propellers accidentally broken during the war, and in several instances sections had been cut right through the heavy root portion adjacent to the boss of a blade, planed, polished and etched, and he was in a position to affirm that it is extremely doubtful whether one would ever happen upon a crystal grain of a diameter larger than $\frac{3}{8}$ in.

The text of Professor Desch's Paper might lead one to believe that in large castings of manganese bronze one can find large grains of the size illustrated in Fig. 3 of his Paper, but this was not so, and he was sure Professor Desch would readily admit his error in this respect.

Composition and Large Grain.

Professor Desch, replying, expressed regret to Mr. Lambert for having misunderstood his communication. It was true that the grain referred to was the one Mr. Lambert had sent him, and he had inferred, from Mr. Lambert's letter, that it had come from a propeller. He was quite prepared to admit that grains in castings never were that size. However, he had had propellers from other sources with crystals of very large size, and it was, after all, a matter of degree. A crystal with a diameter of $\frac{3}{8}$-in. was pretty big, and he was referring to crystals which would break apart and give such a coarse fracture that the size of the crystals was visible to the eye.

The cause of such unusual crystallisation was still obscure and was worth investigating. A simple cast billet of such bronze could not be made to give excessively large crystals by heat-treatment alone. When, however, there was any local chilling in a casting, cooling stresses might be set up, so that on re-heating the mass of metal was in a similar condition to a mass which had been cold worked, and therefore grain growth could take place. It was quite possible that the occurrence of exceptionally large grains in some propellers was due to such local stresses, but the conclusion had not yet been proved. It was remarkable that such grains were only observed within certain ranges of chemical composition.

Result of Insufficient Feeding May Resemble Contraction Stress Pull.

Mr. Wesley Lambert, reopening the discussion on the following day, said that he had again read Prof. Desch's Paper, and would like to bear testimony to the fact that it was a really valuable contribution, containing a considerable amount of very useful information. Discussing the Paper further, he called attention to the author's statement, in a reference to chill castings, that "When the chill is very severe, as in pressure die-casting, there may be great shrinking stresses, and this has been observed with aluminium alloys. Pistons, when die cast under pressure, have been known to separate into two concentric shells, completely distinct from one another, owing to sharp contraction stresses between the two rapidly-chilled surfaces." It so happened, he said, that a few days ago a member of the Institute had sent him a gunmetal plate, having a superficial area of about 2 sq. ft. and about $\frac{3}{8}$ in. thick. The casting appeared to be quite good, but the member in question had had occasion to machine it somewhat deeply, and had then found, to his great consternation, that there appeared to be some defect. In exploring it he had found that there was a wall space in the interior of the casting, and that it was possible, without very much trouble, to divide the casting into two distinct parts. This was not at all an uncommon thing in non-ferrous work when one was casting thin castings. Prof. Desch, apparently, would lead one to believe that it was due to contraction *stresses*. If it were due to contraction stresses, however, one would expect to find some evidence of rupture of metal, but, as a matter of fact, in the majority of these cases, if one examined the surfaces exposed by tearing the two apart, one found that the crystal formation had not been disturbed by fracture or rupture in any way. There were skeleton crystals and perfectly-formed crystals exposed, and he believed it would be found, if one examined them closely, that the trouble was due to a dual freezing, *i.e.*, freezing taking place on both sides of a thin casting, and that there was insufficient liquid metal to follow up the contraction. It did not appear to be due so much to contraction stresses as to the fact that one had not been able to feed the thin casting. In order to demonstrate that this was not at all uncommon, he said that on several occasions specimens had been sent to him and he had been asked for advice as to how to get over the trouble. The remedy suggested itself. One must endeavour as far as possible to get the freezing to take place from one side of a thin casting. That could be done by having one half the mould warm and the other half colder. He had met cases of pistons showing two concentric castings, one inside the other, but he had no evidence whatever that they had parted as the result of internal contraction stresses; the trouble was due to the fact that the castings were improperly fed.

Burning-On and Annealing.

Later on in the Paper Prof. Desch had referred to burning-on at defective places as being a prolific source of trouble. Unfortunately, however, burning-on had to be resorted to, and Prof. Desch went on to say that such trouble could only be avoided by annealing. It was very kind of him to call attention to that fact, but all practical foundrymen recognised that when they had to have resort to burning-on, an annealing operation followed, otherwise there would be many more failures to record than were actually recorded. Reference had also been made to the cracking of valve castings used in the construction of the Catskill Aqueduct to New York. He had been asked, in 1915, by American authorities to contribute to the investigation into the failure of these valves. It was true that in some instances the valves had failed because of the burning-on that had been carried out, which apparently had not been followed by adequate annealing, but in some instances these large valves had failed because the core was not made in such a manner that it would collapse sufficiently to enable the casting to contract as it should have done normally. He did not think that, at the time the castings were made, the makers had understood the idiosyncrasies of manganese bronze to the extent that they were understood to-day.

Manganese-Bronze Propellers.

A statement in Prof. Desch's Paper which needed a little explanation was to the effect that it was well known to all who had been concerned with the casting of marine propellers in manganese bronze or similar alloys that occasionally a brittle casting was obtained, which might fracture on a blow, invariably showing a coarse intercrystalline fracture. Such a statement, said Mr. Lambert, might arouse some suspicion in the mind of the purchaser of a propeller as to whether he had not got hold of one of the brittle ones. Some 15 years ago the high-tensile bronzes, *i.e.*, the bronzes of the beta range, were introduced, and on account of their high tenacity and good elongation they were considered to be an excellent material for propellers, so that a very large number of propellers was made in the beta bronzes. Unfortunately, however, these beta bronzes had to be controlled within very narrow limits, and he believed propeller manufacturers would concede that 14 or 15 years ago a rather brittle propeller blade or solid propeller might occasionally have been made, but he was pleased to say that to-day they knew the limitations of the beta bronzes.

The Mercury Test.

Discussing the mercury test, referred to by Prof. Desch, he said that with the beta bronzes, of a brittle character, one could get disintegration in a very short time, but the bronzes of the alpha-beta type, which were used more than the wholly beta bronzes, did not disintegrate in mercury to anything like the same extent. He had asked

Prof. Desch whether he had arrived at an explanation of the inter-penetration of mercury, and the reply was that he was still carrying out research work in that direction. The penetration of manganese bronzes, particularly the beta bronzes, by mercury was a very interesting phenomenon. Incidentally, one would gather from the Paper that the late Prof. Huntington had discovered this remarkable effect of mercury on bronzes. Dr. Rogers was credited with having first published this effect, but, as a matter of fact, it was within his (Mr. Lambert's) knowledge that some years before Dr. Rogers had dealt with the subject the effect of mercury on brasses had been discovered as the result of the fulminate of mercury used in the detonating caps of cartridge cases having caused the fracture of a very large number of cases.

Mr. A. Logan was glad that Prof. Desch had drawn attention to the question of volume changes during solidification, because this point, particularly with regard to non-ferrous alloys, was one on which a great deal more information was required. He had experienced with gunmetal what Prof. Desch called "apparent expansion." If one had a gunmetal liner, for instance, 10 ft. or more long, 14 in. dia., and, say, 1¼ in. thick, and moulded it in a box which was rather small, so that there was only a small thickness of sand on the joint, it was quite possible to see the result of the actual expansion of that casting. It was such that the two halves of the box were actually forced apart, and one could see the red casting showing through the joint. That was a case in which expansion was not merely "apparent," but very real. Prof. Desch explained it by saying that it was due to the thrust of the crystals. Whatever it was due to, it was very interesting, and was a point which required further investigation. Of course, the final result was a contraction or shrinkage. The statement in the Paper, already referred to by Mr. Lambert, that it was well known to all who had been concerned with the casting of marine propellers in manganese bronze or similar alloys that occasionally a brittle casting was obtained, was incorrect, and likely to be misleading. This point had been effectively dealt with by Mr. Lambert, however, and he (Mr. Logan) would only add his own confirmatory evidence.

Prevalence of Contraction Strains.

Mr. H. C. Dews (London) wrote that, on reading the first two sentences of the Paper, the practical foundryman is likely to be seriously perturbed by the reflection that yet another worry is being added to the already multifarious troubles he has daily to overcome. It seems desirable to ask Prof. Desch if he intended to convey that the position is quite so serious as his words may lead one to suppose. Considering the large number of castings which are put into service "as cast" one cannot imagine the presence of internal strains to be very widespread. If internal stress were liberated during the life of the castings one would expect deformation or cracking to occur. Such cases, however, are seldom reported, and even in the latter event the cracks can generally be ascribed to causes other than internal stress. One is thus forced to the conclusion that the internal stress is locked up harmlessly in the casting till, in the course of years, it finds its way back to the scrap-heap, or else stress is not present to such an extent as may be presumed. There is little doubt, as Prof. Desch points out, that "burning" is a prolific cause of dangerous internal stress, but the severe local heating and cooling in this case is not usually met with in the ordinary cooling of a complete casting.

It is difficult to agree with Prof. Desch that volume change on solidification is responsible for internal stresses. It is well known how metals and alloys rapidly lose their strength at high temperatures. Researches seem to indicate that the fall generally persists to a very low value, and although at some temperature below the melting point the temperature-stress curve may straighten out, it seems reasonable to suggest that near the melting point the strengh of most alloys is only of the order of a few pounds per square inch. No internal stress of any appreciable magnitude could be held by an alloy in such a weak state.

There appears to be a little confusion in the reasoning of the paragraph which states that coefficient of expansion figures are of little value to patternmakers in dealing with shrinkage allowance. It can readily be agreed that good working rules can be obtained by measuring actual castings, but it is sometimes desirable to have a more scientific check on these figures. This can be calculated from coefficient of expansion data where such are known up to near the melting point of the alloy. Figures from ordinary temperatures to near the melting point are not generally available, but in cases where they are known remarkable agreement can be seen to exist between the net expansion obtained from those figures and that found empirically by the patternmaker. It is important also in making such a comparison to deal only with sound castings, as the presence of internal cavities may seriously affect the apparent shrinkage. In choosing aluminium alloys to illustrate his remarks Prof. Desch has confused that portion of the total shrinkage which the foundryman has to contend with and that which is rectified by the patternmaker. The difficulty in the foundry with some aluminium alloys and the ease with which others may be cast is due to a high liquid contraction and volume change on freezing in one case and low values in the other. The foundryman can make good the liquid contraction and volume change on freezing by suitable feeding and the pattern has to rectify the solid contraction, which may be much the same for alloys with very different liquid and pasty contraction values. No allowance which the patternmaker can put on will make good the shrinkage which takes in the liquid, and on passing to the solid, and conversely, once these two stages are past, none of the foundryman's artifice can make good the solid contraction. From this point of view it would not seem reasonable to expect published data on the solid contraction to agree with the foundryman's observations which refer to the alloy in the liquid and pasty stage.

Mr. S. B. Hole wrote asking whether Dr. Desch considered that disintegration of bronzes by action of mercury is due to penetration of mercury into the intercrystalline cement which (due to strain to which it is subjected) amalgamates much more readily. The strain gradient present probably causes an "active" condition in which an amalgam is formed and the cohesion between grains being destroyed, disintegration takes place.

Author's Reply.

Professor Desch wrote in reply that the use of mercury salts for the detection of stress in severely cold-worked metals, such as brass cartridge cases, was, he was well aware, known many years ago. The separation of grains of beta brass in a casting by immersion in mercury was quite a different thing, an effect which had not yet been explained, and possibly unconnected with stress. He first learned of it from Professor Huntington, and he was not aware of any previous observation of the kind. The statement in the Paper was therefore correct. He was not prepared to say whether the explanation was that suggested by Mr. Hole. This was one of the cases in which the hypothesis of the amorphous cement fitted the facts well, but he was not ready to commit himself to that hypothesis without further investigation. Mr. Dews had rather missed the point of the remarks concerning expansion figures. The coefficient of expansion was a most useful figure to know for the purpose of calculating contraction allowances. Unfortunately, it was known for very few alloys, and most of the published figures, especially for aluminium alloys, were worthless. The extent of the volume change during solidification was chiefly of importance for die-casting. It was quite unknown for most metals, and it was only lately that an apparatus had been devised and constructed in the University of Sheffield, by means of which that quantity could be determined accurately.

NOTE ON THE MANUFACTURE OF STEAM CYLINDERS FOR LOCOMOTIVES AND PISTON RINGS FOR THE PARIS-ORLEANS RAILWAY COMPANY.

By L. Audo, Ingénieur des Arts et Métiers, Works Director of the Paris-Orleans Railway Company.

[French Exchange Paper.]

> "*There will therefore be two things to consider in experimental research: Firstly, the art of obtaining exact facts by rigorous investigation: secondly, the art of applying them by means of experimental reasoning, in order to establish knowledge of the laws of phenomena.*"
>
> Claude Bernard.
> On "Observation and Experiment."

The manufacture of high-tensile castings presented difficulties at a time which may be regarded as having preceded the war, when the methods of investigation available to foundrymen were rather crude. Manufacture was governed entirely by empiricism and observation. The production of high tensile metals was restricted to a few firms who had acquired a world-wide reputation which was no doubt deserved, and to the special metals employed, which were generally of British origin.

In his Paper presented to the Paris Congress in November, 1925, M. Varlet defined these special irons as follows: metals manufactured with cold blast, at low pressure, in small blast furnaces heated by coke or wood charcoal. The mechanical properties of such metals, when subjected to similar tests, are undeniably superior to those of irons manufactured in blast furnaces of large capacity worked with hot blast. These differences can be ascribed only to the method of preparation, it being impossible at present to determine their precise cause.

Nevertheless, the productive capacity of small blast furnaces is restricted, whilst the cost price of the iron obtained is high. The difficulties of importation during the war, and later the regrettable influence of the exchange impelled Continental foundrymen to endeavour to obtain high-tensile castings from the products of their own country's soil.

The manufacture of semi-steel projectiles during the war was a first step towards the desired result. But even the manufacture of these was at that time carried out, for the most part, in an empirical manner. The scientific study of such metal by M. Portevin, who has determined its structural characteristics, enabled its manufacture to be carried on methodically and its uses to be extended.

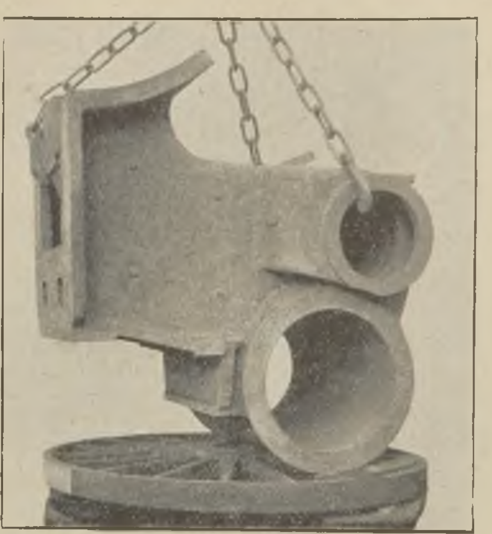


FIG. 1.—AMERICAN TYPE LOCOMOTIVE CYLINDER, WEIGHT 7,260 LBS. TWO CYLINDERS FOR EACH ENGINE MADE FROM ONE PATTERN. ERECTED ON THE VERTICAL PLAN OF SYMMETRY.

The lack of homogeneity of semi-steel made in the cupola for direct casting, however, does not permit of its employment for castings subjected to friction, in particular for engine cylinders and piston rings. This defect can be remedied by a preliminary pigging. This remelted metal will be made either in the cupola by the founder himself or in the electric furnace by specialists.

Although the cost of the final product is increased by remelting in the cupola, it is possible to obtain high-tensile metals at a practicable price by the employment of new metal, even if of indifferent quality (provided, of course, that it does not contain the injurious elements P and S in large quantities), larger quantities of scrap, and steel scrap— that is to say, cheap products. This steel may be of various origins, manganese steel being excluded as, owing to the presence of that element, there would be a risk of producing an abnormal quantity of cementite, which would be prejudicial to the strength of the castings and their efficiency in service.

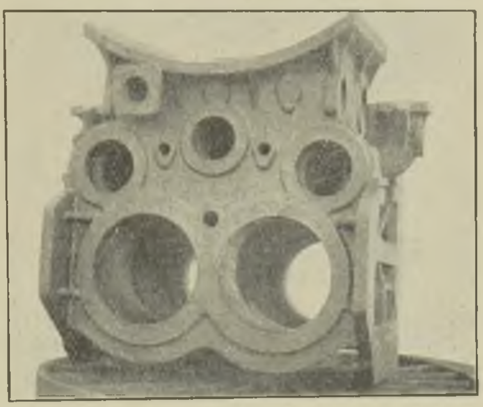


FIG. 2.—LOCOMOTIVE TWIN H.P. CYLINDER OF THE DECAPORT TYPE, WEIGHING 11,000 LBS.

When the author first introduced steel at the works of the Paris-Orleans Railway, he used spring steel derived from the broken leaves of the suspension springs of vehicles. This steel has the following composition:—TC, 0.523; Si, 1.5; Mn, 0.6; P, 0.03; and S, 0.02 per cent. The similarity of this analysis, except as regards the carbon, with that of a good hematite will be noticed.

These leaves are about 15 mm. in thickness and have a maximum length of 20 cm.

He then extended the use of steel to old rivets and clippings from shearing machines—small pieces which are easy to handle and are quickly melted in the cupola.

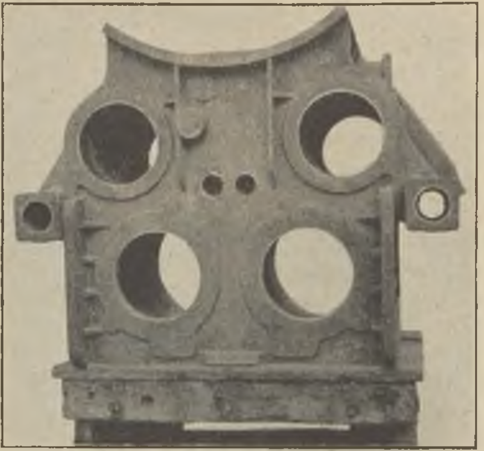


Fig. 3.—Locomotive L.P. Twin-Cylinder of the Pacific Type, Weight 12,210 lbs.

The preparation of the remelted mixtures should provide, as far as possible, for all the necessary additions of ferro-alloys, so that the re-melting may not necessitate any modification of the charge. In these two operations account should be taken of the influence of the cupola on the various elements, each cupola being, of course, the subject of special study. The use of ferro-alloys with high contents will, of course, be avoided, as they are generally friable and their loss in melting is high. These ferro-alloys, moreover, produce irregular products.

The object of the introduction of steel is, of course, to lower the total carbon content and to adjust it to the silicon content so as to obtain the pearlitic structure. It is evident that the production of high-tensile metals does not necessarily imply the addition of steel, and that by the use of special irons and of well selected hematite scrap the object in view may be attained more directly.*

Semi-steel has been described as an "artificial metal." But very many articles which one habitually uses nowadays are manufactured artificially, yet one is perfectly satisfied with them. The metal to be obtained, whether manufactured with or without accessories, should have a pearlitic

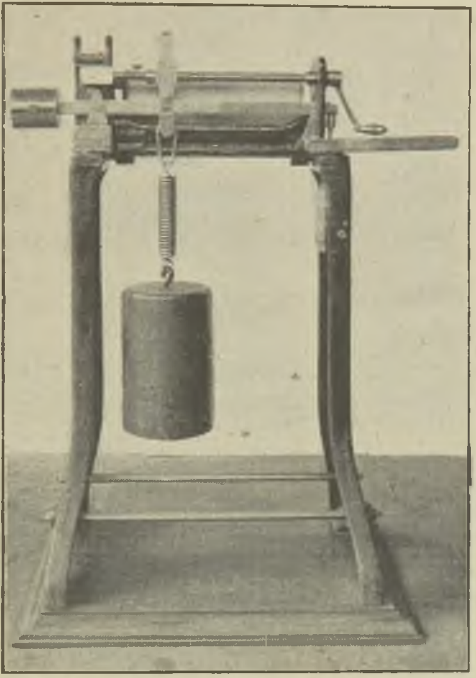


FIG. 4.—SHEARING TEST MACHINE (FRÉMONT TYPE) FOR SMALL BARS OF 5.64 MM. DIAMETER.

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* See "Study on Perlitic Metal," by M. Le Thomas, Marine Engineer, "Fonderie Moderne," February, 1926.

structure. This can be effected by an adjustment of the C and Si contents, which is a very easy operation in the manufacture of steam cylinders and piston rings, castings in which the thicknesses are practically regular and constant. In addition the graphite laminæ should be reduced as far as possible, and the adjustment of the C and Si contents will be effected in such a manner that the final product will be less hard in regard to the rings than the cylinders. As these castings are

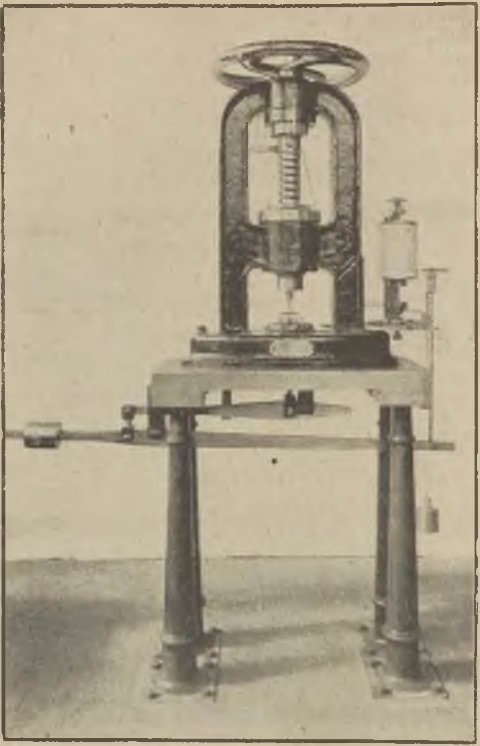

FIG. 5.—TRANSVERSE TESTING MACHINE (FRÉMONT TYPE) FOR SMALL BARS OF 8 × 10 × 35 MM.

constantly in frictional contact the wear will take place normally on the ring, a type of casting, the cost of which is relatively low and which can be easily replaced.

In order to obtain this orientation of the Brinell numbers, account must be taken of:—(1) The fact that the thickness of the rings is generally less; (2) the more rapid cooling of these rings.

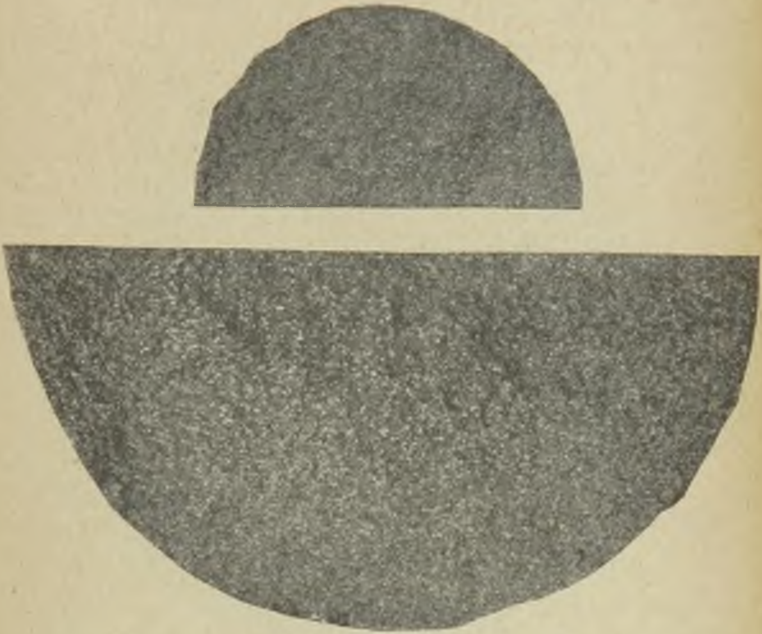

Fig. 6.—Fractures from Piston Ring Iron, all Cast from the same Iron. Actual Size.

The mixture for the latter should therefore be modified by slightly increasing the C and Si contents, the basis metals being strictly identical in both cases. On the other hand, while obtaining the pearlitic structure in the rings, a relatively high graphite content may be allowed owing to the lubricating action of this ingredient.

The following is the chemical composition of the metals adopted by the Paris-Orleans Railway Company:—

Steam Cylinders.—TC, 3.0; Si, 1.5; Mn, 0.65; P, 0.2; and S, 0.10 per cent. max.

Piston Rings.—TC, 3.3; Si, 1.7; Mn, 0.65; P, 0.2; and S, 0.10 per cent. max.

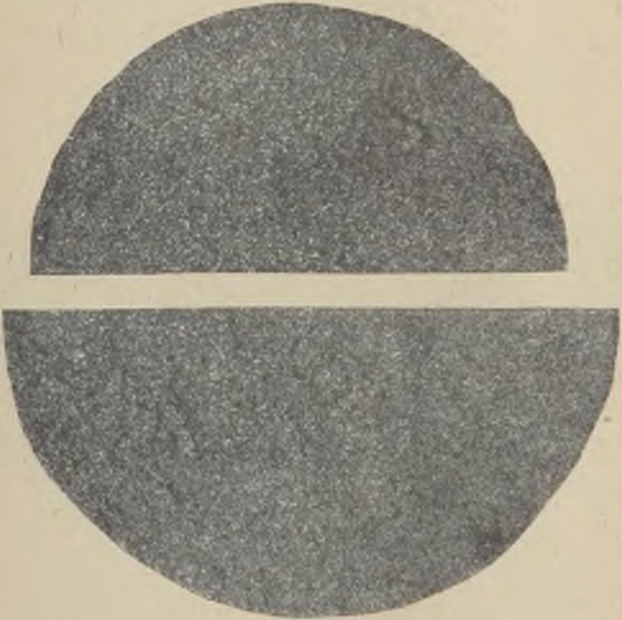

Fig. 6.—*Continued.*

The Brinell numbers approximate to 230 in the case of the cylinders and vary from 200 to 210 in that of the rings.

Melting.

The melting of the steel in the cupola sometimes occasions difficulties. In order to overcome them it is desirable to give the melting apparatus somewhat special features, viz:—A height from hearth to throat rather greater than that generally adopted; about 6 times the diameter of the hearth may be taken; and rectangular tuyeres, wide but not very high in order to prevent oxidation. The total section of tuyeres is one quarter of that of the cupola at their level; The air blown in should be regulated by means of registering apparatus as far as possible. The diagrams should be completed with all the particulars which will enable the foundry manager to exercise his control over the smallest details.

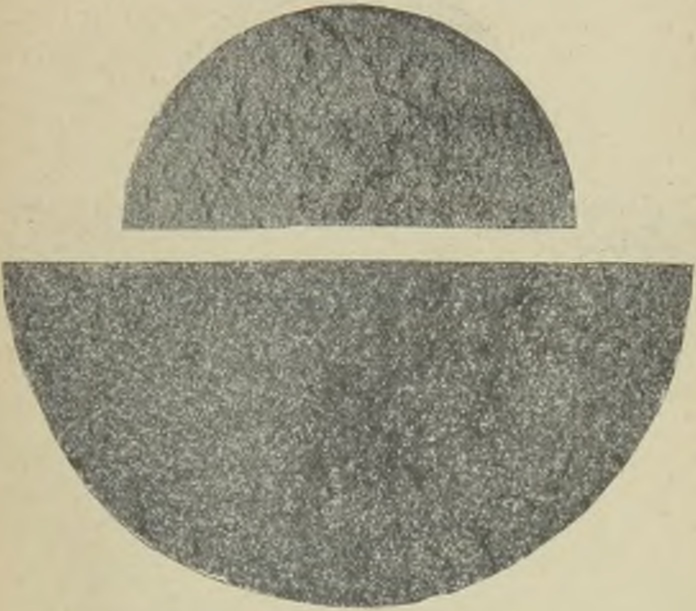

FIG. 6.—*Continued.*

The following should be shown, for example: The time of starting, intentional or accidental stoppages and their causes, the temperature of the metal, the nature of the charge (semi-steel, engineering castings, etc.), the number of slaggings, the precise time of these slaggings, the time of stopping, etc. Thus these diagrams may in fact serve as a daily record of the work of the foundry.

The charges are made in the following order: the steel, the pig, the scrap. The furnace is lightly forced with 12 to 14 per cent. coke, the best quality being chosen. All these conditions being observed, the pressure of the air blown in will be about 35 to 40 cm. (14 to 16 ins.).

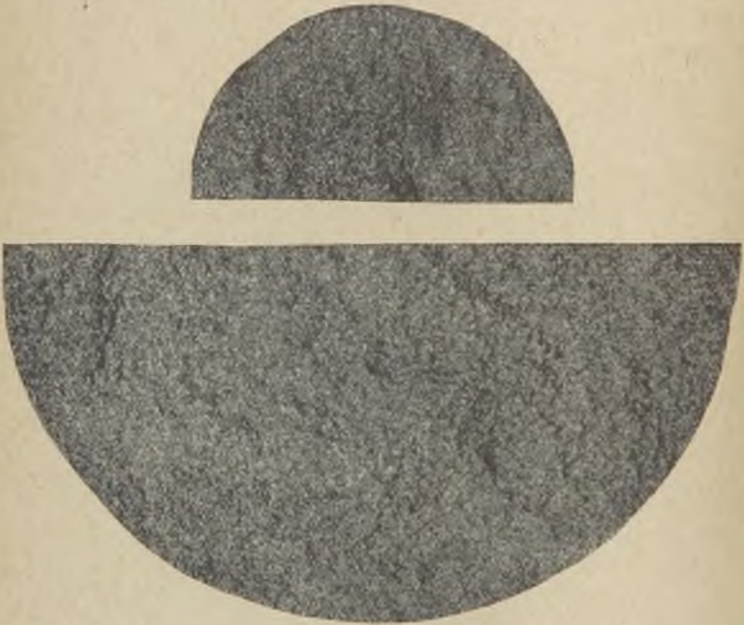

FIG. 7.—FRACTURES OF RUNNERS TAKEN FROM A STEAM CYLINDER IRON. ALL HAVE BEEN CAST FROM THE SAME IRON. ACTUAL SIZE.

In addition to the features already mentioned the cupolas used by the Paris-Orleans Railway Company are furnished with receivers with a capacity of 2½ tons. These enable the metal to be protected from the recarburising action of the coke, which is appreciable in an ordinary cupola. Thus in this apparatus the recarburisation is only 0.05 per cent. with carbon contents of 3.0 per cent. The receivers are furnished with an inspection hole enabling the quantity of metal contained in them to be ascertained. Their capacity of 2½ tons enables small and medium cylinders to be drawn in a single tapping, and large cylinders up to 5½ tons in two tappings. Under favourable conditions they have given 6½ tons without botting in.

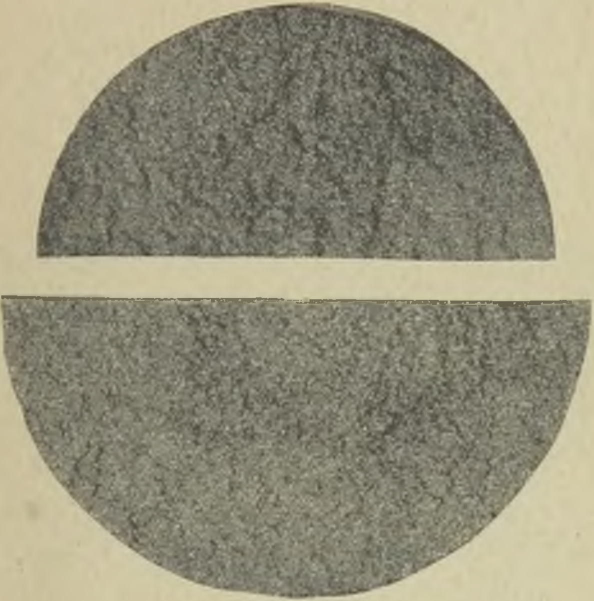

FIG. 7.—*Continued.*

The proportion of steel to be used must obviously vary according to the basis metals employed and the thickness of the castings to be obtained. The quantities of steel are determined by the chemical analyses of these basis metals and of the final product required, and also by micrographical examination, which should show the pearlitic structure.

Inspection Conditions.

The French railway companies repair and maintain their plant in their own works. Orders for new material are generally entrusted to private enterprise. Their manufactures, particularly those of steam cylinders and piston rings, therefore cover a large number of types, but on the other hand only a small number of castings to each type. The terms of inspection for these castings apply to work executed by private manufacturers as well as to that done by the works of the companies themselves. At present the inspection tests are as follows:

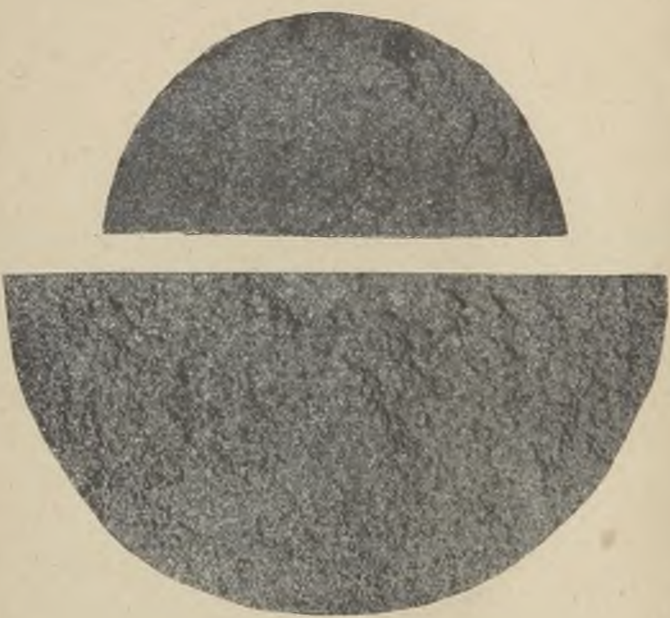

Fig. 7.—*Continued.*

Steam Cylinders.

Shock test: hammer 12kg. (26 lb.); test pieces of 40 by 40 by 200 mm. (1.5 by 1.5 by 7.8 ins.); distance between knife supports 160 mm. (6.3 ins.); first blow 30 cm. (11.8 ins.); successive increases 5 cm. (1.9 ins.); minimum rupture 50 cm. (19 ins.).

Tensile test: minimum rupture 18 kg. per sq. mm. (11.4 tons per sq. in.) on bars suitable for the available machines.

Porosity: hydraulic test at a pressure equal to that of the working pressure of the boiler increased by 1 kg. in the case of high pressure cylinders; at a uniform pressure of 10 kg. (22 lbs.) in the case of low pressure cylinders.

Piston Rings.

Shock test: identical with that used for the cylinders. *Tensile test*: identical with that used for the cylinders. *Transverse test*: a ring machined on its four faces to 26 by 15 mm. (1.0 by 0.59 ins.) is opened by two saw-cuts giving an opening of 25 mm. (0.98 ins.). The segment thus obtained is suspended to a fixed point, the centre of the opening coinciding with the horizontal diameter. Tension is exerted vertically by the successive addition of weights arranged on a plate until rupture takes place.

The characteristics required are given in the following table:—

External diameter of the finished rings.	Breaking load.		Opening at breaking point.	
	Minimum.	Average.	Minimum.	Average.
348	135	140	75	100
368	128	133	85	113
388	120	128	95	125
408	110	115	100	130
428	105	110	105	135
448	100	105	115	145
468	95	100	120	150
488	90	95	130	160
508	87	92	140	170
528	85	90	150	180
548	82	86	165	195
568	78	82	180	210

From the point of view of characterising the metals for cylinders and piston rings, the tests

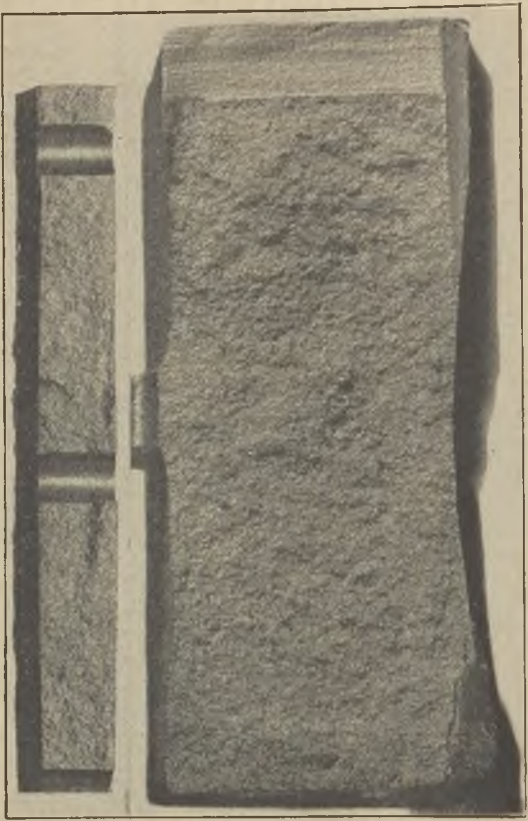

FIG. 8.—TEST SAMPLE FOR METAL FOR STEAM CYLINDERS.

Note the similarity of grain in the two different sections the smaller of which (25 mm.) was attached at right angles to the larger (55 mm.). Two-thirds actual size.

such as have been described cannot indicate very clearly the actual mechanical properties

FIG. 9a.—PISTON RING IRON (1) CEMENTITE, (2) LIGHT REFLECTIONS FROM THE GRAPHITE × 760.

of the products cast. Here the shock test has no significance, while the tensile test, as M. Portevin has pointed out, is frequently impaired by errors.

A few months ago the author had recourse to the tests recommended by the Association Technique Française de Fonderie, viz., transverse and shearing tests on small bars. To these were added the hardness test, which is indispensable in determining the properties of castings subject to friction.

The test bars are taken as test pieces poured with the castings, their dimensions being identical with those of the castings, so that the bars and castings may both have the same "thermal history."

The transverse test carried out on the Frémont machine, which registers the curves, is most valuable in examining metals designed for piston rings, owing to the possibility of studying these curves and the ease with which the test can be repeated.

The tests made by the Paris-Orleans Railway Company applied to a large number of cases, so as to find simple formulæ connecting the old tests and the new. This was for the purpose of at once imparting the results obtained to private foundrymen without their requiring to carry out themselves the lengthy research work involved.

The formulæ established by the railway company are obviously of particular interest in connection with its own manufactures. It must be remembered that the relations in question are influenced by the chemical composition of the metals employed, the rate of cooling, etc. These formulæ are as follows:—

Tensile strength $= 0.916$ shearing strength $- 1.2$.
Shearing strength $= (\triangle \times 0.23) - 25$.

Manufacture.

A. *Steam Cylinders.*—Contrary to the method generally adopted in Great Britain, where cylinders are cast on the flat, in France and Belgium they are cast vertically. With regard to the moulding, mention will only be by way of reminder of the different processes employed:

(1.) By an ordinary pattern having loose side pieces;

(2.) With a pattern and core boxes for the sides, the copes being filled round the cores after being put in place (a process very suitable in repetition practice);

(3.) Using an ordinary pattern and a series of box parts.

The last process is that in general use by the French railway companies which do not manufacture in quantity.

The most suitable method of pouring should be bottom casting and at an inverse pressure. Single cylinders should be cast at the base of the cylindrical body, and double cylinders at the bosses for fixing them to the engine frame, which will ensure a maximum passage for the first metal introduced. The inverse pressure, which will amount to 15 per cent., is obtained by narrowing the upper part of the gate. A quiet pouring will thus be secured. The metal is received in a decantation basin of the Wan Riet type, either provided with a stopper or not.

The rate of pouring must be dependent upon, (a) the weight of the cylinder; (b) the average value of its horizontal section in relation to the weight, so as to obtain an ascensional linear speed sufficiently low to enable the gases to escape from the cores; and (c) the number of the cores, *i.e.*, the difficulty of the liquid metal in entering the mould.

Taking these considerations into account, the author has adopted the following speeds for filling:—

					Pouring Time.
44 lbs.	per second for	1	ton cylinders	..	50 seconds.
66	,, ,,	2	,, ,,	..	70 ,,
81	,, ,,	3	,, ,,	..	80 ,,
99	,, ,,	4	,, ,,	..	90 ,,
110	,, ,,	5	,, ,,	..	100 ,,

The cylindrical casing and the distributors (valves) are surmounted by surplus metal from 4 to 6 ins. in height, its thickness being equal to that of the cylinder. These projections are not, properly speaking, feeding dead heads. Their upper parts are connected towards the outside so as to form a "spout" enabling the mould to be lightly "washed" in case of accidental boiling. It will be found that vertical casting facilitates the elimination of possible blow-holes.

Piston Rings.

The tangential casting of cylindrical work, whether by bottom casting alone or by bottom casting with a return gate, has long been recommended in connection with piston rings. Its purpose, according to those who advocate it, is to produce in the mould a rotary movement of the metal which helps to loosen the slag along the walls. If this movement could be effected over the entire height of the casting and during the entire duration of pouring, bottom casting would undoubtedly fulfil its purpose and would be desirable.

FIG. 9b.—STEAM CYLINDER × 450.

Unfortunately, this is not the case. The rotary movement is produced effectively at the beginning of the filling, but it takes place only in the drag, and becomes progressively feebler towards the surface of the liquid, ceasing at a height of 10 to 15 cm. As the hottest metal is at the middle circumference it breaks the upper film of cooler metal, and brings any slag that may have formed down on to the walls.

With top pouring by filtration the author has obtained excellent results, and has adopted it generally for cylinder work.

The piston rings are poured open by means of a basin placed astride the cope and the core. The lower part of the basin is pierced with 15 mm. (0.59 in.) holes, their number varying with the weight of the casting to be poured. The filling is done at a speed of 220 lbs. in 15 seconds, that is to say, quickly.

FIG. 9c.—STEAM CYLINDER IRON × 450.

This rate of pouring is the result of two facts which are readily observable in connection with the filling of open moulds:—(1) The presence in the liquid metal of an ascending movement proceeding from the walls of the mould to the central stream, which movement carries the impurities towards it. This is the same phenomenon which all have observed on the surface of a ladleful of hot metal; (2) the production, owing to the rapid fall, of a disturbance favouring the freeing of these impurities.

Certain authors have recommended learned formulæ for the purpose of determining the rate at which moulds should be filled. The author, however, does not consider it possible to apply such formulæ, owing to the differences in thickness and the varying amount of coring in castings. Each casting must be the subject of special study. Some must be poured quickly, others less quickly, and others, again, slowly. Then, in certain cases, the method of slow pouring so frequently recommended by M. Ronceray will be adopted, this method being one which gives remarkable results, owing to the possibility of obtaining by it sound castings without feeding heads.

Fig. 9d.—Steam Cylinder Iron × 450.

Machining Rings and Boring Cylinders.

The piston rings of engines and valves are machined under the following conditions:—(1) Roughing down to the diameters D and Dl determined by the formulæ:

$$D = d + \frac{d \times 0.07}{3.1416} + 4 \text{ mm.}$$

$$Dl = dl + \frac{d \times 0.07}{3.1416} - 4 \text{ mm.}$$

in which d is the diameter of the cylinder and $d1$ the diameter of the cylinder less twice the thickness of the ring.

(2) Cutting the rings in two planes passing through the axis of the cylinder, their distance at the periphery being

$$e = D \times 0.07$$

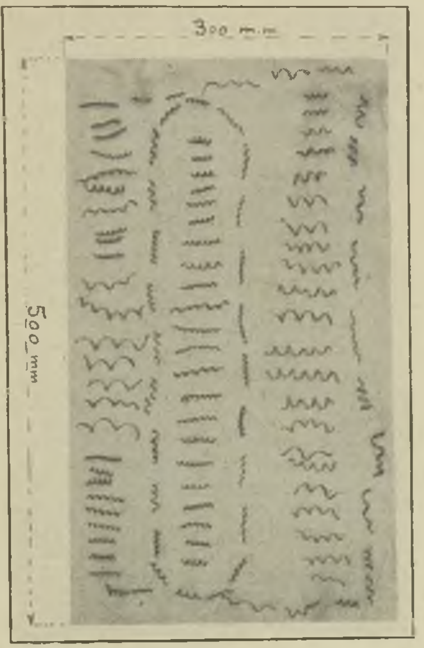

FIG. 10.—TURNINGS FROM A C. I. CYLINDER.

Note the number of spirals (8 and 9) and the length of the turnings (up to 2¾ ins.). They are indicative of the good machining and mechanical quality of the iron from which they have been formed.

(3) Pressing the ring by means of two or three collars made of flat iron with a maximum thickness of 3 mm. (0.12 in.) and 35 to 40 mm. (1.3 to 1.5 ins.) wide.

(4) Truing and finishing to the diameters:

External diameter d = diameter of the steam cylinder at its smallest part;

Internal diameter d1 = d less twice the thickness of the ring.

The rings are adjusted in the cylinder so that the play between the section planes is equal to $\frac{1}{1000}$ of the diameter at the smallest part. The purpose of this play is to enable the ring to expand freely.

The rings are replaced: (1) When they are broken or seized, (2) when the distance between the two edges of the section reaches $\frac{1}{100}$ of the diameter, (3) when the lateral play in the grooves reaches $\frac{2}{10}$ mm., (4) when their elasticity is insufficient, i.e., when the distance between the sections when free is only $\frac{3.5}{100}$ of the diameter.

Periodical inspections are made as follows:—

In a summary manner, for every 10,000 km. run.

In detail: After every 40,000 km. for the locomotives of express or fast trains.

After every 35,000 km. for the locomotives of ordinary and mixed trains.

After every 30,000 km. for the locomotives of goods trains.

After each stoppage the amount of wear in the cylinders and jackets is measured with a micrometric gauge. In particular the greatest vertical diameter and the smallest horizontal diameter are generally measured. The wear is greatest in the middle of the stroke in the case of pistons with rods, and at the ends of the stroke and opposite the inlets in that of pistons without them. The cylinders are rebored when the difference between these two diameters is 1 mm. or more, when traces of seizing are found, or if scratches 1 mm. or more in depth have been caused.

The cylinders are reformed when their thickness reaches a figure given by the formula:—

$$E = \frac{P\,(D + 30)}{500}$$

in which D is the original diameter of the cylinder in millimetres and P the working pressure of the boiler in kg. per sq. cm. For low pressure cylinders P is made to equal 10. E should in any circumstances be more than 10 mm.

Supervision of Manufactures.

All the observations made during casting, the mechanical strength of the metals and the analytical and micrographical data are registered by the foundry. The steam cylinders are given an order number, and the piston rings a casting

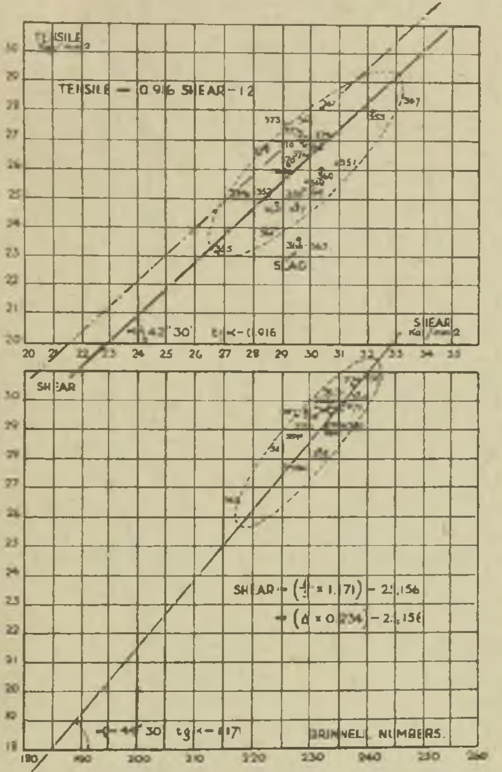

Fig. 11.—Showing the Relationship Between the Shear Test and the Tensile, and the Shear Test and the Brinell Numbers.

number as they come from the foundry, these numbers being in relief on the castings.

The machine shops of the Company's system or the sections using the castings carefully note any observations made during the machining, erecting and dismantling. These particulars are communicated to the foundry which, after comparing them with the observations already made by them, may be able to introduce useful modifications into the next work of a similar nature produced.

The most conclusive results are those obtained during the periodical inspections of the cylinders and piston rings. Thus rings will obviously be regarded as good which have done long journeys (longer than the minima previously mentioned), which show only slight wear on being taken to pieces, and which have affected the wear of the cylinders only slightly.

The data of a physical nature and the deductions drawn from them with regard to the satisfactory working of the products enable a considerable saving to be made in fuel and lubricants. They also enable a factor which is by no means negligible to be determined—the skill of the engine driver.

Results.

The average distance run by 100 superheated engines on fast trains was 3,410 miles. The wear of the engine rings are round about 3 mm. (0.12) and the corresponding wear in the cylinders is $\frac{5}{100}$ mm.

These are a few particulars based upon recent observations. The author considers these results satisfactory, and he would be glad if these notes should prove useful to his colleagues in the foundry industry. Should their own results be better he would beg them to communicate them, together with their methods, for the greater advantage of all.

Passenger Train Engine No. 3650 (*superheated*).

Diameter of wheels ..	.. 1.9 m. (74 ins.)
Circumference of wheels	.. 5.97 m. (19 ft.)
Stroke of engine pistons	.. 0.65 m. (25 ins.)
Working pressure of boiler	.. 16 kg. (35.2 lbs.)

Cylinders.	Diameter. Before.	Cylinders. After.	Distance travelled.	Wear in rings on dismantling. in min.
	Mm.	Mm.	Miles.	
HP Right ..	423.53	423.57	34,659	3
HP Left ..	423.65	423.68	,,	4
LP Right ..	640.30	640.35	,,	2
LP Left ..	640.55	640.55	,,	2
EG Right ..	270.20	270.20	,,	1
EG Left ..	270.20	270.20	,,	1

N.B.—The total rectilinear distance travelled by the rings in the cylinders was 8,543 miles.

Passenger Train Engine No. 3557 (*superheated*).

Same characteristics as the foregoing.

Cylinders.	Diameter. Before.	Cylinders. After.	Distance travelled.	Wear in rings on dismantling. in min.
	Mm.	Mm.	Miles.	
HP Right ..	422.60	422.63	33,975	3
HP Left ..	423.90	424.10	,,	3.5
LP Right ..	643.80	643.85	,,	3
LP Left ..	643.95	644.00	,,	3
EG Right ..	270.15	270.15	,,	1
EG Left ..	270.15	270.15	,,	1

N.B.—Total rectilinear distance travelled by the rings in the cylinders: 7,397 miles.

Goods Engine No. 5822 (*superheated*).

Diameter of wheels	63 ins.
Circumference of wheels	16 ft. 6 ins.
Stroke of pistons	24.4 ins.

Cylinders.	Diameter. Before.	Cylinders. After.	Distance travelled.	Wear in rings on dismantling. in min.
	Mm.	Mm.	Miles.	
Right	622.97	623.00	35,017	3
Left	623.95	623.99	,,	3

Rectilinear distance travelled by rings in cylinders: 8,648 miles.

Goods Engine No. 5850 (*superheated*).

Cylinders.	Diameter. Before.	Cylinders. After.	Distance travelled.	Wear in rings on dismantling. in min.
	Mm.	Mm.	Miles.	
Right	624.00	624.08	44,818	5
Left	625.00	625.07	,,	4

Rectilinear distance travelled by rings in cylinders: 13,522 miles.

Goods Engine No. 5878 (*superheated*).

Cylinders.	Diameter. Before.	Cylinders. After.	Distance travelled.	Wear in rings on dismantling. in min.
	Mm.	Mm.	Miles.	
Right	622.92	623.00	62,758	4.5
Left	622.95	623.01	,,	4.5

Rectilinear distance travelled by rings in cylinders: 13,980 miles.

DISCUSSION.

Mr. A. S. Beech (who is also a member of the Association Technique de Fonderie de France) presented the Paper, in the absence of the author, and conveyed from the French Association good wishes for the success of the Conference.

Referring to the details given in the Paper as to the melting of the metals, used for cylinders and piston rings, in the cupolas, Mr. Beech pointed to the statement that, all the conditions being observed, the pressure of the air blown into the cupola would be about 35 to 40 cm. (14 to 16 ins.), and said he presumed that in this case the author was referring to water pressure. With regard to the methods of manufacture adopted in France and Belgium, as mentioned in the Paper, he said the particular point which appealed to him was that the cylinders were cast vertically in France and Belgium, but were cast on the flat in Great Britain. He personally had seen many examples of the successful results obtained by slow pouring, and it would appear that Monsieur Audo was somewhat in agreement with Monsieur

Rouceray in this matter. Finally, Mr. Beech commented that the supervision of manufacture seemed to be fairly thorough.

Errors from the "Fremont" Test.

Mr. John Shaw said that the value of the author's description of his method of cylinder production was enhanced by his statement of the machining methods, and, to a still greater extent, by the wear figures given at the end of the Paper. The Paper was valuable in enabling those concerned with cylinder production in this country to compare their methods and results with those of Monsieur Audo, which comparison would benefit all. Discussing the author's remarks as to his recent use of the "Fremont" shearing and bending test, Mr. Shaw said that its chief advocates had put forward as one of the merits of this new test that it was so much more reliable than the tensile test, the specimen in the latter case being subject to want of alignment in the machine; yet in the Paper it was found that the tensile results were being used to build up the data from the "Fremont" machine. There were a number of grave objections to this test, of which the small size of the bar, 0.222 in., with its multiplication of any slight error, was not the least. Also, he noted that the tests were not taken from holes drilled out of the casting, but from projections cast on the surface of the casting, and he asked if the author could give some idea of the size of these bars, say, on a cylinder varying from 1 in. to 2 ins. in different parts.

Wear and Hardness Said to be Different.

Mr. F. J. Cook (Past-President) said that in some respects the experience of the author in the making of cylinders for steam locomotives was contrary to his own experience in the production of cylinders for stationary steam engines. The author had paid very special attention to hardness as shown by the Brinell test as being a measure of wearability, but he himself believed that anyone who had tried to get some co-relation between hardness and wearability would come to the conclusion that there was no relation *per se* between the two. He assured his hearers that he could make an iron as hard as one could wish for, but which would not wear at all well, and another which was as soft as possible but which would give the opposite result. The question of wearability was quite an interesting one, and a great many people would be very pleased to find a reliable test. In his view the author was paying too much attention to the Brinell hardness as a measure of wearability, and he believed it was generally agreed that for thick castings, such as locomotive cylinders, the Brinell hardness test was not a reliable test from any point of view. It was his experience that the drill method would give a very much better and more reliable indication of the nature of the casting as to general hardness and wearability than would the Brinell hardness test, whilst the tensile test was also a good guide for wearability. It appeared also that the author had struck a fallacy with regard to the soft ring in the hard cylinder. It looked very feasible, and it was quite a good talking point to say that it was better to wear the ring than the cylinder, the ring being much more easily reproduced than the cylinder itself. His own experience, however—and he had dealt with many thousands of cylinders—was that one should not aim at getting either of the items to wear, because if one set up wear in a soft piston ring it did not stop there; the cylinder also would wear.

Cylinders and Rings Better of Similar Composition.

The old adage about casting the piston rings out of the same pot as the cylinder was a very wise one, and it was his experience that if the piston ring were made out of the same metal as the cylinder very good results were obtained. That experience had been gained after running many thousands of cylinders, with very high superheats, high piston speeds and high pressures, and in many instances without any lubrication of any description in the high-pressure cylinder. It was desirable to have a metal which would very quickly attain a very high polish on the surface, because that tended to give very good wearing qualities. For this purpose a liberal amount of pearlite seemed to be very good, but he preferred to have, not a full pearlitic structure, but rather, one somewhat on the lines of white bearing metals, where one had hard spots interspersed in a soft matrix. One heard of cylinders made in the old days which had given wonderful results from the point of view of wearability, but the analyses were not startling, except that they showed the metal to be of poor quality. In the old days it was not unusual to run the engines very slowly on no load with saturated steam, with a liberal amount of lubricant, for long periods; he knew of cylinders which were running for six weeks, with the result that a hard skin was produced, giving good wearability, even with the commoner kinds of metals. Nowadays, however, an engine of perhaps 1,000 h.p., with very high superheats, was put on to the test plate, turned round a few times by hand in order to see that all was clear, and then put straight on to full load. If one used some of the poor metals, such as were used in the old days, under those conditions, one would find that the working results were not what they appeared to be from the earlier results. Finally, Mr. Cook asked if the author would give the ultimate life of the cylinders made by the Paris-Orleans Railway Company.

Influence of Cooling Conditions.

Mr. W. H. Poole asked whether Mr. Cook, in advocating the use of the same metal for both the cylinder and the piston ring, had taken into account cooling conditions.

Mr. Cook said he should have pointed out that the cylinders he had referred to were thick, and that the piston rings were also relatively thick, although not so thick as the cylinders themselves, but the cooling action was slow enough not to influence unduly the relative hardness. He had had experience of many thousands of cylinders and rings, which proved that the suggested system would give good results.

Fallacy of Correlating Formula.

Mr. J. G. Pearce (Director, British Cast Iron Research Association) said that the significance of the Δ in the formula on p. 140 of the Paper was not specifically stated. Presumably it referred to Brinell hardness. Various Continental workers, notably Portevin and Schuz, had advanced formulæ connecting Brinell hardness and tensile strength, but these formulæ had not been found reliable for cast iron when tested by results obtained in this country. Did the results given in Fig. 11 represent the whole of the experimental data obtained for the construction of the formulæ? If not, references to detailed publications of the results would be appreciated. As Mr. Shaw had pointed out, it was a little inconsistent to advocate the shearing test on account of the deficiencies of the tensile test, and then to use a formula for converting the one to the other. So far as was known, shearing-test figures had not been obtained in this country, so that the first formula on p. 140 could not be criticised, but it was hoped to do this shortly.

Effect of Small Changes in Composition.

MR. HORACE J. YOUNG, F.I.C., in a written communication, asked whether the compositions of the metals used by the Paris-Orleans Railway Company for cylinders and piston rings, as given in the Paper, referred to metals in the actual castings as used on the locomotives. He had noted that the cylinders and the piston rings were alike in all else save that the rings had 0.3 per cent. more carbon and 0.2 per cent. more silicon. It would appear difficult to control these compositions, so that the total carbon contents were 3 per cent. in the one and 3.3 per cent. in the other. Moreover, it was not clear to him why the piston rings should have more carbon than the cylinders. Theoretically it might appear that, therefore, the piston rings would have more graphite flakes, but there had been little proof in practice that low-carbon irons were better wearing, or, at any rate, that there was any advantage to be gained by such small differences as would be practicable under the specifications set out by the author. In another part of the Paper the author had claimed a recarburisation of only 0.05 per cent, with carbon content of 3 per cent. Did this mean that when he charged into the cupola irons containing a total of 3 per cent. of carbon he obtained from the cupola a cast iron containing only 3.05 per cent.? The author had unusual facilities for ascertaining the effect of various elements upon the wearing properties of cast iron. Suppose he took irons all of the same hardness, and differing only in one constituent, would he find that an iron containing 0.05 per cent. of sulphur would be different from one containing 0.15 per cent.; or that one containing 0.65 per cent. of manganese would be different from one containing 1.15 per cent.; or that one with 3 per cent. of carbon would be different from one with 3.3 per cent.? These points were vital: we were uncertain of ourselves when it came down to definite figures and single comparisons of this nature, and he felt sure that if the author would be good enough to give his experience it would be appreciated.

Limits of Composition Sought.

Mr. W. H. Poole, referring to the fact that the phosphorus content of the metals used by the author was 0.2 per cent., asked whether there was any advantage to be gained by such a low phosphorus content as against 0.6 or 0.8 per cent. The general practice in this country was to have a low phosphorus content. He asked for information as to the relation between phosphorus content and wear, and carbon content and wear, and also whether the author aimed at a particular limit of the combined carbon.

Mr. Colin Gresty (Newcastle Branch), commenting on Mr. Cook's remarks as to wearability, and the question of whether or not the pearlitic structure gave the best wearing properties, referred to a paper read recently in Germany by Lehmann, which supported Mr. Cook's statement that Brinell hardness and wearability were not related at all. The same worker had proved that irons with a pearlitic structure gave the best wearing qualities, which was in accordance with his (Mr. Gresty's) experience.

Mr. Cook said he had read the Paper, but in his view it was a question of degree. One could find plenty of cases in which, for wearability, one did require a pearlitic structure. He had not had experience with a wholly pearlitic structure, but he aimed at a pearlitic structure as a ground work, with probably more cementite than was usually accepted by the wholly pearlitic structure people, for the reason he had stated, namely, that as with white metals where one had a more or less soft matrix with harder spots in it the best results were obtained from a wearing point of view.

Mr. E. Longden, after remarking that the discussion had emphasised the complex nature of cast iron, said that the phosphorus content of the metal used by Monsieur Audo had reminded him of an experience of his some years ago, when he was making heavy gas engines. For years the company making these engines had employed a No. 4 Derbyshire iron, with a silicon content of 2.68, and a phosphorus content of just over 1 per cent., and they had never heard of any trouble being experienced. An inspector had then specified what was considered to be a better analysis, the phosphorus content being low, but that metal had less wearing qualities than had the No. 4 Derbyshire iron prievously used.

Centrifugal Cast Liners and Piston Rings.

The President, dealing with the question of the hardness of cylinder liners and piston rings, as referred to by Mr. Cook, said that whilst he would not attempt to dispute Mr. Cook's word, he would like to allay any misapprehension which might arise. He assumed that Mr. Cook had in mind casting in the usual way in green or dry-sand moulds.

Mr. Cook said that the casting was made in dry sand.

The President emphasised that rings made by the centrifugal process should be considered apart from sand cast rings. The question as to whether a pearlitic structure is desirable in a centrifugal casting is a very debatable one, and he felt that a great deal of information had yet to be gained in regard to centrifugal casting. Certainly, from practical experience at his works, together with the information available in many of the technical journals, he was led to believe that centrifugal casting for cylinder liners and piston rings had a great future. He felt that further information had been gained from the results of actual industrial applications, and that he could assure his hearers that we were only on the fringe of its uses yet. He hoped that some day they would be able to say that they had data which was standard data and embraced the results of tests under most conditions likely to be met in service, and that he would have an opportunity of placing it before members of the Institute.

Importance of Weights of Bearings Emphasised.

Professor T. Turner (Late Professor of Metallurgy at Birmingham University, and Past-President of the Institute of Metals), discussing the relation between Brinell hardness and wearing properties, said that one knew, of course, that metal which was extremely soft did not grind away so readily as a harder metal. From the general use of bearing metals we had learned something with regard to wear, and the same factors might be applied to cast iron. For some purposes one might use an expensive Babbit metal, rich in tin, and in some cases one might get better wearing properties with a metal costing about a quarter as much, having a lead base. It depended to a considerable extent on the weight the bearing had to stand, *i.e.*, the pressure per sq. in., and the speed. These again affected the temperature. With regard to the wear of cast iron, he said that for some purposes a soft, non-pearlitic iron—a highly graphitic iron—would give very admirable wearing properties, as, for example, in the case of the old large reciprocating engines. There was a certain smoothing effect, due to the large flakes of graphite, and no doubt there was produced what we had been in the habit of perhaps mis-calling an "amorphous" material, as a coating on the inner surface of the cylinder. In other cases, where the pressure was greater or where the temperature was higher, one might require to use another kind of cast iron. He suggested that, while it could be accepted as proved that the Brinell hardness test did not necessarily indicate the wearing properties of the cast iron, the question of the kind of cast iron which would wear best would depend to a considerable extent upon the conditions of the service of the specimen.

Mr. J. E. Fletcher (Consultant, British Cast Iron Research Association), as one who had had experience in the measurement of the effects of both engine cylinder and rolling mill journal friction, associated himself with Professor Turner's remarks, and drew attention to the difference there was in the type of wear, say, in rolling mill roll-neck, when running in a cast-iron bearing, which had sometimes been tried, as was illustrated by the older engines, and in that of a steam-engine cylinder. He had taken some of the old cast-iron shafts out of rolling mills after they had been at work for many years. There seemed to be a closer connection between Brinell hardness and the wearing properties in a revolving piece in a journal than in, say, a piston ring and a cylinder; there was a difference between the resistance from revolving friction and sliding friction when compared with Brinell hardness values. Commenting on the difference between the methods of casting cylinders, particularly the modern form of locomotive cylinders, in this country and on the Continent, he said that founders needed carefully to study that question, because there was a very great difference between the way in which the molten metal rose in the mould, producing different types of structure in the bottom and the top of the casting, and one must view that in the light of vertical and horizontal casting methods. The British Cast Iron Research Association had found some rather curious structural differences in the cast iron, in the cases of cylinders cast horizontally and those cast vertically, due to differences in the rate of pouring and cooling.

AUTHOR'S WRITTEN REPLY.

After expressing his thanks to Mr. A. S. Beech for submitting the Paper, M. Audo pointed out that the control of the blower ought not to be confined exclusively to pressure, but first and foremost to the output. The cupola might be regarded as an apparatus for burning coke. Starting from this principle it was necessary to supply it with the quantity of air necessary to effect combustion under the best possible conditions, namely, with a minimum production of CO. The pressure would be the resultant of the factors output and sections, the latter of which should be calculated liberally. Practical steps should be taken to ensure that the penetration of the blast was such that the entire mass of the materials forming the charge should be completely subjected to the action of the air.

In addition to the checks carried out during the melting the automatic output meter would enable the oxidation, which was invariably caused if the pressures only were controlled, to be suppressed

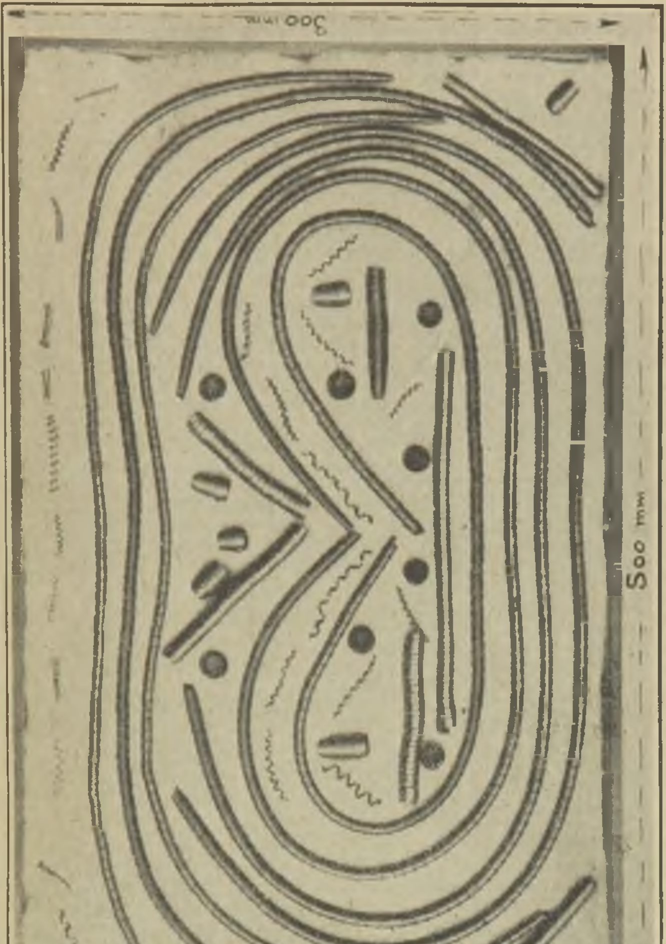

FIG. 12.

when the melt was finished. The furnace, in fact, was emptied at that moment. The materials offered but a feeble resistance to the blast, and if a constant pressure were relied upon a considerable excess of air was introduced, which was unfavourable to the production of sound metal. He had thus found that with an almost constant output the melt was finished with a pressure of only a few centimetres.

Errors of the Frémont Test.

The very simple standardisation of the Frémont machine in the shearing test permitted of remarkably concordant results being obtained, notwithstanding the small section of the test piece. It was precisely this small section that enabled the test to be repeated and permitted of test pieces being taken from the castings. It was this latter method which ensured of the metal of the casting itself being tested and not the metal of the melt as a whole.

The test piece might be taken either from the casting itself, or from a test bar of the same dimensions as the casting sent from the foundry with the casting and attached to it by its entire section. This method ensured that the bar should have a thermal history absolutely identical with that of the casting. It was sufficient to provide for a test bar at each part of the casting to be examined in order to ascertain the properties of the casting in all its parts.

Thus a locomotive cylinder might be provided with the following test bars:—

(*a*) One in the lower third of the cylinder body, 150 × 150 × 35 mm. (*b*) One in the upper third of the cylinder body, 150 × 150 × 35 mm., and (*c*) one on the steam chest, 150 × 150 × 30 mm.

Each test bar was separated mechanically (without shock) and then sawn into two portions, one for ball tests and chemical analysis, the other for bending and shearing test and micrographical examination.

Difference Between Wear and Hardness.

It had never occurred to the author, M. Audo observed, to establish a correlation between hardness and wear. Here a regrettable confusion existed. The ball test enabled the degree of homogeneity to be ascertained owing to the ease with which it could be repeated, as also the machining capabilities of castings. He agreed with Mr. F. J. Cook in recognising that in the latter case a machining, drilling or turning test was excellent. In another connection he also agreed that neither the wear of the piston ring nor of the cylinder should be sought for, but rather the wear of that one of the two castings the cost price of which was lower. This did not mean that he recommended a soft ring. On the contrary; the Brinell numbers he had given (200 to 210) demonstrated this.

What, he asked, was the part played by the ring in the cylinder? (1) To ensure a good fit between the two faces of the piston—the property of elasticity ascertained by the transverse test (measurement of the loads and deflections, determination of the coefficient of elasticity). (2) To prevent abrasive action on the cylinder; hence the necessity for free carbon, which was a lubricating element, and, on the other hand, the necessity of avoiding hard constituents (cementite and steadite).

For segments Mr. Cook preferred a metal identical with the white metals, viz., hard crystals encased in a soft constituent. He (M. Audo) was not convinced that this view was correct. A white alloy was an intimate mixture of hard and soft crystals, the purpose of the former being to support a load which was generally high and to resist wear, while the soft constituent enabled the hard crystals to dispose themselves suitably in its mass, while conforming to the shape of the rotating chamber, itself consisting of a homogeneous metal of great hardness. The soft crystals were more subject to wear than the hard, as a result of which depressions of 5 or 6 microns, in which the lubricant was deposited, were produced on the surface of the metal. Could an identical phenomenon be looked for in the cylinder if the pressure of the segments were weak and the two metals in contact were practically identical? Could it be supposed that the very hard cementite crystals would arrange themselves in the pearlitic mass, which was itself hard ($\Delta = 200$ to 260), according to the fineness of the lamellæ, merely under the in-

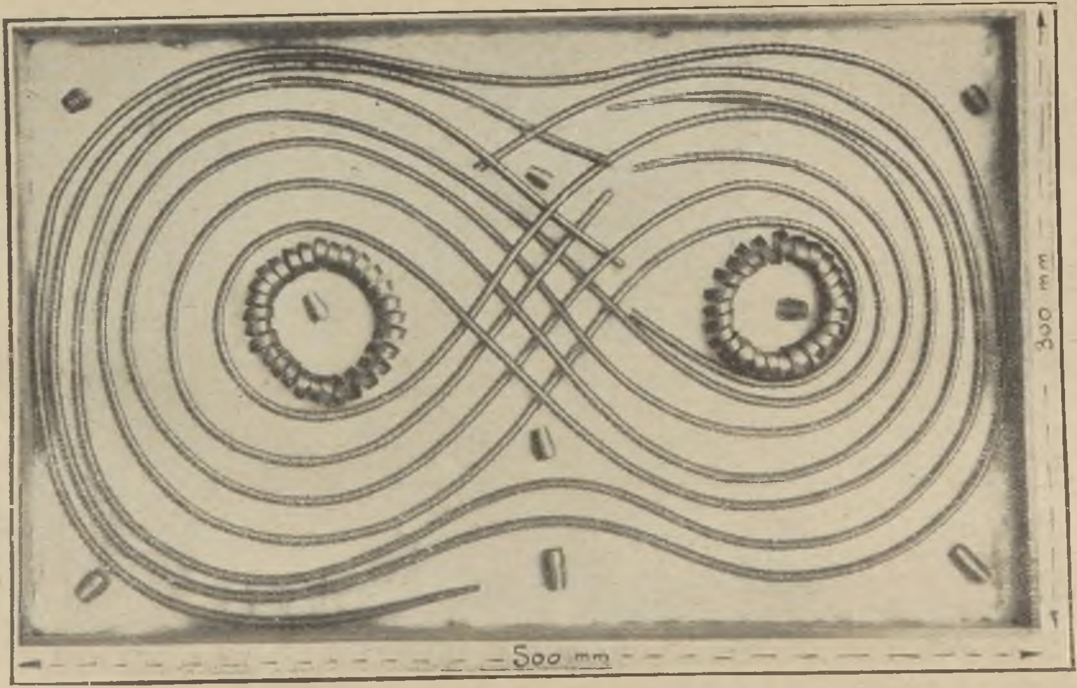

Fig. 12.

fluence of the low load due to the elasticity of the segment? Might it not be concluded, on the other hand, that, as the pearlite was worn because it was less hard, the particles of cementite would present their sharp edges and accelerate the wear as rapidly as an equal number of small high-speed steel tools would do?

M. Audo regretted that he was unable to reply definitely regarding the distances travelled, and the wear and tear in service, and that he personally could not give any other figures than those he had quoted, which, however, he regarded as satisfactory. He alluded to the wearing tests carried out by MM. B. Buffet and A. Roeder, quoting the following figures:—

Dry tests.

Number of alterations per minute ..	110
Area of contact	58.75 sq. cm.
Pressure per sq. cm.	293 gm.
Loss of weight:	
Cylinder metal	10 gm. in 4 days.
Pearlitic cast-iron	7 gm. in 4 weeks

Influence of the Cooling Conditions.

The divergences indicated in the carbon and the silicon contents were due: (1) To the differences in thickness of the two cylinder castings (in the body), viz., 35 to 40 mm., and of the segments 25 to 30 mm.; (2) to the differences of temperature of the moulds at the moment of casting, due to the differences in mass of the moulds and the heat losses by radiation between the time of leaving the drying stove and casting; and (3) to the differences in the rate of heat exchange due to the ratio between the mass of the castings and the mass of the moulds.

Error in the Correlative Formula.

M. Audo directed attention to the restricted limits within which the formulæ given were valid. He said that they had been drawn up merely for the purpose of informing the suppliers of the Company at once in case the Fremont tests were to be applied at the inspection of the castings, so as to make it unnecessary for them to carry out long and costly researches for the same purpose.

Effects of Slight Changes in Composition.

The compositions he had specified were those at present in use. No practical man, however, would imagine that they could be obtained mathematically in the cupola. These compositions were averages, and special efforts were now being made to obtain divergences of content in the different elements in proportion to the differences of speed in cooling, as already explained, and with the very definite object of obtaining the pearlitic structure in the various parts. The feeble recarburisation he had indicated was due to the presence of cupola receivers, which enabled the liquid metal to be withdrawn rapidly from contact with the liquid coke. This recarburisation was fully 0.05 per cent. of total carbon per 3 per cent. of the charge.

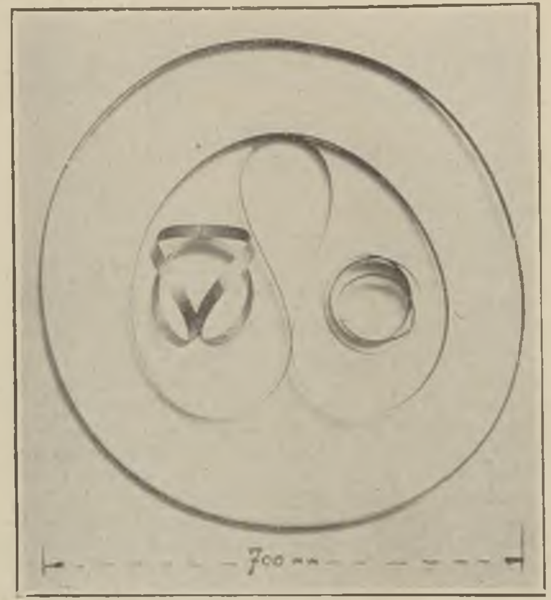

FIG. 13.

He did not give the process of manufacture as absolute. He had merely described it in the belief that it might prove profitable. With regard to the compositions adopted they were the result: (1) Of the study of the various factors affecting the mechanical properties of cast iron in general; (2) of an examination of the cooling conditions of the castings concerned, according to the method of manufacture adopted; and (3) of an examination of the results obtained in service—results which had been specified in his Paper and which appeared to him satisfactory.

The limits of his present note were too restricted to enable him to go into the question of the influence of the various elements contained in cast iron of different types on their mechanical properties. He would therefore beg his readers to refer to the studies already made on the subject, and more particularly to the very interesting communication of M. Portevin in March, 1927.† There they would find an account of the transverse strength and the value of the deflections, properties which were of supreme importance in the manufacture of piston rings.

With regard to the phosphorus content, and in reply to Mr. W. H. Poole, he stated that he adopted 0.2 per cent. (sometimes 0.3 per cent.) in place of 0.6 to 0.8 per cent., owing to the possibility of the formation of steadite (phosphorus eutectic), a hard and brittle constituent, the abrasive properties of which were comparable with those of cementite. Phosphorus tended, moreover, to diminish the deformation capacity on rupture. He regretted that he was unable to give particulars on the subject of centrifugal casting. He considered, however, that this method of manufacture ought to give excellent results. He wished to thank his British colleagues for the interest they had been good enough to show in his Paper, and trusted researches of a more exhaustive nature would be carried out on the subject of wear.

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† See Bulletin de l'Association Technique Française de Fonderie, March, 1927.

ON THE EFFECT OF NICKEL AND CHROMIUM ON THE STRENGTH PROPERTIES OF GREY CAST IRON.

By Professor E. Piwowarsky, Dr.Eng., Aix-la-Chapelle.

A fairly extensive literature already exists on the effect of nickel and chromium additions on the properties of cast iron.[1] From these works, and also from the reports and communications of numerous manufacturing and consuming concerns, it is apparent that even a nickel addition of from 0.5 to 3.0 per cent. appreciably increases the uniformity and density of the structure, ensures very good machinability even in hard types of iron, prevents the appearance of hard spots, and increases the resistance to corrosion and wear, etc. It is also known that a moderate addition of chromium in cast iron with a nickel content has a particularly beneficial effect in improving the structure and increasing the resistance to wear and the liability to "grow." Most of these chemico-metallurgical and physical advantages are present—and far too little regard is paid to this fact—even when the mechanical test shows scarcely any, or only a moderate increase in the strength figures. In point of fact, indeed, the increase of strength found by numerous investigators (Campion, Hurst, Moldenke, Piwowarsky and Baver, Smalley, Merica, Wickenden, Vanick, etc.) in pearlitic cast iron as a result of alloying with nickel and chromium, as a rule hardly exceeds 30 per cent. So long, therefore, as the mechanical properties obtained by alloying do not exceed these limits, which are such as can be obtained in unalloyed cast iron by suitably mixing the charge and by paying regard to the more recent refining processes (*e.g.*, abnormal superheating of the liquid iron[2]), there is obviously no occasion to add nickel and chromium to the metal merely for the purpose of increasing its strength. Moreover, it is by no means certain at present

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[1] *Cf.* the bibliography in the Bulletin of the British Cast Iron Research Association, No. 8, April, 1925, p. 5.

[2] German Patents, under G. 63,543 VI/18 b., February 21, 1925.

whether the results so far obtained in increasing the mechanical properties of cast iron by nickel and chromium additions may not be mainly attributable to causes which—as, for example, the refinement of the graphite—could be obtained by cheaper and simpler means (deoxidation, superheating the molten metal, etc.). It appeared necessary, therefore, to investigate the influence of these two most important alloying elements, which unquestionably operate beneficially in regard to their physico-metallurgical reaction, on cast iron to which the best mechanical qualities, as far as technical judgment could anticipate, had been imparted by suitable treatment.

The course was therefore adopted of bringing very hot molten iron to a state of solidification, at first mainly white, and of graphitising it only by subsequent annealing so that it contained:—

(1) The primary carbon in the finest and most favourable arrangement possible, and (2) as fine-grained a sorbitic-pearlite ground mass as possible.

At the same time it was intended to pay special attention to the effect of nickel and chromium on the thermal stability of the metal. The charge of the melts had, therefore, to be adjusted so that by accelerated solidification and cooling the iron solidified preponderatingly white, but nevertheless contained sufficient silicon to render probable the complete dissociation of the hyper-eutectic carbon by means of as short as possible a subsequent annealing at not too high a temperature, for a long period of annealing, particularly at too high a temperature, might possibly have eliminated again the advantages of the fine primary structure. It was necessary, however, that the silicon content should not be so high as to permit of large quantities of ferrite making their appearance during the cooling when the annealing had been effected. This could be secured if a grey to mottled charge were caused to solidify mottled to grey by artificially accelerated cooling.

For the tests in question two main series of experiments were arranged, viz., one with high carbon and low silicon iron (indicated by A), and one with low carbon and high silicon metal (indicated by B).

Within these two series heats were carried out without nickel, as well as heats which were adjusted to 1 and 3 per cent. nickel and 3 per cent. nickel + 0.5 per cent chromium in the final product. A charge of German hematite and ingot iron (dead mild steel) was used as raw material in all the heats. About 10 per cent. of Swedish pig-iron was used in the charge of heat 1 only. The increase of the silicon addition in series B was effected by adding high percentage ferro-silicon to the finished heat. The weight of all the casts in the tests was about 25 kg. (55 lbs.). They were carried out in a graphite crucible lined with magnesite, and in an oil-heated furnace. The temperature of the heat was in all cases raised to about 1,550 deg. C., when the crucible was taken out of the furnace, and the heat poured when the temperature had fallen to 1,400 deg. The temperature was measured optically (by the Holborn-Kurlbaum pyrometer) and by inserting platinum and platinum-rhodium thermo-elements in the heats to check the measurements. From each heat four test bars about 33 mm. in diameter and 700 mm. in length were cast, two of these being poured into an iron chill, lined fairly thickly with clay, which was in each case preheated to 100 deg. The last two bars were cast in a dry sand mould.[3] Top casting was employed throughout. The bars cast in chills were rapidly heated in a gas muffle furnace to about 925 to 950 deg. C. As soon as they had reached this temperature the furnace was shut off and the samples were left to cool. Half of these chill bars were thereupon reheated to 20 to 30 deg. above the A_3 point and quenched in oil. The hardening temperature varied, according to the composition of the samples, from 820 to 850 deg. The quenched samples were kept at 650 deg. for half an hour, when they were again quenched in oil; they were then reheated to 450

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[3] The bars cast in sand showed throughout a eutectic to temper-carbon-like structural formation, and had a transverse strength of 48 to 65 kg/mm² with a tensile strength of 28 to 36 kg/mm² (17.8 to 20.3 tons per sq. in.). As these heats had not been deoxidised and consequently did not approach the best values hitherto reached in sand casting by superheating the melt [up to about 75 kg/mm² transverse strength and 36 to 42 kg/mm² (22.8 to 26.6 tons per sq. in.) tensile strength] they have been omitted from consideration in the treatment of the present Paper.

deg. for 15 minutes for the removal of any hardness stresses, and then left to cool.

For mechanical testing all the bars were turned to a diameter of 30 mm. The results of the research are summarised in Table 1. These show that as a result of the thermal and melting process here employed unusually high bending strengths were in fact attained. These might possibly have been even higher if more care had been devoted to the process of deoxidation and to overcoming the occurrence of piping, to which further reference is made later. Series of tests on this point are in preparation. It should be noted that very high deflection values are peculiar to high transverse strengths. When it is considered that in the normal transverse test, with a bar diameter of 30 mm. and a distance between the supports equal to 20 times the diameter, deflections of 10 to 15 mm. are usual and normal, the deflection values of 20 to about 45 mm. must be characterised as exceptionally high. They demonstrate the great toughness[4] and elasticity of the material. In these tests, unfortunately, it was not as yet possible, as has already been stated, entirely to eliminate the piping favoured by the white or mottled solidification and the large diameter of the bars. Suitable signs are accordingly inserted in column 5 of Table 1 to indicate whether the fracture was found faultless, or showed a slight or a serious pipe. When it is considered that only a few of the values are indicated as free from piping it is surprising that notwithstanding this occurrence of defects such high transverse values were still obtained. No doubt the reason of this is that in the transverse test the neutral fibre plays a relatively small part in straining the material, while the pipe is generally disposed centrally (see Fig. 1, which shows the fracture of certain bars in which the size of the pipe is reduced). On the other hand, the effect of the pipe became all the more unpleasantly observable in the tensile test. For this test, however, the broken pieces from the transverse test were used.

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[4] The specific shock energy of the alloyed samples was two to three times the values hitherto observed in ordinary grey cast iron. For example, heat 5 showed 1.39 mkg/cm^2; heat 12, 1.05 mkg/cm^2.

1	2	3							
Heat No.	Type of Heat.	Chemical Composition.							
		Gr.	C.C.	Si.	Mn.	P.	S.	Ni.	Cr.
1	A I A I v	0.28	1.98	1.57	0.76	0.068	0.014	—	—
2	A II A II v	0.14	2.70	1.88	0.62	0.092	0.027	—	—
3	A III A III v	0.21	2.38	1.74	0.60	0.076	0.025	0.89	—
4	A IV A IV v	0.59	2.48	1.61	0.56	0.083	0.025	2.73	—
5	A V A V v	0.19	2.88	1.40	0.75	0.052	0.015	2.86	—
6	A VI A VI v	0.26	2.60	1.74	0.60	0.084	0.024	3.10	0.80
7	B I B I v	0.37	1.98	2.58	0.60	0.040	0.020	—	—
8	B II B II v	0.23	2.03	2.49	0.53	0.092	0.03	0.86	—
9	B III B III v	0.33	1.99	0.96	0.48	0.060	0.032	3.02	—
10	B IV B IV v	1.54	1.38	2.09	0.55	0.072	0.028	3.17	—
1	B V B V v	0.35	2.13	2.06	0.52	0.04	0.026	2.80	0.50
12	B VI B VI v	0.37	2.05	1.70	0.68	0.06	0.016	2.69	0.47

O=Perfect fracture. *=Small pipe. **=Large pipe.

I.

4		5			6			7
Composition after Heat Treatment.		Transverse Test.			Tensile Test.			Brinell Hardness Number.
Gr.	C.C.	kg/mm^2.	Deflection in mm.	Fracture.	kg/mm^2.	Dia. of bars. mm.	Fracture.	
2.34	0.69	87.0	39.5	*	44.5†	5	*	240
1.78	0.60	90.5	32.3	**	51.7	20	*	249
2.07	0.73	85.6	38.8	*O*	30.9 ?	20	***	238
2.37	0.45	—	—	—	36.9 ?	20	***	167
1.98	0.58	90.3	38.8	*O*	24.3 ?	20	***	263
1.94	0.73	75.8	19.0	**	26.8 ?	20	***	255
—	—	—	—	—	31.7 ?	20	***	—
—	—	93.4	22.5	**	57.2	5	**	—
2.18	0.71	90.2	24.2	*	40.7 ?	20	***	2.63
—	—	87.4	23.5	**	42.8 ?	20	***	2.73
1.85	0.97	100.0	30.2	*	69.4	5	*	300
—	—	102.0	15.6	*	71.4	5	*O*	300
1.43	0.85	99.25	43.2	*	38.5	20	**	238
1.43	0.82	90.7	26.0	*	28.8	20	**	233
1.38	0.78	—	—	—	—	—	—	—
1.50	0.76	104.0	28.5	*O*	33.5	20	**	225
1.43	0.58	58.3 ?	109 ?	**	—	—	—	257
1.77	0.47	106.0	32.0	**	37.4	20	***	246
2.72	0.20	81.8	8.0 ?	**	39.4	20	*	218
—	—	71.7	15.6	*	33.7	20	**	183
—	—	—	—	—	75.7	5	*	292
—	—	102.3	27.5	*	67.3	5	*	285
1.46	0.95	119.6	28.7	*O*	60.0	5	*	303
—	—	128.6	37.2	*	56.7	5	*	316

***=Very large pipe. † To convert kg/mm^2 to tons/sq. in. multiply by 0.63.

A Iv

A V

A II

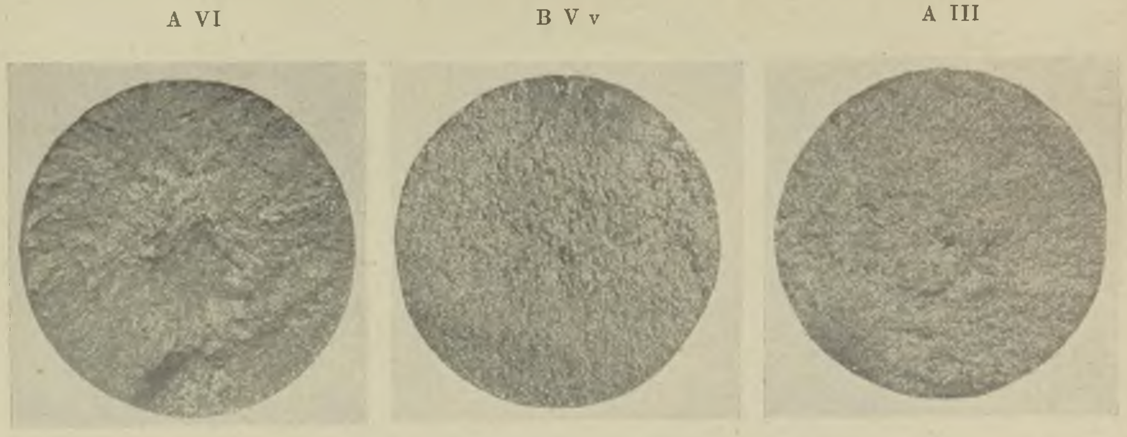


Fig. 1.—Fracture of Several Transverse Test Pieces to the Diminishing Size of Pipe. × 1.5.

They had been turned to a diameter of 20 mm. in order that the tensile test bars might have conical enlargements at their ends. The majority of the tensile bars consequently show much too low values, for notwithstanding the weakening owing to the pipe the maximum load was in relation to the entire cross section. The figures of tensile strength nevertheless show that with tolerably good bars one can count on tensile strengths of over 50 kg/mm.² (31.7 tons per sq. in.). To prove this, small tensile test bars, 5 mm. in diameter (also

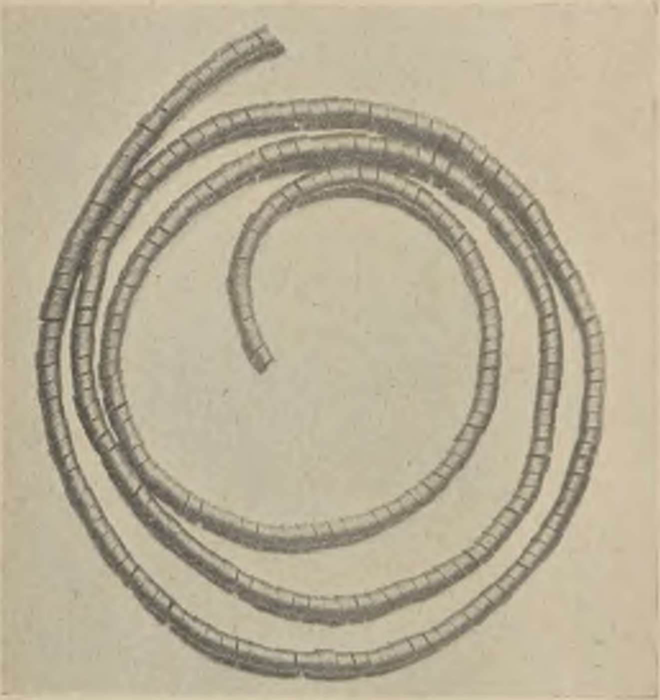


Fig. 2.—Appearance of Turnings showing Elasticity—Natural Size.

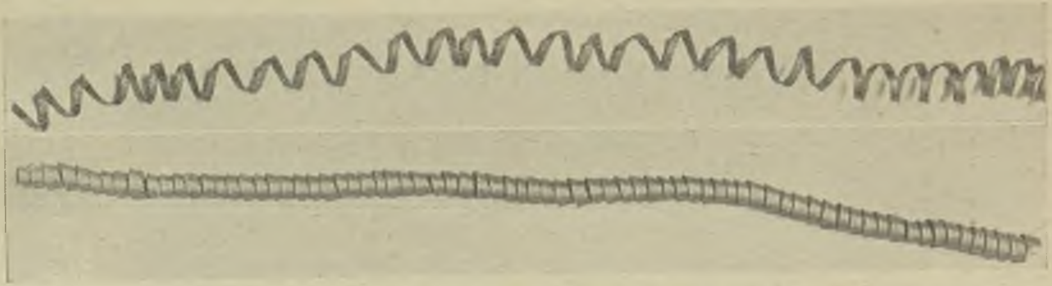


FIG. 3.—APPEARANCE OF THE TURNINGS SHOWING ELASTICITY.

with conical enlargements at the ends) were made from certain bars in which the pipe formation was less pronounced, the sides which were free from defect being used for the purpose. It will be seen from Table 1 that these bars showed tensile strengths up to about 75 kg./mm.^{2} (47.6 tons per sq. in.), even in cases where these small bars still showed a slight defect in the fracture. More-

Fig. 4.—Broken Transverse Test Pieces from Heat Bvi × 1.5.

over, an elongation of 2 to 4 per cent. was noted in most of these small tensile samples.

The Brinell hardness of almost all the alloys is fairly high. It varies between about 200 and 300. Notwithstanding these high hardness figures all the bars were found to be easily machined with ordinary turning tools, and showed no appreciable increase in shearing strength compared with ordinary cast iron. Continuous turnings 3 to 5 m. in length were obtained on machining, and these were maintained even when the feed was increased. Figs. 2 and 3 show the appearance of these turnings. From the transverse strength figures, and in part also from the tensile strength figures of the different samples, it is apparent that a nickel addition clearly exercises a beneficial, although not a very great, effect on the mechanical properties; while on the other hand, nickel in conjunction with chromium is capable of increasing the mechanical properties even of this high-grade iron by 10 to 20 per cent. in the high-carbon series A and by 10 to 30 per cent. in the low-carbon series B. The treated samples, however, indicated in column 2 of Table I by the letter *v*, do not show any noteworthy improvement in the mechanical properties compared with the untreated samples. This is in itself remarkable, but it may be explained as follows: The grain of the ground mass and the structure of the primary carbon liberated by the annealing process are so fine, owing to the thermal treatment mentioned, that a subsequent alloying process is incapable of rendering the grain still finer. As a matter of fact, in the samples cast in sand an increase of strength of about 10 to 15 per cent was observed as a result of such treatment. Although not large, the increase was certainly present. Among the bars cast in chill moulds, on the other hand, only the melts containing chromium and nickel showed a slight increase in the figures relating to mechanical properties as a result of the adjusting process (*cf.* melts 6 and 12 in Table I).

The structure of the fracture in a large number of the heats—particularly those containing nickel and chromium—was so fine in grain that the material could be distinguished from hardened tool steel only by a practised eye. Fig. 4 shows, by way of example, two fragments which were chipped off in the fracture, which took the form of a cup or basin, of a transverse test bar in heat 12. The fineness of grain resembles, in fact, that seen in the fracture of high-grade tool steel.

At the outset of this Paper it was stated that the thermal after-treatment was so adjusted that a sorbitic-pearlite ground mass with finely-distributed primary carbon must make its appearance. All the micros, in fact, showed in the unetched state a structure of primary carbon in an arrangement as regards magnitude such as is shown in Fig. 5a, magnified 100 times. Only a single heat, namely, No. 10, in which through an oversight the carbon content turned out too high, showed even in the final condition, together with considerable quantities of ferrite, very fine-grained

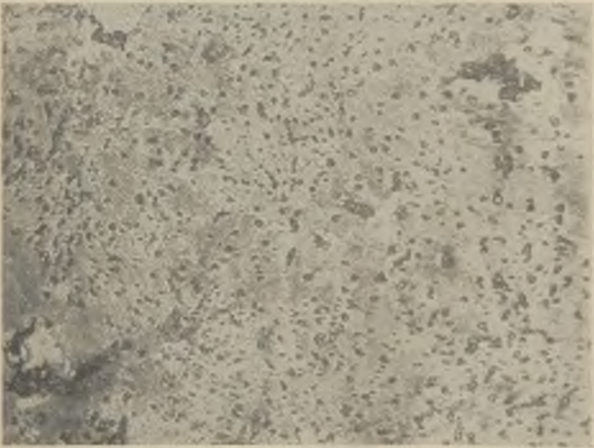
FIG. 5A.—GRAPHITE STRUCTURE FROM HEAT A VI × 100.

eutectic graphite, which could scarcely be distinguished when magnified 100 times. The unetched micro. of this heat had therefore to be reproduced (Fig. 5b) magnified 500 times. Some of the bars showed in parts, together with the primary, as shown in Fig. 5a magnified 100 times, also primary carbon—distributed very uniformly over the sorbitic-pearlite ground mass—of such a high degree of fineness that it had to be magnified 500 times to be identified. This is apparent from Fig. 6 (a and b). These illustrations reproduce the structure of heat 7 magnified 500 and 1,000 times. It will be seen that here also one has to do with a sorbitic-pearlite ground mass, for even when magnified 1,000 times it was still impossible to distinguish certain pearlite fields, which, however, could be done in the case of the heats con-

FIG. 5B.—GRAPHITE STRUCTURE FROM B I v × 500.

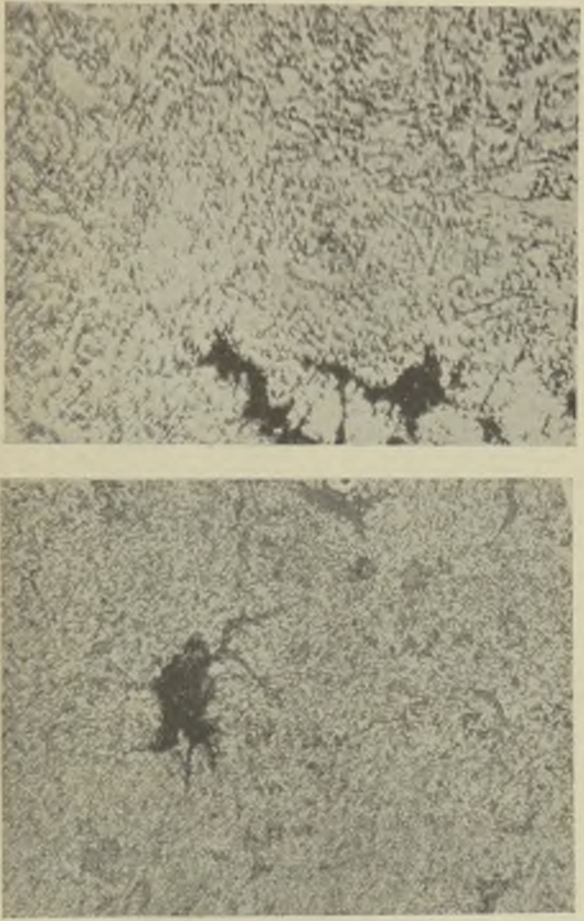
taining chromium and nickel. The illustrations c and d of Fig. 6 show the structure of the same

(b) × 500.



(a) × 500.

heat after the adjusting process, namely, at those points where the coarsest separation of temper carbon was found, so that a comparison of the illustrations *a* and *d* shows the upper and lower limit values in the formation of the elementary carbon in respect of magnitude. It is apparent,



(*c*) × 1,000. (*d*) × 1,000.

FIG. 6.—STRUCTURE OF HEAT VII, *a* AND *b* BEFORE AND *c* AND *d* AFTER TREATMENT.

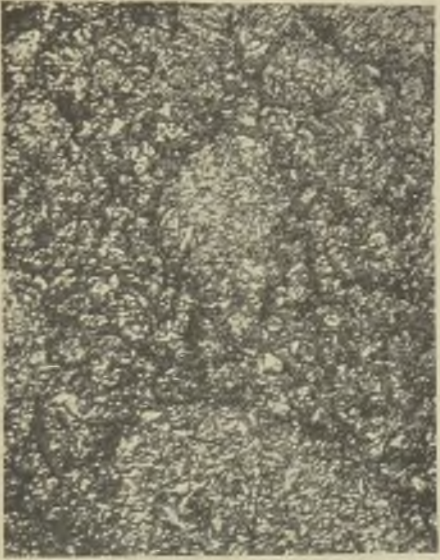
moreover, that by the adjusting process the sorbitic-pearlite ground mass has been converted into exceptionally fine granular pearlite of the coagulated cementite. In this connection reference should also be made to Fig. 7, which shows the structure in thermally-regulated sand-cast iron, 7a being that in ordinary grey cast iron, while that in Figs. 7b and 7c is from the samples of sand-cast iron mentioned at the beginning of this Paper, the graphite content of which was caused to solidify in the form of a fine structure by thermal superheating of the melt. It had struck the author that in ordinary, or superheated unalloyed grey cast iron, thermal treatment frequently produces a structure which in its formation resembles blunt needles of martensite, but

(*a*)

Fig. 7.—Structure of Heat-Treated Cast Irons, × 500.

which in reality has also a preponderatingly granular-pearlitic ground mass, which, however, bears an *apparent* resemblance to martensite—a structural phenomenon which is also observable in the hardening and tempering of steel, and which has led Haneman to establish a new theory of hardening[5] on a metallographic basis.

Whilst it follows from these tests that a nickel addition, particularly in combination with a moderate chromium content, is very well adapted to produce a noteworthy increase in the mechanical properties, even with the best formation of the elementary carbon, it is further apparent,



(*b*)

FIG. 7.—*Continued.*

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[5] Werkstoffausschuss-Bericht des V.D.E. (Report of the Materials Committee of the German Engineers' Association), No. 61.

even from the tests so far carried out, that it is possible to obtain by the methods here adopted a special type of malleable cast iron[6] with which strengths hitherto unreached will be associated. Here it is simply a question, in contradistinction to the known malleable-iron process, to cause a metal of which the charge is grey to mottled, to solidify white to mottled by means of artificially-accelerated cooling (pouring in chill moulds or in wet moulds). This type of charge requires, according to the carbon content, silicon contents of about 1.4 to about 2.2 per cent. These small

(c)

FIG. 7.—*Continued.*

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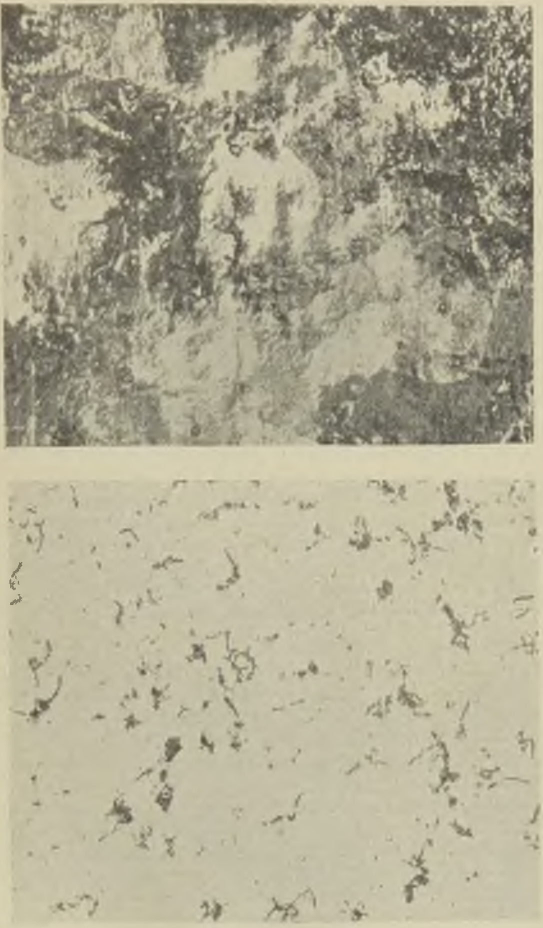
[6] K. Emmel has already published some figures of the same order of magnitude based upon a similar process (*cf. Stahl und Eisen*, 1925, II, page 1469). P. Bardenheuer also obtained approximately similar figures (*cf. Stahl und Eisen*, 1927, page 857).

castings, poured white or mottled, can be completely graphitised within a few minutes. The author succeeded, in fact, in completely and uniformly graphitising small castings with a wall



(a) × 100. (b) × 500.

Fig. 8.—Structure of an Insulator Bell.

thickness up to 35 mm. as quickly as 10 mins. by immersing them in a salt bath at a temperature of 925 to 950 deg. C., when the ground mass showed a sorbitic-pearlite structure with a much finer temper-carbon formation than is observable with the malleablising process as normally practised to-day in America and Europe.

From the results of these researches, moreover, the introduction of a new annealing process, in which quick malleablising would be effected in continuous service with the use of salt baths, would appear to be advantageous. This process was, in fact, practically tested by the author; among other things, insulator bells, which are still made of malleable iron or cast steel, were produced by way of trial in the manner here described in material of excellent quality which was also economical. Fig. 8 shows the structure of an insulator bell of the kind (magnified 100 times), in connection with which it should be expressly noted that the illustration *a* does not by any means represent the finest formation of the elementary carbon. The illustration *b* shows that here also the ground mass is sorbitic pearlite.

The phosphorus content of all the heats dealt with was very low. Tests with higher phosphorus contents will be made before completing these researches, and with moderate contents (up to about 0.30 per cent. P) they may even be expected to give still higher strength values, particularly after the addition of nickel and chromium.

Summary.

By causing a cast iron having a grey to mottled charge to solidify at first white to mottled by accelerated cooling, and graphitising it only by subsequent annealing, mechanical strengths of a range hitherto unreached were obtained. In high-grade material of this kind (transverse strengths of 80 to 100 kg./mm^2. in a perfect bar), a still further increase in the tensile properties of 10 to 30 per cent. (100 to 130 kg./mm^2.) was effected by the addition of nickel or of nickel and chromium. The deflection of such material in the transverse test is two to three times that of ordinary pearlitic grey cast iron. Tensile tests, in which the elimination of large defects was ensured, showed measurable elongations of 2 to 4 per cent., with values up to 75 kg./mm^2. (47.6 tons per sq. in.). Notwithstanding the high hardness figures (200 to 300), the machinability of all the samples was at least as good as that of ordinary good grey cast iron.

If suitably turned to account, these tests should result in a quick annealing process giving unusually high strength values with the shortest possible heating period.

THE STRENGTH OF CAST IRON.

By J. E. Fletcher, M.I.Mech.E., Consultant to the British Cast Iron Research Association (Member).

Many foundrymen are unaware of the difficulties experienced by the blast-furnaceman in the production of foundry pig-iron of uniform mechanical strength, in the pig form, even though the chemical analysis be closely similar in the pigs of a particular cast. The number of drops on the pig sampler's anvil necessary to break pigs from different parts of the pig bed may vary considerably, and the fractures may vary correspondingly. The so-called " scattered " fracture has always been a source of anxiety to the blast-furnaceman, and he is perhaps as much at sea to-day as ever in diagnosing the cause of the vari-grained fracture in cast irons of medium silicon content (1.5 to 2.5 per cent.).

It is well known that within this range—which is the one most used by the foundryman—there is the greatest variation in blast-furnace behaviour, the cause being probably complex in character. In trying to avoid the trouble all kinds of methods have been tried, no one of which seems to be universally successful.

In the re-melted pig-iron from this critical range the variations in structure and mechanical strength, especially in iron of 1.2 to 1.8 per cent. silicon content, are even more pronounced, fractures from mottled to grey occurring between narrow ranges of silicon variation. Sometimes 1.5 per cent. silicon iron is unmachinable, and at others is extremely soft. The author has found that this critical range corresponds with the passage through the maximum pearlite condition, the range being commercially that between mottled and No. 4 hard pig-irons, these irons becoming white or mottled when remelted. The abruptness of the pearlitic change is seen in Fig. I (*a*). The pearlite percentage in a series of Scotch pig-irons is seen to reach its maximum at about 1.25 per cent. silicon. Here the pig-iron fracture would be a close grey, but a thick fin or flash on the pig would be mottled or white in fracture. Such a pearlitic pig when remelted and cast into a 1.2-in. dia. bar would be mottled or soft-white in fracture when poured into a cold mould.

Fig. I (*a*) shows a method of graphing the structural composition of a series of pig-irons from a certain blast-furnace and was first used by the author in his A.F.A. Paper of 1925. It is perhaps the first attempt to produce a descriptive graph characteristic of the production of a blast-furnace working on a certain burden. From such a furnace graph the foundry metallurgist is enabled to choose the iron most suitable for his cupola mixture.

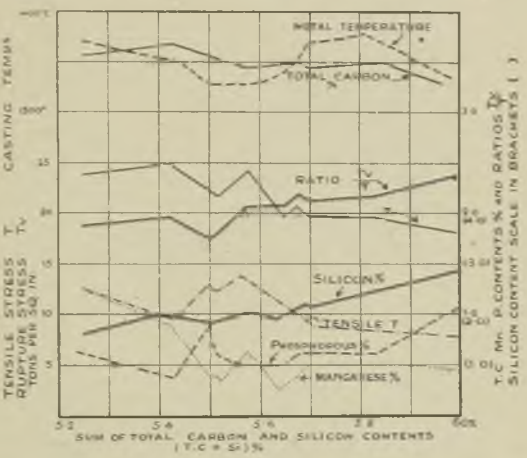
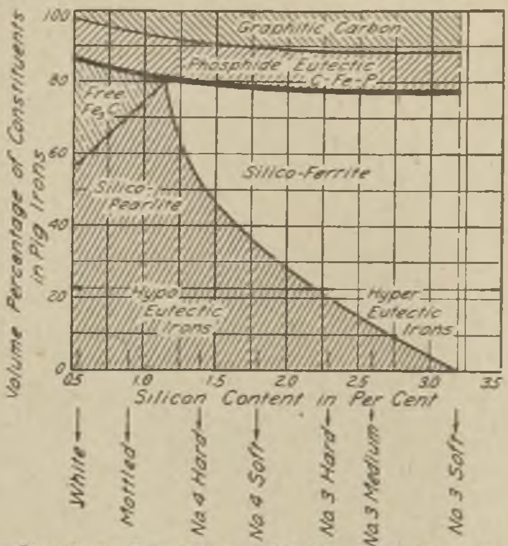


FIG. 1.

It shows clearly the critical character of the blast-furnace operation when running on 1.0 to 2.0 per cent. silicon irons, and should make foundrymen sympathetic towards the blast-furnacemen who are not infrequently asked to work to fracture *and* analysis when supplying pig-irons within this critical range. The request is at once seen to be unreasonable, and is the cause of innumerable quarrels.

The variations in the structure and mechanical properties of foundry pig-iron are reflected in the remelted metal, and it is obvious that the foundryman must take account of this fact when making up any cupola mixtures for the production of castings which must comply with a specification containing mechanical strength clauses.



Structural Composition, in Per Cent, of a Range of Pig Irons from Same Furnace

T.C	C.C.	Gr.C.	Si.	Mn	S.	P.
3.4	2.8	0.6	0.55	0.70	0.30	0.70
to	to	to	to	to	to	to
3.6	0.2	3.4	3.25	1.10	0.03	0.75

FIG. 1A.

In considering the mechanical strength of cast iron the metallurgical engineer is faced with the fact that considerable variation in tensile, transverse, torsional, compressive and impact tests must be looked for in a group of test bars cast simultaneously from the same ladle of metal in similarly prepared moulds cooled at equal rates. This is a disturbing fact, the reasons for the lack of uniformity having occupied the minds of foundrymen, engineers and metallurgists for many years.

The Institute of British Foundrymen has rendered a signal service to the engineering world by its attention to the matter of standard mechanical tests for cast iron, and in the many hundreds of bars of various sizes tested—of varying chemical composition—the values recorded for the tensile and transverse breaking loads in any one series of bars of similar size and approximately similar composition vary considerably from the mean of the series. The same kind of variation has been found in the many series of tests carried out by the British Cast Iron Research Association under conditions which have enabled the important details of the cupola mixtures, melting practice, pouring temperatures and cooling rates to be correlated with the analysis and micro-structure of the tested bars.

Work of a parallel nature has been done in the U.S.A., Germany, France, Belgium, Japan and elsewhere, the results of the tests on similar bars giving the characteristic variations. These indicate that the same causes for such irregularities are at work whatever casting material has been used—within the range of chemical composition common to the cast iron series. In this Paper the writer does not intend to convey the idea that the range of strength variations makes it impossible to arrive at a practical working mean in any particular narrow range of cast iron compositions, but, in view of the developments which are taking place in cupola melting practice, and in the methods of casting and cooling the pieces, he would seek to call attention to some of the possible causes of these variations. Before doing this, a few typical examples of strength variations may be placed on record, drawn from reliable sources.

Example No. 1 is drawn from a series of 1.2-in. dia. dry-sand cast bars having the following range of chemical analysis:—T.C., 3.3 to 3.6; Si, 2.0 to 2.5; Mn, 0.3 to 0.65; P, 0.5 to 0.7; and S, 0.11 to 0.145 per cent.; the average analyses of the series being: T.C., 3.47; Si, 2.22; Mn, 0.52; P, 0.62; and S, 0.13 per cent.

Actually, the divergences from the mean are as under:—

	Per cent.		Per cent.		
T.C. ..	0.13	above, and	0.17	below mean	(actual values)
	(3.75)		(4.9)		
C.C. ..	0.12	,,	0.28	,,	,,
	(31.0)		(72.0)		
Gr ..	0.31	,,	0.14	,,	,,
	(10.0)		(4.5)		
Si ..	0.28	,,	0.12	,,	,,
	(12.6)		(5.4)		
Mn ..	0.12	,,	0.09	,,	,,
	(23.0)		(17.3)		
S ..	0.015	,,	0.02	,,	,,
	(11.5)		(17.3)		
P ..	0.05	,,	0.10	,,	,,
	(8.1)		(16.2)		

Total Carbon plus Silicon Contents.—These values were:—Maximum, 5.83; minimum, 5.57; and mean, 5.69 per cent.

Tensile Tests.—Maximum, 11.1; minimum, 8.3; and mean, 9.1 tons per sq. in.

Transverse Tests.—Maximum rupture stress (modulus of rupture), 23.8; minimum, 19.7; and mean, 20.9 tons per sq. in.

Ratio $\left[\frac{\text{Rupture stress, tons per sq. in.}}{\text{Ultimate Tensile stress, tons per sq. in.}}\right]$ $=\frac{Tv}{T}$ Maximum 2.39, minimum 2.14, and mean 2.29.

The divergences in the contents of the various elements are expressed in percentages of the mean analysis values and are not abnormal. The differences in the mechanical strength of the irons are, however, seen to be considerable and are difficult to account for in terms of the analysis. When the tensile and transverse rupture stresses were plotted as ordinates over a base indicating the *total carbon plus silicon* contents, and the various elements also similarly plotted, it was seen that the ratio of the transverse rupture stress to ultimate tensile stress curve followed the silicon line closely in the above series (see Fig. 1), but in others the characteristics of the two curves were not so closely alike. The dominant influence of the two elements carbon and silicon is generally seen by thus plotting the results, and when the metal temperatures—as taken from the stream leaving the cupola spout—are also plotted, it is often possible to see the effect of varying metal temperatures.

In the series in question the spout temperatures were low when irons of between 2.0 and 2.2 per cent. were being tapped. The silicon, manganese, sulphur, phosphorus, and carbon curves show a series of kinks, all but the carbon showing what appears to be a fall in the contents due to greater oxidation at the lower metal temperature. The kinks are reflected also in the rupture stress/tensile stress curve. (See Fig. 1.) This ratio is of some—perhaps considerable—importance in connection with strength investigations concerning cast iron. The writer has elsewhere shown the connection of the ratio with the compressional and tensile strengths of cast iron, and has attempted to determine therefrom the relative values of these strengths; also the position of the neutral axis or plane in the transverse test bar when under load. The higher values of the ratio represent lower tensile strength, the curves showing these higher values as the silicon—and silicon plus carbon—contents are increased. It does not necessarily follow that the deflections of the transversely tested bars will increase in the inverse sense to that of the rupture modulus/ultimate tensile ratios; because of the lower tensile strength signified, for it is well known that a softer iron will sometimes give a better deflection than a harder one. The writer has found the Brinell figures to give fairly concordant results when comparing these with the carbon-plus-silicon values, and, as these are generally comparable with the rupture modulus/tensile ratios further research should make the Brinell test more useful than it has been in cast-iron investigations.

Example No. 2 is from a similar series of dry sand cast bars having the following range of chemical analysis:—T.C., 3.3 to 3.7; Si, 1.6 to 1.9; Mn, 0.40 to 0.96; S, 0.09 to 0.14; and P, 0.42 to 0.50 per cent.; the mean analysis being:—T.C., 3.45; Si, 1.77; Mn, 0.71; S, 0.11; and P, 0.46 per cent.

The divergences from the mean are as shown below:—

	Per cent.		Per cent.		
T.C. ..	0.24	above, and	0.16	below mean	(actual values)
	(7.0)		(4.6)		
Si ..	0.13	,,	0.17	,,	,,
	(7.2)		(9.6)		
Mn ..	0.19	,,	0.31	,,	,,
	(2.6)		(4.2)		
S ..	0.03	,,	0.03	,,	,,
	(2.7)		(2.7)		
P ..	0.04	,,	0.04	,,	,,
	(8.7)		(8.7)		

The figures in brackets give the variation in terms of the mean contents of the various elements, as in the case of Examples 1 and 3.

The variations in the combined and graphitic carbon contents were:—

	Per cent.		Per cent.	
Gr	0.15	above, and	0.25	below mean.
	(5.1)		(8.5)	
C.C.	0.19	,,	0.27	,,
	(36.0)		(51.0)	

Total Carbon plus Silicon contents were:—Maximum, 5.44; minimum, 4.95; and mean, 5.23 per cent.

Tensile Results.—Maximum, 14.9; minimum, 10.6; and mean, 12.8 tons per sq. in.

Transverse Tests.—Rupture stress (modulus of rupture): Maximum, 27.5; minimum, 20.9; and mean 24.9 tons per sq. in.

The Ratio—Transverse Rupture Stress: Tensile Stress (ultimate) was found to be: Maximum, 2.25; minimum, 1.68; and mean, 1.81.

In a third series, Example No. 3 represents similarly cast bars to those in the two former series. The chemical analyses were:—T.C., 3.4 to 3.6; Si, 1.0 to 1.7; Mn, 0.5 to 1.0; S, 0.09 to 0.13; and P, 0.33 to 0.53 per cent.; the mean analysis being:—T.C., 3.55; Si, 1.43; Mn, 0.75; S, 0.11; and P, 0.41 per cent.

The divergences from the mean were as follows:—

	Per cent.		Per cent.	
T.C.	0.04	above, and	0.06	below mean.
	(1.1)		(1.7)	
C.C.	0.09	,,	0.13	,,
	(14.8)		(21.3)	
Gr	0.14	,,	0.11	,,
	(4.7)		(3.7)	
Si	0.28	,,	0.37	,,
	(19.0)		(26)	
Mn	0.23	,,	0.22	,,
	(30.6)		(29.7)	
S	0.02	,,	0.02	,,
	(18)		(18)	
P	0.12	,,	0.09	,,
	(29.3)		(22.0)	

Total Carbon plus Silicon contents were:—Maximum, 5.28; minimum, 4.55; and mean, 4.99 per cent.

Tensile Tests.—Maximum, 15.1; minimum, 11.6; and mean, 13.0 tons per sq. in.

Transverse Tests (Modulus of Rupture).—Maximum, 25.9; minimum, 22.3; and mean, 24.4 tons per sq. in.

Ratio—Transverse Rupture Stress: Ultimate Tensile Stress; Maximum, 2.07; minimum, 1.72; and mean, 1.95.

Other series of tests, including the valuable results recorded by J. T. MacKenzie, in his A.F.A. Paper of 1926, have furnished closely comparable figures in which the interesting relationship between the Brinell hardness values and the carbon-plus-silicon contents is clearly brought out. These are graphed in Figs. 2 and 3. Two sets of curves are shown, illustrating a series of irons of low manganese (below 0.5 per cent.), low phosphorus (under 0.5 per cent.), with variable carbon and silicon contents, Fig. 2, and higher manganese (0.5 to 1.0 per cent.), together with other two sets of curves, illustrative of higher phosphorus content (0.5 to 1.0 per cent.), Fig. 3.

Combined Functions of Total Carbon and Silicon.

In recording the results of the three examples of ordinary cast irons, the first of which is graphed in Fig. 1, it will be noted that the various curves showing the analyses, mechanical strengths and casting temperatures are plotted over a base representing the sum of the total carbon and silicon contents in each of the irons tested. If the total carbon content in each of the irons had been constant the silicon curve would have been a straight line in the case where

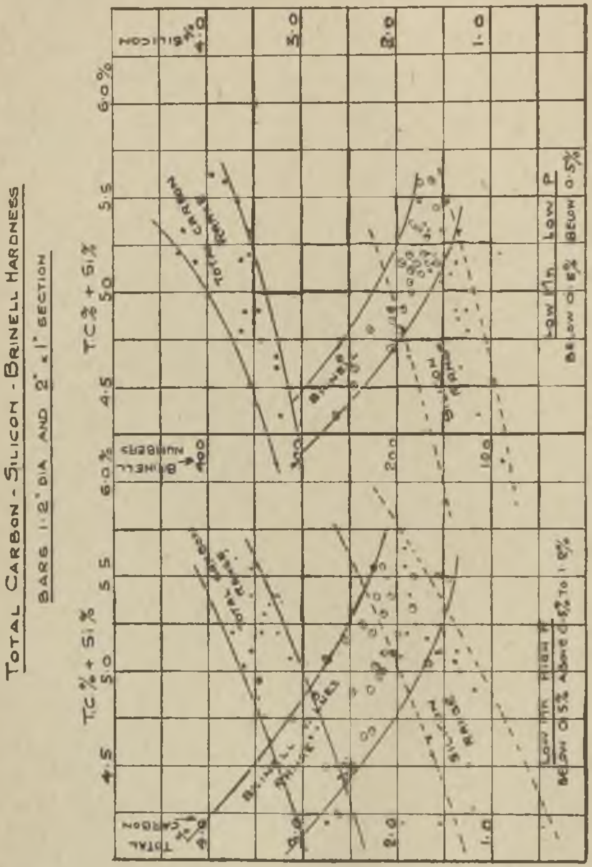


FIG. 2.

the sum of the total carbon and silicon contents was constant or where the silicon contents progressively increased or decreased by a like amount from cast to cast throughout the series. The usual divergences of the carbon and silicon contents result in a broken line or curve, and this variably contoured line has been found by the author to give a most useful index to the effect of variations in analysis when plotted above the total carbon-plus-silicon base. Ledebur was probably the first to point out that desirable properties in cast iron could be expressed in terms of the total carbon and silicon contents, his results being shown in a formula which can be simply stated in the following form:—

Silicon content $= 6.6 - 1.5 \times$ total carbon content (max.) to $5.7 - 1.5 \times$ total carbon content (min.).

The total carbon content is here made the basis for determining the silicon content, and, though the expression has been simplified in more recent days, Ledebur's fundamental conception that the sum of the total carbon and silicon contents in a cast iron are of first importance is now generally accepted, modified to suit the thickness of the casting, conditions of service required, and the mould temperature (Lanz hot-mould iron).

TABLE I.—*Ledebur's Table of Silicon with varying Total Carbon contents in Cast Iron.*—

T.C.	Si.		T.C.+Si.		$\frac{\text{Si.}}{\text{T.C.+Si}}$	
	Max.	Min.	Max.	Min.	Max.	Min.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
3.8	0.9	0.0	4.7	3.8	0.192	—
3.6	1.2	0.3	4.8	3.9	0.250	0.083
3.4	1.5	0.6	4.9	4.0	0.306	0.150
3.2	1.8	0.9	5.0	4.1	0.360	0.248
3.0	2.1	1.2	5.1	4.2	0.412	0.286
2.8	2.4	1.5	5.2	4.3	0.462	0.349
2.6	2.7	1.8	5.3	4.4	0.510	0.410

The preceding table is of interest as showing the Ledebur determinations of silicon per cent. in cast irons of total carbon content varying between 3.8 and 2.6 per cent. (3.8 per cent. T.C. being the maximum content the formula allows).

A glance at the table will show that the modern expression used regularly on the Continent, per cent. T.C. per cent. + Si per cent. = 4.0 to 5.2 has been directly deduced from Ledebur's original formula.

Ledebur (Das Roheisen: p. 57) expresses the T.C. and Si relationship thus:— $\text{T.C.} + \frac{\text{Si}}{1.5} =$ 4.2 to 4.4 and, for low Si irons the constants 4.2 and 4.4 may fall to 3.8.

This worker realised the function of the eutectic containing 4.3 per cent. carbon in cast iron structural strength connections, and it will be seen that the original formula expresses the

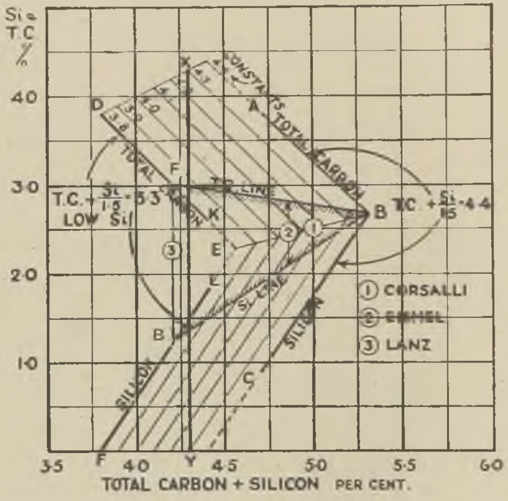


Fig. 2a.

view that ⅔rds of the silicon content corresponds with the difference between the total carbon content and 4.3 (which is the carbon percentage of the iron-carbon eutectic), in the compositions recommended for general service. Thus a 1.5 per cent. Si iron should have a T.C. per cent. of 3.3 when the eutectic constant 4.3 is used. The values given in Table I, when graphed above a T.C. + Si base, are shown in Fig. 2a. The T.C. and Si percentages for the maximum and minimum values of the constants (4.4 and 3.8) are indicated by lines DK-LF and AB-BC respectively. The lines DK-LF, when extended, meet in point E and the line EB is the locus of the junctions of

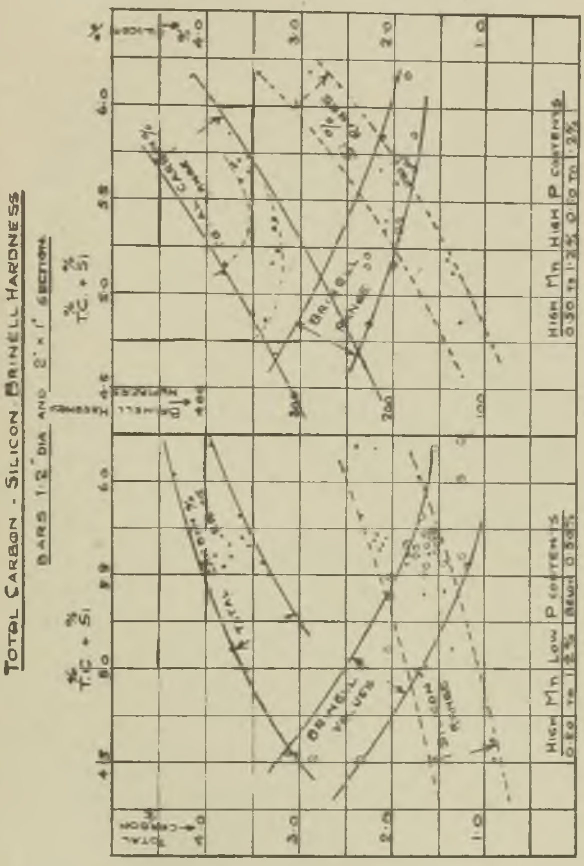


Fig. 3.

all other T.C. and Si lines corresponding to constants between 4.4 and 3.8. These junction points, such as E, O and B, illustrate the cast irons having similar T.C. and Si contents. The vertical YX represents the 4.3 per cent. T.C. eutectic (Si per cent. = O) corresponding to the expression T.C. per cent. + Si per cent. = 4.3, where the maximum Si and minimum T.C. have like values; when T.C. + Si = 5.15 per cent. (point O). The triangle XYO graphically verifies the eutectic basis of the Ledebur formula. The diagram has a peculiar interest in showing the compositions (with respect to T.C. and Si contents) of modern cast irons of maximum strength. The writer has found that by drawing the lines FB, GB, the T.C. and Si contents of strong irons may be taken to vary between 3.0 and 2.6 per cent. T.C. and 1.2 and 2.6 per cent. Si. The triangle FBG gives the limiting T.C. contents line FB—and the limiting Si contents line GB.

The compositions of the strong Perlit, Emmel and Corsalli cast irons are indicated. Recent research has shown that Ledebur's work was of great importance, and it should be noted that, after Professor Turner's researches had proved the importance of silicon in cast iron, Ledebur indicated the fundamentals governing the combined effect of total carbon and silicon, or, at any rate, pointed out the direction in which future research should proceed in finding the conjoint influence of the two all-important elements.

Relationship between the T.C. + Si Contents and Mechanical Strength.

In Fig. 1 the actual results of a series of cast irons made for the experimental purpose of testing out the 1.2-in. dia. bar by the German Ironfounding Employers' Federation, Dusseldorf, have furnished the writer with the means for determining the influence of total carbon and silicon (primarily) on the physical properties of ordinary irons. Similarly, Mr. J. T. MacKenzie's experiments have enabled the Brinell hardness factor to be related to the iron composition. In both sets of tests the important function of the combined silicon and carbon contents in regulating the structural strength and hardness is confirmed, much additional works data having been examined before the author felt certain of his ground. Both the German and American results are representative of somewhat weaker irons than would result from

British mixtures yielding similar analyses, but the many British tests examined confirm the accuracy of the fundamental trend of the combined silicon and carbon action as illustrated in Figs. 1 and 2.

Effect of Altering the Silicon Content in the T.C. + Si Factor.

It will be easily realised that the total carbon and silicon contents in a cast iron whose carbon and silicon percentages together equal, say, 5.0 may vary between 4.0 per cent. T.C. with 1.0 per cent. Si and 2.5 per cent. T.C. with 2.5 per cent. Si. The T.C. + Si factors may be alike, but clearly the structural and strength characteristics must vary as the ratio $\frac{\text{Si}}{\text{T.C.}}$ changes.

The comparison between any cast irons of similar T.C. + Si contents is perhaps best seen by using the ratio $\frac{\text{Si}}{\text{T.C.} + \text{Si}}$ as the index of comparison. This is well illustrated in Table II, where a series of irons having T.C. + Si contents is equal to 5.6 per cent.

TABLE II.

T.C.	Si.	T.C. + Si.	$\frac{\text{Si.}}{\text{T.C.} + \text{Si.}}$
Per cent.	Per cent.	Per cent.	
2.6	3.0	5.6	0.536
2.8	2.8	5.6	0.500
3.0	2.6	5.6	0.465
3.2	2.4	5.6	0.429
3.4	2.2	5.6	0.393
3.6	2.0	5.6	0.357
3.8	1.8	5.6	0.322
4.0	1.6	5.6	0.286

The characteristics of the irons of equal T.C. + Si contents differ more considerably as the T.C. + Si values are smaller, as shown in Table III.

If the irons in Table III are assumed to cool at such a rate that the structures are fully pearlitic, the graphitic carbon and combined carbon contents will closely approximate to the values given in columns (*a*) and (*b*), manganese, sulphur and phosphorus contents being ignored in the estimations for the sake of simplicity. This enables the student to visualise the relative effect of the total carbon and silicon in producing graphitisation between the solidification and pearlitisation points. Thus a rise of 0.5 per cent. in total carbon and a corresponding fall of 0.5 per cent. in the silicon contents results in an increase of the graphitic carbon content of about 0.50 per cent. in irons having similar T.C. + Si contents. But the weakening effect of the increasing graphite contents in the four irons in Table III is best seen by comparing the volumetric compositions of the castings thus:—

TABLE III.

T.C.	Si.	T.C.+Si.	$\frac{\text{Si.}}{\text{T.C.+Si.}}$	G.C. (*a*)	In pearlitic condition. C.C. (*b*)
Per cent.	Per cent.	Per cent.		Per cent.	Per cent.
2.5	2.0	4.5	0.44	1.67	0.83
3.0	1.5	4.5	0.33	2.16	0.84
3.5	1.0	4.5	0.22	2.65	0.85
4.0	0.5	4.5	0.11	3.14	0.86

Per cent.		Per cent.		Per cent.
(1) 2.5 T.C. iron	Gr.	5.47	Silico-Pearlite	94.53
(2) 3.0 T.C. iron	,,	7.05	,,	92.95
(3) 3.5 T.C. iron	,,	8.65	,,	91.35
(4) 4.0 T. C. iron	,,	10.10	,,	89.90

Accepting Sauveur's conclusion that the graphite volume (per cent.) is approximately equal to the sectional area per cent. as shown on the micro structure photographs, the above figures for the volumetric analysis of the four cast irons may be taken as showing the areas of the graphite flakes and of the pearlite approximately.

The T.C. + Si contents of a cast iron do not, therefore, indicate the strength of the iron, unless the silicon influence, as shown by the ratio $\frac{\text{Si}}{\text{T.C.} + \text{Si}}$ is taken into consideration, together with that of the total carbon content.

In a series of bars 1.2-in. dia., cast at similar temperatures, and of similar T.C.+Si contents, the rupture stress (transverse tests) varies in proportion to the ratio $\frac{\text{Si}}{\text{T.C.}+\text{Si}}$ approximately. Phosphorus, between say 0.4 and 0.8 per cent., does not affect the strength to any considerable extent, neither does sulphur, up to, say, 0.12 per cent., but manganese has a very powerful effect, increasingly as the content exceeds, say, 0.6 per cent., the ratio $\frac{\text{Mn}}{\text{Si}}$ being an index to the increase in transverse and tensile strength.

Generally, the irons low in manganese (below 0.5 per cent.) show the greatest variations in mechanical strength. Here the power of the silicon in promoting graphitisation is unrestricted, manganese being in an insufficient proportion to stabilise the combined carbon. Whenever the silicon exceeds, say, 1.5 per cent., sulphur, even up to 0.13 per cent., though increasing the Brinell hardness, does not materially affect the rupture stress. In the irons of lower Si-content sulphur has a more potent effect, hardening and lowering the rupture stress and diminishing the deflection.

The author has found that by recording the T.C.+Si contents the ratio $\frac{\text{Si}}{\text{T.C.}+\text{Si}}$ and the T.C. per cent. in irons cast at the same temperatures from similar mixtures, an index to the rupture stress may be obtained. This index corresponds to a low manganese content in the iron (below 0.5 per cent.). Higher Mn-contents may be expected to increase the strength, whilst in low Mn, low Si irons the presence of sulphur may be expected to reduce the strength.

In examining a large number of test results the divergence in the transverse and tensile strength values was very confusing. It was found possible to divide the mass of data into groups according to the T.C.+Si and $\frac{\text{Si}}{\text{T.C.}+\text{Si}}$ proportions. This has been done in the case of the Dusseldorf group of irons, which were cast under systematised conditions and therefore give comparisons of an extremely useful character. In an examination of British irons the conditions varied so much and the lack of information with respect to casting temperatures (together with the fact that so many of the bars were not 1.2-in. dia.), has compelled the author to keep these results out of Table IV, but it may be definitely stated that, generally, the mechanical strengths in the British irons were somewhat higher than the German, whilst being related to the T.C. and Si sum, and to the ratios $\frac{\text{Si}}{\text{T.C.} + \text{Si}}$ and $\frac{\text{T.C.}}{\text{Si}}$ in the same manner as shown in Table IV.

In compiling the table it was necessary to take the average values of a number of tests in each of the seven series as the variations were often confusing. By so doing the general trend of the various influences was revealed. The individual influence of the elements was seen in the majority of the test results, but not clearly unless compared with the mean values. The most useful pointers were seen to be the various ratios between the chief elements which affect the mechanical strength, viz., total carbon, combined carbon, silicon, and manganese. Sulphur, which is so often quoted as being detrimental to transverse and tensile strength, does not appear seriously to affect the results. Indeed, in examining the deflections, sulphur contents in excess of 0.13 per cent. are associated with the highest deflections. In Fig. 4 the ratios $\frac{\text{T.C.}}{\text{Si}}$; $\frac{\text{Mn}}{\text{Si}}$; $\frac{\text{Tv}}{\text{T}}$ and $\frac{\text{Si}}{\text{T.C.} + \text{Si}}$ are plotted over a T.C. +Si base. In the case of the last-named ratio this is plotted downwards (from the horizontal A B) in order to show more clearly its connection with the transverse rupture stress (Tv) and the tensile strength (ultimate) (T). The graphs are self-explanatory, but attention should be drawn to the relationships of total carbon to silicon, silicon to total carbon plus silicon, and manganese to silicon. These influence the combined carbon content and the ratio of transverse rupture to the ultimate tensile stresses.

TABLE IV.

Analysis per cent.							Mech. Tests. Tons per sq. in.		$\frac{\text{T.C.}}{\text{Si.}}$	$\frac{\text{Si.}}{\text{T.C.}+\text{Si.}}$	$\frac{\text{Mn.}}{\text{Si.}}$	$\frac{\text{Tv.}}{\text{T.}}$	D.
T.C.+Si	C.C.	T.C.	Si.	Mn.	S.	P.	Tv.	T.					
6.01	0.07	3.35	2.66	0.46	0.10	0.95	19.0	8.2	1.26	0.44	0.17	2.33	0.40
5.74	0.41	3.52	2.22	0.53	0.13	0.68	20.5	9.2	1.58	0.39	0.24	2.23	0.44
5.59	0.56	3.52	2.07	0.45	0.11	0.58	21.9	11.1	1.70	0.37	0.22	1.97	0.35
5.43	0.55	3.46	1.97	0.66	0.11	0.48	23.0	11.3	1.75	0.36	0.33	2.05	0.46
5.10	0.51	3.50	1.60	0.77	0.10	0.48	24.1	12.5	2.18	0.31	0.48	1.93	0.44
4.89	0.58	3.42	1.47	0.64	0.10	0.50	26.1	13.4	2.32	0.30	0.44	1.80	0.49
4.34	0.76	3.34	1.00	0.60	0.13	0.33	27.6	14.5	3.34	0.23	0.60	1.91	0.48
Averages:													
5.31	0.50	3.44	1.86	0.59	0.11	0.57	23.2	11.4	2.02	0.35	0.35	2.03	0.44

The Significance of the Ratio $\dfrac{\text{Transverse Rupture Stress}}{\text{Ultimate Tensile Stress}} = \dfrac{\text{Tv}}{\text{T}}$

In a number of earlier investigations, where the tensile, transverse, and compression tests were correlated, it was apparent that the ratio of the tensile to the compression strengths was an index to the transverse strength of cast iron—not a new finding, for Hodgkinson and other early investigators had attempted to relate the two in formulæ for the determination of the strengths of cast-iron beams. In Table IV it will be seen that the ratio $\frac{\text{Tv}}{\text{T}}$ increases when the T.C.+Si values fall below about 5.4 per cent., the tensile strength falling to between 8 and 9 tons per sq. in. when the T.C.+Si contents exceed 5.8 per cent., with low Mn (below 0.5 per cent.) and high P (above 0.8 per cent.). With lower T.C.+Si values the $\frac{\text{Tv}}{\text{T}}$ ratios fall.

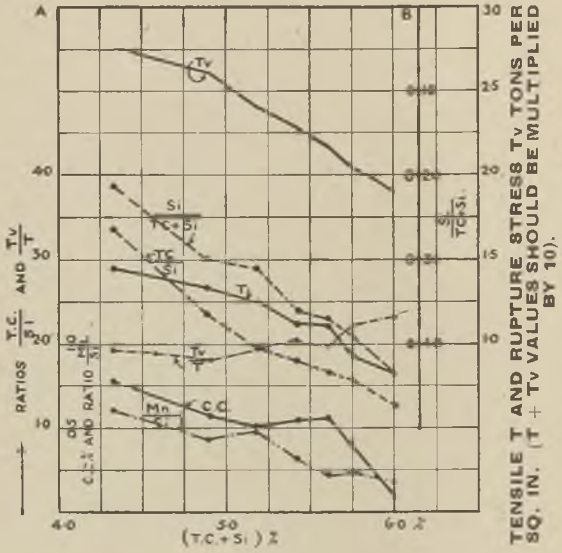


FIG. 4.

TABLE V.

	T.C.	C.C.	Si.	$\frac{\text{T.C.}}{\text{Si.}}$	$\frac{\text{Si.}}{\text{T.C.}+\text{Si.}}$	$\frac{\text{Mn.}}{\text{Si.}}$	T.	Tc.	$\frac{\text{Tc.}}{\text{T.}}$	Tv.	$\frac{\text{Tv.}}{\text{T.}}$	$\frac{\text{Tv.}}{\text{Tc.}}$
(1)	2.97	0.93	1.04	2.85	0.26	0.39	11.6	50.8	4.38	26.5	2.28	0.52
(2)	2.96	1.00	1.08	2.74	0.27	0.37	13.6	50.4	3.70	26.3	1.93	0.52
(3)	2.94	1.03	1.08	2.72	0.27	0.37	11.4	49.2	4.32	25.7	2.25	0.52
(4)	2.91	0.92	1.11	2.62	0.28	0.36	14.8	55.2	3.73	25.8	1.74	0.47
(5)	2.90	0.95	1.08	2.68	0.27	0.37	12.0	49.7	4.15	26.1	2.17	0.52
(6)	2.88	0.96	1.06	2.71	0.27	0.38	12.8	48.8	3.81	25.1	1.96	0.51
(7)	2.86	1.03	1.10	2.60	0.26	0.39	11.9	49.2	4.15	26.2	2.20	0.53
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*

The rupture stress Tv accompanying the fracture of a transverse bar, the tensile strength T of whose metal is known, is related to the compression strength of the material. When the Tv/T ratio is high the tensile strength T is low, and *vice versa.*

A useful example is recorded, a cylinder about 9 ft. long, 1.75 in. thick, having been cut up for tests. The analysis of the metal averaged:—T.C., 3.09; C.C., 0.80; Gr.C., 2.29; Si, 1.14; Mn, 0.70; S, 0.13; and P, 0.39 per cent.

Tensile, compression and transverse tests showed the following variations:—*Tensile*, 11.65 to 14.77 tons per sq. in.; *compression*, 48.8 to 55.2 tons per sq. in; and *transverse rupture stress*, 25.1 to 26.5 tons per sq. in.

In the various test pieces broken the relationships between the rupture stresses and the analyses were as shown in Table V.

The greatest care was exercised in the preparation and measurement of the test pieces, which were sound throughout. The accuracy of the determinations was unquestionable, and the author has therefore no doubt or hesitation in working upon the data provided by the chemical analyses, micro-examination and mechanical tests, which were carried out at the Sheffield University.

The results furnish a clue to the relationship between the transverse rupture stress and the ultimate tensile and compression stresses.

If the values in the columns (i), (k) and (l) are examined it will be found that the ratio $\frac{\text{Ultimate compression stress}}{\text{Ultimate tensile stress}} = \frac{\text{Tc}}{\text{T}}$ and the ratio $\frac{\text{Transverse rupture stress}}{\text{Ultimate tensile stress}} = \frac{\text{Tv}}{\text{T}}$ are in almost exact relationship, being in the proportion of 1.93:1.0, except in test No. 4, where the highest tensile and compression values were found, which, incidentally, was taken from near the bottom of the cylinder as cast, test No. 3 being nearest the top and of lowest tensile strength.

The point of interest is that the ratio Tc/Tv is practically constant, notwithstanding the considerable variations in the tensile and compression (ultimate stresses T and Tc). The mean values for the stresses T and Tc are 12.61 and 50.5 respectively, and for Tv 25.9. The rupture stress (transverse) Tv is therefore nearly 52 per cent. of the compressive stress for the cast iron in question in all except test No. 4, whereas the relation between the rupture stress Tv and the tensile stress T varies throughout the series. This fact supports the view held by the author that the rupture stress Tv is directly proportional to the ultimate compression stress in a cast bar and not in direct proportion to the tensile strength, which varies in its relation to the compression strength. This is supported by the results given in column (i), where the Tc/T ratio varies, and in Table IV, where the ratio Tv/T diminishes in value as the T.C.+Si contents and the $\frac{\text{Si}}{\text{T.C.}+\text{Si}}$ ratios fall. A warning is necessary here in respect to conclusions arrived at from odd tests taken under different conditions of casting. It is only by means of comparisons with series of bars cast under similar conditions and from the same type of mixtures, cooled in similar fashion, that comparisons between the tensile, compression and transverse tests will furnish information of a really useful character. The use of the compression test for cast iron has not been general, the tensile and transverse tests being considered sufficient. The fact that tensile and transverse test results so generally show differences in the ratio of the ultimate tensile to the rupture stress would point to the use of the compression test in order to reveal the real value and meaning of the transverse test. It has already been shown in Table IV that the variable character of the Tv/T ratio is due to the total carbon and silicon proportions—modified mainly by the manganese content. A knowledge of the ultimate compressive strength in addition is necessary if the results of the transverse tests are to be interpreted fully. It is not the desire of the author to suggest that these additional tests are commercially necessary in ordinary foundry testing practice, but a more complete knowledge of cast iron is demanded, further systematic research on the relationship between the analysis, structure and mechanical strength being overdue.

Deflection in Transverse Tests.

There has always been great difficulty in accounting for differences in the amount of deflection in the transverse test bar. The usual deflection formula is based on the assumption that the deflection varies inversely as the modulus of elasticity, taken as 6,000 tons per sq. in., there being no allowance for possible differences in elastic deformation in tension and compression, which differences would alter the position of the neutral axis or plane. The author does not propose to touch the complex mathematical problem involved in any rational method of calculation, but, as in the case of the rupture stress estimation, would draw attention to the fact that the ratio of tensile to compression strength (ultimate), which has been already observed to be related to the Tv/T ratio, also appears to be approximately related to the deflection at moment of rupture.

If the deflection values given in Table IV be divided by the corresponding Tv/T ratios, the resulting figures will be found to increase as the $T.C. + Si$, $\frac{T.C}{Si}$, and $\frac{Si}{T.C. + Si}$ values decrease, as shown below:—

TABLE VI.

Deflection in ins.	T.C.+Si.	$\frac{\text{Deflection}}{\text{Tv/T.}}$	Tv/T.
0.40	6.01	0.172	2.33
0.44	5.74	0.197	2.23
0.35	5.59	0.177	1.97
0.46	5.43	0.225	2.05
0.44	5.10	0.228	1.93
0.49	4.89	0.272	1.80
0.48	4.34	0.250	1.91

The deflections in the standard test bars may therefore be expected to increase in cast irons of low T.C.+Si content, the increase being greatest when the ratio $\frac{Si}{T.C. + Si}$ is the least practical minimum. It may be expected also that the deflections will be increased when the ratio $\frac{Mn}{Si}$ exceeds 0.6. It should also be noted that the phosphorus, in excess of 0.7 or 0.8 per cent., detrimentally affects the deflection, as proved by J. T. MacKenzie, whose A.F.A. Paper (Syracuse meeting, 1925) is well worthy of close study.

The Influence of Micro-Structure.

As the method of interpreting the chemical analysis of cast iron in terms of the various structural constituents is now well known, the range of cast irons taken for illustration (Tables IV and V) can be readily analysed structurally, and the degree of pearlitisation and graphitisation arrived at.

Summary.

The dominating influence of silicon and total carbon together, and the importance of the carbon and silicon proportions in the (T.C.+Si) factor must have first attention when attempting to interpret the analysis of a cast iron in terms of its mechanical strength.

Fig. 5 has been prepared from a mass of test results and shows how many different compositions (in respect to total carbon and silicon contents) may be used in obtaining iron of given transverse rupture strength. The position of the special modern strong irons, such as Corsalli, Perlit and Meehanite, in the ranges of silicon and T.C.+Si should be noted (marked C. P. and M.).

The influence of total carbon, silicon, manganese and phosphorus have been related to Brinell hardness values. Here again the sum of the total carbon and silicon contents have been shown to be of great importance. In Figs. 2 and 3 the ranges of total carbon and silicon, plotted over a T.C.+Si per cent. base, are correlated with the ranges of Brinell hardness.

The modulus of rupture or rupture stress in transverse tests, when considered in relationship to the ultimate tensile strength, yield a valuable factor, Tv/T, which plays an important part in the study of the strength of cast iron. This factor is related to the deflection, to the sum of the total carbon and silicon contents, and to the relationship of carbon to silicon in that sum.

In conclusion, the author ventures the hope that by this new view of the factors at work in determining the strength of cast iron some further light will be thrown on the reasons for some of the great differences in mechanical strength in cast irons of apparently similar chemical analysis. The question of impact testing has not been considered in the Paper for the reason that the author does not believe the time has arrived for concluding

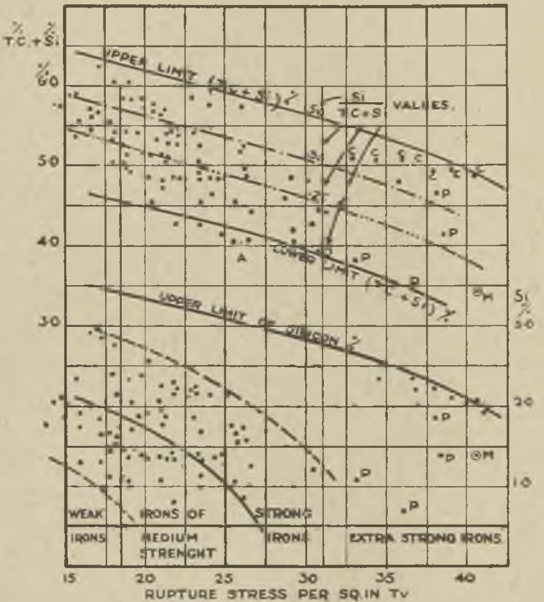


FIG. 5.

that a notched bar of small dimensions (hammered at two opposite sides alternately when broken by a certain number of blows of arbitrarily determined falling energy) can furnish figures which are a true measure of the strength of cast iron, especially when it is realised that the iron has been mutilated by ploughing a groove through what is often the strong envelope of a weak cored metal. The test is of use as a measure of toughness and of resistance to shock in a very approximate sense only, for, as is well known, cast-iron test bars less than, say, 1.2-in. dia. retain casting stresses which in many cases prevent the obtaining of tensile or transverse strength values actually representative of the metal as a whole.

The outer half of the bar area contains the best portion of the iron, and if this is turned off the weaker and often micro-porous metal core becomes the test piece. This trouble is common in the preparation of tensile and transverse bars if too much is tooled off the outside, and is much more serious in the case of impact test specimens. Grey cast iron is heterogeneously fissured by the graphite, and in cast bars the degree of structural homogeneity decreases rapidly from the outside to the inside. If from any cause the cast bar is, during pouring, caused to cool more slowly on one side than on the other, as when a bar is cast on to a larger casting, or if the metal stream hugs one side of the mould, the metal when cold has an irregular structure. Recently a case was examined where two test bars, one cast separately and another cast on to the flange of a large cylinder, gave tensile results showing a difference of 3 tons per sq. in., the metal being cast from the same ladle. The weaker metal showed a mixture of coarse- and fine-grained structures in the broken bar.

This example is typical of the variations in test results so often found in series of similar bars cast from the same ladle, and points to the difference in cooling rate as perhaps the chief reason for the divergences in mechanical strength of material known to have been cast from similar mixtures of like chemical analysis and in moulds of similar size, of the same character, gated and poured in the same manner.

The paramount influence of the rate of cooling of the metal in the mould has not been lost sight of, but the author has purposely avoided touching the many-sided problem involved in the consideration of the variations in strength due to varying thicknesses of a casting.

The present Paper therefore seeks to point out the differences in mechanical strength in castings of about $1\frac{1}{4}$ in. dia., or 2-in. × 1-in. section, having approximately the same cooling ratio $\left(\frac{\text{perimeter of section}}{\text{area of section}}\right)$ All the data given refers to bars or castings of this type (excepting the 1.75-in. thick cylinder referred to in Table V).

In view of the general trend of opinion in regarding a 1.2 or 1.25-in. dia. bar as the most suitable size for an arbitration or standard test for cast iron, the author has drawn his illustrations from and based his conclusions on the results of many hundreds of tests made on bars and castings of similar thickness to that of the bar recommended in the I.B.F. tentative specification and to that standardised by the A.F.A.

The great variations recorded in the many test results on bars less than 1 in. dia. or thickness, even when cast from the same ladle of metal—obviously due to unavoidable differences in pouring speed, casting temperature and cooling rate—point, in the author's opinion, to the undesirability of using bars less than 1.2-in. dia. for the purpose of standard or arbitration tests for grey cast iron.

The author is greatly indebted to Mr. J. T. Goodwin, of the Sheepbridge Coal & Iron Company, Limited, to Mr. J. T. MacKenzie, of the American Pipe Company, Birmingham, Alabama, U.S.A., to Mr. John Shaw, of the Brightside Foundry Company, and to the British Cast Iron Research Association, through the good offices of the Director, Mr. J. G. Pearce, B.Sc., for much of the data used in the preparation of the Paper.

JOINT DISCUSSION ON PROF. PIWOWARSKY'S AND MR. FLETCHER'S PAPERS.

A New Era in Cast Iron.

Mr. T. H. Turner, of Birmingham University, dealing with the subject of the Paper, said he had been instrumental in starting a research on somewhat similar lines about a year ago, and he welcomed the success that Prof. Piwowarsky's preliminary Paper indicated. It was astounding to find a cast iron of 47 or 48 tons per sq. in. tensile strength, though that might not be a commercial matter yet. We might not yet have reached the alloy-cast-iron age in the way that—as Sheffield told us every day—we had reached the alloy-steel age (having passed the ordinary-steel age introduced by Bessemer), but Prof. Piwowarsky and others had shown that, at any rate, we were entering the alloy-cast-iron age. We could make this sort of cast iron, but it would probably be less expensive, for three reasons—its machinability, strength, and resistance to corrosion. It was extraordinary to find that Prof Piwowarsky's cast iron, of 45 tons or so tensile, machined as well as an ordinary one. Diesel engines, aeroplane engines, and machines of that type would call for the greatest strength and resistance to corrosion, and in that connection he mentioned that a Midland firm were making alloys with a still higher percentage of nickel and chromium than that mentioned by Prof. Piwowarsky, as corrosion-resisting material for ordinary purposes. The varying results that had been obtained in Great Britain during the past few years could best be seen in a still later bibliography than that mentioned in the Paper, *i.e.*, that prepared by Dr. Everest and published by the British Cast Iron Research Association this year. Most of the workers who had tried adding nickel and chromium to cast iron had made practically no alteration to the cast iron itself.

Nickel to be Added to Low Silicon Irons.

The advantage of nickel was obtained only when the silicon content was lowered, because silicon and nickel acted in the same direction in that they produced graphite, but the nickel did not produce it so much as silicon. Silicon tended to produce a coarse graphite, and nickel tended to produce a finer graphite, and in some cases, with extraordinarily successful heat treatment, it had given a truly fine graphite—so fine that it could hardly be seen under the microscope. The two alloys, steel and cast iron, must hang together when one bore in mind that one factor, graphite. By various means one could alter the size of the graphite, and that was fundamental in the strength of a cast iron. Every engineering achievement was now attained by the use of alloy steel. Major Seagrave's car was built of nickel-chrome steel or nickel steel; the same applied to Lindbergh's aeroplane engine, so that when we wanted the best strength in cast iron it was essential that we should follow the same movement. The addition of nickel would never be successful unless we reduced the silicon, and he believed also that the best results would be attained with a combination of nickel and chromium, but the proportion must be like that of the alloy steels—the amount of nickel must be two or three times greater than the amount of chromium. Finally, he said that, since the very best results were attained with an alloy steel always after it had been heat treated, Prof. Piwowarsky was proceeding on logical lines in developing not only alloying but heat treatment also. That was not always necessary, however, and for mere machinability the addition of nickel alone, without heat treatment, had been successful.

Dr. P. Longmuir welcomed Prof. Piwowarsky's Paper, not only because of its merit, but also because of the exceptionally good work which had been done in Aachen in connection with both cast iron and steel. Dealing with the author's brief reference, at the beginning of the Paper, to the work done in Germany and in other countries, Dr. Longmuir asked if he would state the method of melting, because a crucible-melted alloy cast iron should not be compared with a cupola-melted cast iron. A good deal of work had been done successfully in earlier days on the influence of what, in Sheffield, were called special elements, but much of that work had not been published. The author had opened out a field of very great promise to the foundry world in the after-treatment of cast iron, including quenching. Some years ago preliminary work was done at Sheepbridge, he believed, by the late Mr. Herbert Pilkington, a Past-President of the Institute, on quenching, with a quenching medium of clay wash, and some very promising results were then obtained. The author had also opened out an interesting field in the study of cast iron by producing a casting with the carbon in a state of combination, thus to a large extent eliminating crystallised graphite. Some very promising work was done by Royston, at Mason College, Birmingham, years ago on quick heat treatment. That work, unfortunately, had not been followed up to the extent that it might have been, but he (Dr. Longmuir) had had the pleasure of repeating some of Royston's experiments at Sheffield University, and of confirming them and carrying them forward to quenching. This work was done on crucible-melted cast-iron alloys. Commercial alloy cast irons, containing combinations of nickel, chromium, and other special elements, were being produced in Sheffield, and the extra expense entailed in producing them was amply justified.

Importance of Factors Other than C + Si Stressed.

Mr. John Shaw said that, although any Paper by Mr. Fletcher merited careful attention, he must confess to a feeling of disappointment with the present one. It was so general in character and was hedged about with so many qualifications that its practical utility was doubtful. The author was apparently obsessed with the idea of reducing everything to graphs and formulæ. His ratio $\frac{Tv}{T}$ might hold good when using the same mixture, and under standard conditions, but if the phosphorus content were increased to any extent a new ratio would be formed. This, for one thing, answered Mr. Fletcher's query with regard to the fact that tensile and transverse test results *so generally* showed differences in the ratio of the ultimate tensile to the rupture stress. Manganese and sulphur were stated to have an influence on strength. If that were admitted, it was necessary considerably to modify the statement that "The higher values of the ratio represent lower tensile strength, the curves showing these higher values as the silicon—and silicon plus carbon—contents are increased. It does not necessarily follow that the deflections of the transversely-tested bars will increase in the inverse sense to that of the rupture modulus-ultimate tensile ratios." The relation of Brinell also needed qualifying, as high phosphorus led to higher readings. The author had then proceeded to build up a theory concerning the dominating influence of total carbon plus silicon, a fact generally admitted, but not to the extent of leaving out the influence of the equally important factors of combined carbon, phosphorus, manganese, sulphur, mould temperature, casting temperature, and the effect of annealing, say, thin jacket cores on structure. One might cast a box of bars of 1, $1\frac{1}{2}$, 2 and 3 in. dia. from one ladle. One would obtain a tensile of 12.9 on the 1 in., 10.84 on the $1\frac{1}{2}$ in., 10.4 on the 2 in., 5.5 on the 3 in. All these bars would have the same total carbon plus silicon and $\frac{\text{Si}}{\text{TC}+\text{Si}}$, but what a difference there would be in the physical result due to the cooling action alone! Mr. Fletcher did attempt to rectify one objection to TC + Si = 5 or 4, in Table III. He had based his conclusions on the examination of castings, and he (Mr. Shaw) was quite prepared to accept the figures and tables for the particular type Mr. Fletcher had examined. On the other hand, most foundrymen had to visualise the effect of the various elements and the casting and cooling conditions before they could calculate a suitable mixture, which even then might be regulated by the stocks carried.

Correlation with American Experiments.

Mr. Fletcher had quoted from Mr. MacKenzie's Paper before the American Foundrymen's Association last year. The list of, roughly, 200 sets of bars, 2 in. by 1 in. by 24 in., warranted anyone's attention. They were tested on the flat. All the moulds were dried, and the bars cast vertically, top pouring being used. He had spent some hours studying the results, in order to see what confirmation of Mr. Fletcher's results they gave. Unfortunately, the tensile results were not taken. He had first collected all results (except very low carbons) that had a high impact value, and had averaged them. In order to find out the influence of phosphorus, he had extracted the high-phosphorus bars and had averaged them. Going a step further, he had taken all high-sulphur bars, except those with high phosphorus. The results are shown in Table A. (See facing page.)

TABLE A.—*High Impact.*

Load. Lbs.	Def.	Imp.	T. C.	Si.	T.C. + Si.	C.C.	Mn.	S.	$\frac{\text{Mn.}}{\text{S.}}$	P.	Brinell.	
3,454	0.39	16.5	3.1	1.6	4.68	1.02	0.47	0.125	4.05	0.35	243	High impact.
2,212	0.27	9.0	3.38	1.54	4.92	0.7	0.42	0.093	4.9	1.86	250	High P.
3,205	0.35	15.9	3.3	1.45	4.76	1.08	0.52	0.152	3.5	0.13	249	High S.
Tensile =		Tons. 12.5	3.35	1.10	4.45	0.55	0.62	0.095	6.5	0.5	138	Bush.
,,		8.16	3.3	1.14	4.44	0.05	0.58	0.101	5.7	0.39	89	Cylinder.

From Table A it would be seen that a high phosphorus lowered the breaking load, deflection and impact value, while there was a slight increase in the Brinell number. The high-sulphur results certainly showed the same characteristics, but to a smaller degree. This raised the whole question of the manganese-sulphur relation. If the whole of the sulphur were in the manganese-sulphur condition, the sulphur could have no effect on the stabilisation of the carbide. From where did the increase in combined carbon arise? This was much more noticeable in some of the bars than the average showed. The T.C. + Si formula took no account of the heated mould or superheated metal.

The Perlit Process.

Mr. Fletcher had mentioned the Lanz process, but it followed that if one ran a fair quantity of hot metal through the risers, one pre-heated the mould and altered the structure. The design of a casting had also a bearing on the structure. In a recent issue of "The Foundry" an example of that was given. Bars cut from the inner liner of a 25-ton jacketed cylinder gave 8.16 tensile, with a combined carbon of 0.05 per cent., and a Brinell of 89, while bars cut from a bush $3\frac{1}{4}$-in. thick, of approximately the same mixture, gave 12.5 tons tensile, with a combined carbon of 0.55 per cent. and a Brinell of 138. There was no doubt that the poor result shown in the cylinder was due to the annealing effect of the narrow jacket retaining the heat for a long time. This had not been allowed for in the composition, but would meet Mr. Fletcher's formula. He (Mr. Shaw) had not said this in any hypercritical spirit, for no one had a higher respect for Mr. Fletcher's ability than he had, but he was quite sure, from the pre-casting point of view, that it was better to deal with each job on its merits. He personally fixed the carbon, phosphorus and sulphur as low as his materials would allow, and let the thickness of the casting determine the silicon and manganese contents to be employed, aiming to obtain a pearlitic structure. Checking this with a chill test before casting was important.

Nickel-Chrome Cast Iron.

Discussing Professor Piwowarsky's paper, Mr. Shaw first complimented the author upon the large and valuable amount of work he had contributed to the improvement of cast iron. He himself had experimented with chromium and nickel additions for the last six years, and could confirm that the additions did not add much to the physical results, as tested, on bars; in fact, if much carbide were present, the material seemed more brittle under the direct shock test. On the other hand, in very heavy sections it appeared that the fine graphitic structure was carried right down to the centre, and in that case, therefore, gave greater strength. He had carried out a certain amount of work on the heat treatment of small castings containing 0.7 per cent. chromium and 0.45 per cent. nickel. It was found that the best results were obtained with a double heat treatment at over 950 deg. C. The Brinell was reduced from 512 to 269. Quenching in water was tried, with another object in view, and 713 Brinell was registered. His directors were now considering plans for the erection of annealing furnaces to deal with some of this work, which promised to branch out in several directions. Professor Piwowarsky's paper was a model of conciseness; every detail was given, and it was possible to repeat the experiments and compare the results. With regard to the piping, he suggested that possibly this was due to the bubbling action of the clay with which the chill was lined. He himself experienced no difficulty in that direction with much heavier sections cast in chills, with lower carbons and silicons, and about the same chromium content, but less nickel. The commercial aspect of castings of this type was the most serious. It was evident that a lined chill could not be applied to many types of casting. To get the structure aimed at in this investigation with composition alone left very little room for error either in analyses or works methods. To obtain the composition in Table 1 even demanded either an O.H. or electric furnace. It was very doubtful if the carbons could be obtained in the cupola with any certainty, even if all-steel charges were used;

certainly the sulphurs could not. To the cost of annealing there must be added depreciation and interest in respect of the furnace. By this time one was approaching steel castings in cost of manufacture. He asked Professor Piwowarsky if he could give any advantage that could be claimed for such castings over a steel casting. That bugbear of the steel foundry, "flying," was also present in attempting to anneal complicated castings of this metal. They must be stripped as hot as possible and placed in a hot oven. To allow them to go cold and then attempt to anneal was nearly fatal, as he knew to his sorrow. These latter remarks, of course, did not apply to the small type of casting dealt with by the author. The salt-bath method might meet the requirements in that case.

German Results Confirmed.

Mr. J. G. Pearce (Director, British Cast Iron Research Association) suggested that perhaps the nearest commercial approach to the line of laboratory investigation followed by Professor Piwowarsky was not a steel casting, but a whiteheart malleable casting. He could not give figures at the moment to confirm Professor Piwowarsky's results, but the Association had done a little work on nickel and chromium additions and chill casting in respect of commercial whiteheart malleable iron. In some tests on the influence of nickel and chromium on commercial white iron of the malleable-pig type they had found that, in the annealed state, additions of from 1 to 2 per cent. of nickel and chromium did definitely give better results; distinctly higher tensile strength, of the order of from 30 to 40 tons per sq. in., was obtained quite easily, and with additions of up to 1.5 per cent. of nickel the bend test was improved, *i.e.*, the ductility of the metal was improved. It was very difficult to compare the ductilities in the two cases, because they had used the bend test and Professor Piwowarsky had used the transverse test. Also, following the proposals of Mr. Fletcher, the Association had experimented on tough malleable iron with nickel and chromium additions, and had obtained some really remarkable results by casting malleable in chills.

That, of course, might not be a commercial possibility at the present moment, but it did fit in very remarkably with some of the work the Association had in hand. Bars were cast in chills and in sand, and annealed under identical conditions. Sand bars bent 45 deg. before fracture, whereas the chill bars gave a perfect bend of 180 deg. and still showed no sign whatever of fracture. Those parallels might be interesting, in view of the similarity of whiteheart annealing and the heat-treatment adopted by Professor Piwowarsky. He asked if the Professor could give the elongations on the large tensile bars. It was difficult to see from the Paper whether the sand cast bars were actually heat-treated. Referring to Table I in the Paper, Mr. Pearce said there appeared to be one or two errors. The total carbon appeared to be about 2.26 at first, and after heat treatment it was 3.03.

Higher Elongation Sought.

Mr. E. R. Taylor, A.R.S.M., F.I.C., said that the method outlined by Professor Piwowarsky, of pouring the superheated iron into chill moulds and subsequently annealing the castings in such record time, appeared to be a very economical means of producing small malleable castings of great strength but of moderate ductility. Such mechanical properties as 47.6 tons per sq. in. when using a nickel-chromium iron, and of 31.7 tons per sq. in. on unalloyed cast iron, were figures far greater than the usual 20 to 25 tons ordinarily obtaining in malleable cast iron. At the same time, the elongations registered, viz., from 2 to 4 per cent., could not compete with the 8 per cent. on 2 in. which was possible with whiteheart malleable. There should be many uses, however, for an iron of such unusual strength, even if the ductility were of a lower order. It was interesting to know that the results given by Professor Piwowarsky compared with those obtained in the malleablising of Emmel iron. Any successful means, however, of increasing the ductility beyond 4 per cent. would add very greatly to the value of the malleable produced. The real advantage of such a process was not so much in producing a super-strong metal as in obviating the necessity for long annealing; hence its possible economy. High-tensile iron was always possible in the production of whiteheart malleable provided the right composition was employed as the base. As an example, by using a high-manganese hematite iron with a composition Mn 1.25, S 0.13, and annealing for the usual period in the case of whiteheart malleable, tensile strengths of 32.5 tons per sq. in. and elongations of 3 per cent. on 2 in. could always be obtained. This composition base metal would anneal to a sorbitic state, as in the examples cited by Professor Piwowarsky. Such high tensile figures as the 47.6 tons per sq. in. obtained in his experiments were remarkable achievements, but any substitute for malleable cast iron required to have good bending properties, of at least 45 deg. in a ⅜-in. thick bar, in order to satisfy the malleable trade. He would prefer to call the product described by Professor Piwowarsky high-duty malleable cast iron, as distinct from the ordinary whiteheart malleable cast iron, because, apparently, it excelled in strength as distinct from bending properties.

Mr. Colin Gresty (Newcastle Branch), discussing Mr. Fletcher's Paper, said it was surprising to him that so very little had been said about combined carbon. In the various analyses given by Mr. Fletcher, by far the greatest variation from the mean was shown in the combined carbon, and yet that was not plotted in Fig. 1, but everything was put down practically to the total carbon and silicon. It seemed to him that, since the combined carbon varied to such a very great extent, at least it ought to be plotted with the other things, because it might be a vital factor. With regard to the total carbon plus silicon basis it should be remembered that this depended always on a certain assumption, namely, that the cupolas were worked so that the saturation of the metal as regards silicon and carbon was complete, whereas he believed he was right in saying that practically all modern cast iron developments with cupola irons depended on exactly the opposite fact, that is to say, the working of cupolas so that the metal was not completely saturated with silicon and carbon.

Commenting on Mr. Shaw's point that Mr. Fletcher had not dealt with the rate of cooling, he said that Mr. Fletcher had explained, of course, that he had deliberately avoided it. He (Mr. Gresty), however, did not see how one could possibly disregard the rate of cooling factor when considering processes such as the Perlit process or any other in which the rate of cooling was, one might almost say, the predominant factor. In the Perlit process the rate of cooling was controlled by the heat of the mould. In other processes superheated iron was used, and he did not think it was right to draw the conclusions which Mr. Fletcher had drawn unless he did take that factor into consideration.

There appeared to be one or two slips in Fig. 2A. For example, Mr. Fletcher referred in the text to the lines FB and GB, and apparently G was at the end of the total carbon line and F at the end of the silicon line instead of on the base line as shown. Mr. Fletcher said that he had found that by drawing the lines FB, GB, the total carbon and silicon contents of strong irons might be taken to vary between 3.0 and 2.6 per cent. and 1.2 and 2.6 per cent. respectively. Immediately following that he talked of the compositions of the strong Perlit, Emmel and Corsalli cast irons, but he (Mr. Gresty) did not understand this because, in his experience of the Perlit process 1.2 per cent. silicon was the top limit for small castings. In his own practice, metal containing less than 0.5 per cent. silicon was often used, and, therefore, it was difficult to find the basis of Mr. Fletcher's statement. Also, from what he knew of the Emmel process he did not think Mr. Fletcher was justified in putting a definite line marked "2" on Fig. 2A as denoting the composition of Emmel iron—in fact it seemed that Fig. 2A was an attempt to confine these special irons to particular compositions whereas in reality they had much wider limits. For instance, line "3" in Fig. 2A showed Perlit iron as having a total carbon plus silicon content of 4.2 per cent., but a study of the Perlit patent specifications would show that provision was made for the total carbon plus silicon content to be from 3.4 to 4.6 per cent.

He would be glad if Mr. Fletcher would explain further these points regarding the special irons. The Paper was not by any means an easy one to follow, and it might be that he (Mr. Gresty) had not correctly understood some of Mr. Fletcher's references.

Ni and Cr Additions for Ordinary Castings.

Mr. J. G. Robinson, Halifax, asked Prof. Piwowarsky if he had any information with regard to the use of nickel-chrome in ordinary grey iron castings, because he understood that it had been used very extensively for that purpose in the United States. An alloy was now being put on the market in this country with the elements balanced—nickel and chromium—and it was claimed that by adding this to molten metal in the ladle in correct proportions it was possible to produce castings with a low silicon and high combined carbon (up to 0.8 per cent.) which did not give a hard skin and thereby cause trouble in the machine shop, but which were easily machinable, had increased strength and wearing properties and a 25 per cent. increase in Brinell hardness tests. The approximate extra cost of such castings would be about a halfpenny per pound. He asked whether Prof. Piwowarsky had found it possible to add such an alloy to molten metal and obtain these results.

Empiricism Stifling Progress.

Mr. Horace J. Young, in a written communication, said that undoubtedly the addition of alloys to cast iron would be the future of improved iron, but commercially the subject was not sufficiently developed at the moment. Mr. Fletcher and himself had done much work on the heat treatment of iron, and it was possible to double its strength without affecting its machining qualities, whilst at the same time the Brinell was greatly increased. With alloy irons the effects would be even greater. That malleablising would take a few hours instead of days would also be possible, and if we had not fallen into the groove of empirical procedure such changes would have come about long ago. There was very much research going on nowadays with regard to alloy irons, and none was welcomed more than that by Prof. Piwowarsky.

Discussing Mr. Fletcher's Paper, he said that, when speaking of bars only 1¼-in. diameter, or of 2-in. × 1-in. section, Mr. Fletcher had stated that the outer half of the bar area contained the best portion of the iron, which, if turned off, left a weaker and often micro-porous core. He had pointed to a case where a test bar cast separately had given a test 3 tons per sq. in. above that of a bar cast on the flange of a cylinder. He (Mr. Young) could point to cases met with in practice where separately cast test bars had given, say, 11 tons, whereas pieces cut out of the flanges (of turbines or cylinders) had given only about 7 or 8 tons. Competent authorities seemed to dread taking the bull by the horns, and he agreed that a nasty, unpopular bull he was. Still, the fact remained that test bars cast separately, when they weighed a few pounds each, and when the castings weighed many tons each, were about as useless and misleading as anything possibly could be. The fiction that because a test bar gave a certain strength the iron in the casting must be good was not worth discussion. As a matter of fact, the best metal for important castings would rarely make good test bars, and would be unsuitable metal if it did. Moreover, we needed to study our iron in the condition in which it was going to be used, and the grain size, the size of the graphite and of the pearlite, and of the phosphide, in a large casting were quite different from those things in any test bar. Wear, heat resistance, corrosive qualities, and so on were affected by these sizes, and it was high time that foundrymen faced the facts and, in the case of heavy and important castings, recognised that test bars cast as such were no longer to be seriously considered.

PROF. PIWOWARSKY'S REPLY.

Mr. T. H. Turner, who acted as liaison officer between Prof. Piwowarsky and the speakers, and interpreted the reply to the discussion, said that Prof. Piwowarsky wanted to say first that he regarded the Paper as of classical value and not of immediate use. It was said that if the research workers were continually trying to get the strongest cast iron they would have to be stopped by the producers, because the latter said that the former were increasing their difficulties, but it was the research worker's job to try to point out the way to do it, even though they did not claim that the producers could do it at once. Prof. Piwowarsky agreed with Dr. Longmuir that we could not compare crucible-melted with cupola-melted cast irons, but pointed out that when, as had happened in some cases, the cupola was connected with an electric furnace, these results were of direct benefit, and could be translated immediately into works practice. Replying to Mr. Shaw, he said that the occurrence of pipes was due to the wrong pouring temperature. Also, in later tests, the phosphorus content had been altered, and by correcting those two factors he had been able to overcome the trouble with regard to pipes. Replying to Mr. Pearce's question as to elongation on large tensile bars, he said the elongation there was nil, because the bars started to fail from the centre. The sand-cast bars were heat-treated. The Professor had noted the error with regard to total carbon in Table I. With the exception of the top figure, it would be found that the agreement was pretty fair, the general rule being that, through carbon being burned off, the second figure to the right was somewhat lower. If one added together the combined carbon and the graphite one would find that they were generally a little lower in the right-hand column than in the left-hand column, because of the carbon being burned away.

Longer Treatment Gives Higher Elongation.

In reply to Mr. Taylor, he said the elongation was low, but that depended upon the length of time of the annealing process. The annealing period was a very short one. If it had been altered from 15 minutes to, say, an hour, it was possible to sacrifice some of the high tensile strength and to get elongations up to 10 per cent., or still more, according to the tensile strength. Replying to Mr. Robinson's question as to whether it would pay to add nickel and chromium to a ladle of ordinary grey iron, he said that, naturally, figures so high as were shown in the Paper could not be so obtained, because the figures in the Paper had been obtained by additions and superheating. The fine graphite structure could be obtained by the superheating, but the addition of nickel and chromium was an everyday commercial proposition on the lines indicated by Mr. Robinson. It was important to point out that the work described in the Paper was not yet finished, and that tests were still going on. For example, the repeated impact test on some of the new metals had exceeded 250,000 blows, and was still going strong.

Mr. F. J. Cook asked what was the weight of blow.

Mr. Turner replied that the weight was 3 kg., on the standard Krupp testing machine.

Mr. Pearce said he gathered that the tests were made with the smallest drop.

Mr. Turner replied that the drop was 30 mm. With regard to bends, Prof. Piwowarsky had not carried out a bending test, but only a transverse test.

Mr. Faulkner said some misunderstanding had probably arisen because the usual German word for "transverse," was translated by the average technical translator as "bending." He did not just remember the different words in German for "bending" and "transverse," but in French "transverse" was "flexion" and "bending" "pliage."

MR. FLETCHER'S REPLY.

In replying to Mr. Shaw, **Mr. Fletcher** said that the difficulty experienced by every investigator of the strength of cast iron was the interpretation of the results in terms of any one variable. The permutations and combinations possible due to the five principal elements carbon, silicon, manganese, sulphur and phosphorus, taking one-tenth of a per cent. of any one element as producing a difference in the physical strength, were of the order of many millions.

As almost every casting cooled at a different rate to its fellow—if its shape or thickness were different or if the casting temperature varied—the combined carbon and graphitic carbon contents were affected and a further addition to the possible number of variations brought about. Where would the investigator be landed unless he narrowed his view to those influences which could be shown to produce the greatest effect on the metal strength? He, Mr. Fletcher, had therefore dealt with similar castings, made under similar conditions, with a definite view to the comparison of the strengths of bars of the same size as suggested in the I.B.F. tentative specification, viz., 1.2-in. diameter, covering approximately the three grades corresponding to ranges in tensile and transverse strength.

It had been shown that, though there were strength variations in irons of approximately the same chemical analysis, the mean results of many tests made on groups of castings indicated that the tensile and transverse strength decreased progressively, as the sum of the total carbon and silicon contents increased, independently of the variation in manganese, phosphorus and sulphur contents — though these play a minor part. Table IV indicated that although the phosphorus varied between 0.33 and 0.95 per cent.; the sulphur between 0.10 and 0.13; and the manganese between 0.45 and 0.77 per cent., the sum of the total carbon and silicon contents was distinctly related to the tensile and transverse strength.

He had warned the readers against basing conclusions on odd tests, and did not admit that the Paper was general in its nature. On closer study it would be found that particular and not general conclusions had been arrived at. He had pointed to the influence of the sum of T.C. and Si contents, but had also shown that the Si proportion in any T.C. plus Si value was important (see Table IV).

He (Mr. Fletcher) would further emphasise the importance of the relationship between the tensile and transverse strength values (Tv/T). The transverse strength was compounded of the compressive and tensile strengths. Hence the ratio Tv/T had very considerable significance. He made no apologies for the use of graphic methods in showing the trend of the T.C. plus C and other influences.

Could Mr. Shaw express the mass of results in any other intelligible way? Only one formula had been quoted—that of Ledebur—and he (Mr. Fletcher) had shown that this was not empirical, but was based on sound scientific research and conclusions.

Mr. Shaw's Table A bears out the author's conclusions, the impact, deflection, and transverse figures being in proportion to the T.C. plus Si values. The cylinder and bush tests were obviously influenced by different wall thicknesses and rate of cooling. To have attempted the influence of variable cooling rates would have made the Paper unintelligible and overburdened with confusing values, but would not have altered the fact that, under similar cooling conditions and casting temperatures, tests taken from the same position in similar castings would show that the highest strength values are inversely proportional to the total carbon plus silicon contents of the metal. This proportionality, as explained, is not a definitely arithmetic or geometric one, but is influenced by the remaining constituents.

The Paper has not, for obvious reasons, dealt with cast irons cast in specially hot moulds, the cooling of which castings affects the carbon and silicon relationship seriously; but even in Perlit castings, a high T.C. plus Si content is associated with lower tensile strengths, whilst a low T.C. plus Si content is generally coincident with high strength valves. The author recognises that, whilst the composition of a particular Perlit iron is shown at line 3 in Fig. 2A, there is a much wider range for such irons, though these are bounded by the lines marked T.C. line and Si line when extended. Mr. Gresty is correct in assuming that point G is at the end of the total carbon line and point F at the end of the silicon line. It might interest Mr. Gresty to know that much lower silicon percentages than 1.2 have been found in Perlit castings examined by the author (down to 0.5 per cent.). Fig. 2A was not prepared with a view to illustrating special irons, but only as graphically showing the basis of Ledebur's formulæ.

If Mr. Gresty could give the Institute the results of tensile and transverse tests on Perlit irons of varying total carbon and silicon contents such information would be of great interest and value. In this connection the effect of combined carbon content would possibly be more important than in the case of the tests described by the author.

THE MANUFACTURE OF A LARGE STEEL CASTING.

By F. A. Melmoth (Member) and T. W. Brown (Associate Member).

The writers propose in the following Paper to outline the complete history of the production of a large steel casting, and have chosen as their subject the case of a cast steel propeller shaft bracket. They propose to deal with each of the operations entailed in its production, both metallurgically and from the moulding shop standpoints, and to express their reasons for the choice of any particular method where alternatives exist.

The production of any steel casting falls naturally into the performance of the following operations, taken in their order of sequence:—(1) The manufacture of the necessary steel; (2) the preparation of the sand; (3) the making of the mould and cores; (4) the actual casting of the job; (5) the annealing; (6) the fettling, and (7) inspection and testing.

It is not the intention of the writers to deal with the making of the pattern, and it is assumed for the purpose of the Paper that this is provided. Fig. 1 shows the pattern as received ready for work in the foundry.

The Manufacture of the Steel.

The processes open to the steelmaker which are capable of producing steel suitable for the job under discussion are three in number:—(1) Siemens open hearth; (2) converter; and (3) electric. The main points appertaining to each process are appended.

Siemens Open Hearth.

In this process the necessary pig-iron and scrap steel to constitute a satisfactory composition in the molten charge are melted together on either an acid or basic hearth, this depending on both the composition of the materials available and also the nature of the desired product.

In the case of the acid hearth, the existence of a necessarily acid slag permits no possibility of

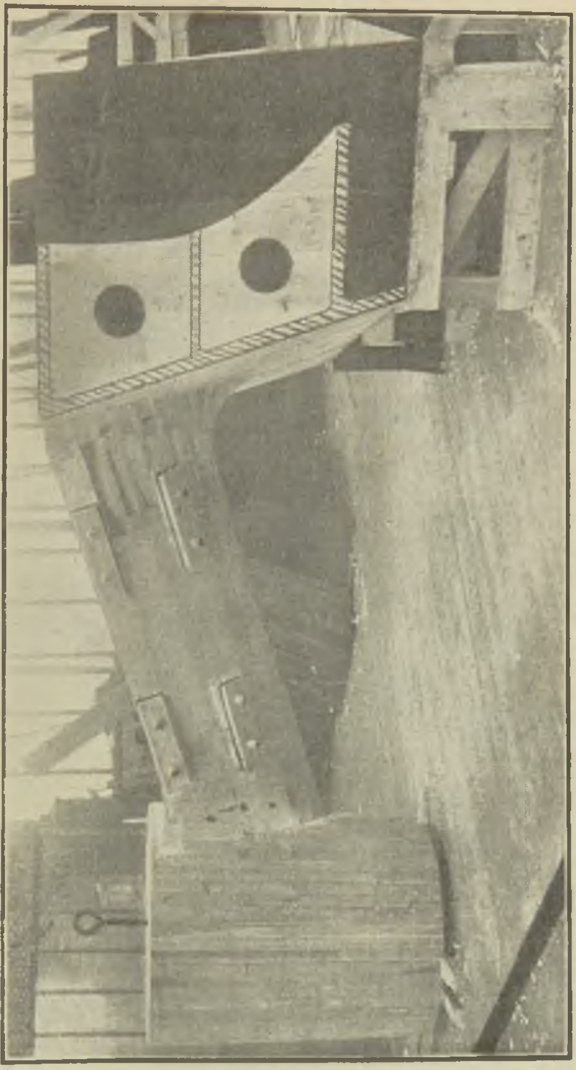


Fig. 1.—Pattern as Received.

refinement where sulphur and phosphorus are concerned, and, therefore, the raw material used must be of the required degree of purity in these two elements. The basic slag used on a furnace equipped with a basic lining, however, aids the possibility of the abstraction, during the process, of a certain amount of these elements, and, therefore, a greater degree of latitude can be allowed in their existence in the original scrap and pig-iron. In this country, acid lining is the more popular, and has been developed to a much greater extent, due probably to the ease with which low sulphur and phosphorus pig-irons can be obtained, and partly due to the generally accepted idea of the superiority of the resulting steel when made by the acid process. The writers do not feel qualified to deal with any serious discussion on the question of this superiority, but there seems little doubt but that the acid process is the more popular and probably the more consistent in its product, whilst possessing in a marked degree an elasticity which makes the production of a wide range of compositions of steel an every-day occurrence.

Procedure When Making a Steel Casting.

The scrap and pig-iron are melted down as quickly as possible, and also as hot as possible. To the resulting molten bath, iron ore is added, which through the agency of the slag oxidises manganese and silicon with their consequent removal to the slag. These elements being removed, the iron ore acts directly upon the carbon present, removing it in the form of carbon monoxide gas, which, escaping in bubbles through the layer of slag, causes the well-known phenomena known as the " boil." This is continued by the addition of the necessary amounts of ore or limestone, or both, until such times as the carbon content is reduced to the neighbourhood of the required figures.

During the whole of the process, the direction of the gas and air through the regenerating chambers and the furnace is frequently reversed, thus building up continually the initial temperature of the incoming gases, with a consequent increase in the temperature produced by their combustion. The slag being in the correct condition, the temperature sufficiently high, and the carbon content near to the required figure, de-oxidising alloys, ferro silicon and ferro manganese, are added to the bath in calculated amounts to remove active oxide, and leave in the steel the amounts called for in the specification. The steel is then tapped into the ladle and poured in the usual way.

FIG. 2.—MOULD READY FOR CLOSING.

The writers recognise that this is an extremely sketchy description of what is in itself a highly skilled and complicated process, but the scope of such a Paper as the one now submitted will not allow of a detailed description of any steel-making process.

Main Characteristics of Siemens Open Hearth Metal.

(1) It can be produced in large charges, and is, therefore, ideally adapted for large, heavy castings; (2) it is under complete control both chemically and in temperature, and therefore specification work can be rigidly adhered to; (3) the temperature obtainable being on the low side as compared with electric or converter processes, coupled to the fact of the large charges usually made, makes the process not so suitable for small work; (4) produced under properly controlled slag conditions, the steel is remarkably free from non-metallic inclusions, and is of consistently high quality; and (5) the process is capable of satisfactorily producing quite a wide range of alloy steels.

The Converter Process.

In this process a quantity of molten cast iron, previously melted in a cupola, is subjected to the oxidising action of a blast of air. The air can be applied either from the bottom, thus passing through the molten metal, or at the side. In either case, the process of operations is identical. The manganese and silicon, and finally the carbon, are oxidised by the air, with the production of a great amount of heat. The blown metal is therefore raised to such a high temperature that, after the addition of the necessary de-oxidisers at the termination of the blow, it is sufficiently hot and fluid to cast the lightest of sections.

No refining is possible from the point of view of sulphur and phosphorus content when the vessel is acid lined, which is the usual practice in this country. It must be remembered, therefore, when selecting the irons used for this process that an increase, particularly of sulphur, will occur due to the cupola melting prior to the blowing operation.

Advantages of the process are:—(1) The steel is extremely hot and possesses in a high degree the property of fluidity, so valuable to the maker of light castings; and (2) the very rapid production of the steel compared with any other process inevitably means some reduction in cost, and is of great assistance particularly where repetition production methods are in progress.

The disadvantages are:—(1) The steelmaker is at the mercy of his scrap and pig-iron supply, as no refining is possible; (2) the vital point at the termination of the blow can only be determined consistently after considerable practice, and the regularity of the required compositions is, therefore, not so great as is the case in either open-hearth or electric processes; and (3) the total weight per charge is limited, and is usually insufficient for heavy castings. This necessitates blowing more than once when a heavy casting has to be made with consequent risk of trouble and failure.

The Electric Process.

From the point of view of reliability and consistently high quality, the production of steel from electrically operated furnaces has met with almost universal approval. Although the latest comer into the foundry field, its merits have won for it a high place as a means of satisfying the somewhat exacting steel requirements of the modern foundry.

Furnaces are available either basic or acid lined, and in the case of the former the composition of the scrap material used is, within wide limits, almost negligible. By correct slag manipulation, impurities can be removed almost to traces, and the simplicity of the process makes it easily possible to produce steels of almost any composition with great regularity. It is admitted that the future of the furnace for such steels as are the normal products of a foundry, depends greatly on a cheap supply of electric power.

A Typical Charge.

It is assumed that the scrap or turnings available are of medium quality, and that a certain amount of refining is necessary to bring sulphur and phosphorus within the specification limits.

The scrap and turnings are charged on to the hearth in the order named, the obtaining and maintaining of a steady arc being more easily effected on the turnings than would be the case were an arc to be struck on bulky masses of scrap steel. By bringing the electrodes into close proximity to the charge, an electric arc is formed between the electrodes and the metallic charge. This arc is maintained as continuously as possible, by the careful regulation of the distance between electrodes and charge, until such time as pools of liquid metal are formed under the electrodes.

From this point the control of the load becomes an easier matter, and after the addition of the required amount of lime to form a covering slag, the power input is maintained at as high a figure as possible until the charge is practically completely melted. Any small amounts of unmelted metal adhering to the banks are then pushed into the bath.

The scrap and turnings commonly possess a sufficient covering of rust to make it tolerably certain that when melted, almost the whole of the carbon, silicon and manganese will have been oxidised. The slag will be definitely oxidising at this point, and in these conditions phosphorus is removed by oxidation from the molten bath and passes to the slag. The removal of this slag, therefore, at this point, ensures that refinement in this element is established. Melting by this method, and with no special additions to maintain a high carbon on melting, the composition of the metal at slagging will probably approximate the following:—Carbon 0.06, Silicon 0.04, Manganese 0.08, Sulphur as charged, and Phosphorus 0.015 per cent.

It will be seen, therefore, that sulphur is the only ordinary element remaining unaffected up to this point. This is due to reducing conditions being a necessity for the removal of sulphur, whereas the former oxidising conditions only satisfactorily accounted for the carbon, silicon, manganese and phosphorus. The reduction of sulphur being desired, it is necessary, therefore, for the oxidised character of the metal to be now removed. A new slag is formed by the addition of lime and fluorspar, the latter lowering the slag fusion point and quickly giving a fluid covering of slag to the metal. The oxidised condition of the bath is removed by small successive additions of ferro-silicon, and at the same time the character of the slag is rendered somewhat reducing by small quantities of crushed anthracite or coke. A continuance of this will produce a steel free from wildness, and under the reducing slag sulphur is removed from the steel, passing into the slag as a sulphide. Carried to the point of what may be

Fig. 3.—Casting as Received in Fettling Shop.

termed super-refining, the slag will, on cooling, definitely fall to a greyish powder.

Tests are taken both for analytical purposes and for temperature, the required additions of ferro-silicon and ferro-manganese, etc., are added to the furnace and the steel poured into the ladle.

Where a high degree of freedom from sulphur and phosphorus is not called for charges can be made quite satisfactorily under one slag only, and it is the opinion of many experienced steel makers that made thus, electric steels possess an increased degree of fluidity, making them much easier to handle in the foundry. Economically, however, very great advantages exist in single slag working as total time per charge is lessened, heat losses during the slagging period are avoided, and slag materials are used in less quantity.

The liability to dangerous variations in the quality of the raw material, more particularly the turnings, makes it somewhat risky, however, to adopt single slag working, unless the origin of the scrap and turnings is definitely known and controllable.

From the rather meagre outline of these processes, perhaps sufficient can be gathered to appreciate their applicability to such a job as the casting which forms the subject of this Paper. In the first place, a converter was not available in the particular shop in which the casting was made. As about 12 tons of steel was needed to cast the job satisfactorily, the writers would, in any case, have hesitated to use the process. Quite apart from the difficulties associated with blowing twice for the one job, the specified tests were of such a high order that nothing but steel of the very highest quality could be contemplated.

It therefore resolved itself into a decision between open hearth and electric steel, both of which were available in ample quantities to cast the job. From the point of view of general suitability, the writers are of the opinion that either would give satisfaction, always with the proviso that pig-iron and scrap of known high quality were used in the open-hearth furnace. Economically, the balance is definitely in favour of the open-hearth process by which steel can be

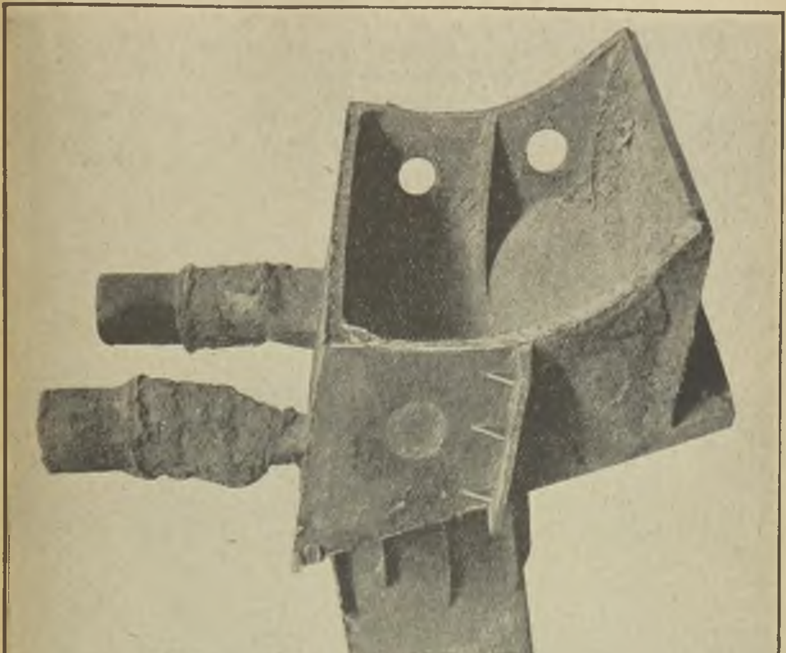


Fig. 4.—Casting as Received in Fettling Shop.—Opposite Side to Fig 3

produced at present at a lower figure than by electric methods.

Circumstances at the time of casting, however, made it necessary to use electric steel for this casting, and in considering test results, etc., it should be remembered that they represent those obtainable from such a casting made from basic electric steel.

Composition of Steel.

Having decided on process, the question of composition requirements now only remains to be dealt with. In considering this, the physical requirements demanded by the inspecting authorities are naturally the controlling factor. For this class of work the test requirements are normally as follows:—Maximum stress 28-35 tons per sq. in., yield point 14-18 tons per sq. in., elongation 20 per cent. minimum, and bend (cold) 90 deg. on 1 in. square.

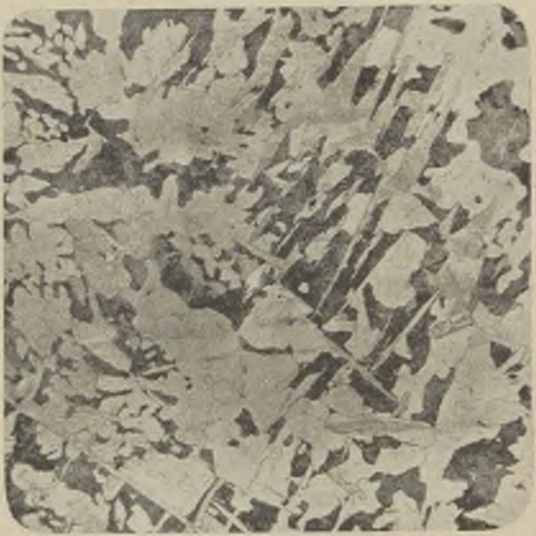


FIG. 5.—STEEL CASTING AS CAST × 50.

The influence of the various elements on the physical test results of the annealed casting is as follows:—

Carbon.—Increases maximum stress with increasing quantity, and coincidently reduces ductility, and therefore elongation and cold bend results.

Silicon.—No appreciable effect in the normal quantities found in commercial mild steel for castings. Is present almost entirely as a deoxidiser to ensure soundness.

Manganese.—Tends to increase maximum strength and yield point, without seriously affecting the ductility if present in the usual amounts. Over 1.2 per cent. tends to reduce elongation to some extent. Is also an effective deoxidiser, and assists soundness very considerably.

FIG. 6.—STEEL CASTING AS CAST × 200.

Sulphur.—An accidental impurity, and detrimental in many ways if in excess—0.05 to 0.06 per cent. being looked upon as upper safe limits. In excessive amounts induces red shortness, and may be the cause of cracks and tears by causing intercrystalline weakness. The amount of manganese present acts as a partial corrective, by forming manganese sulphide, and thus preventing the formation of the extremely detrimental sulphide of iron. From all standpoints best kept within low limits. Maximum stress, yield point, elongation and bend are all badly affected by excess.

Phosphorus.—This element is regarded with great suspicion by steel founders, owing to its tendency to produce cold shortness when in excessive quantities. Maximum stress and elongation may be but little affected after annealing, but impact tests may be badly affected. The safe upper limit is regarded to be 0.05 per cent. to 0.06 per cent.

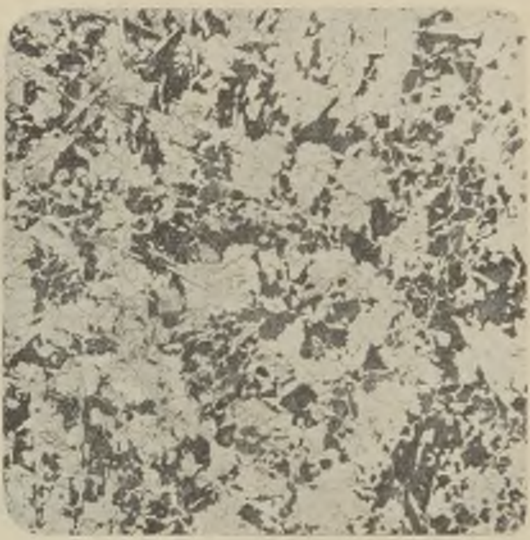


FIG. 7.—STEEL CASTING ANNEALED × 50.

Bearing in mind the previously mentioned test requirements, and the effects of composition in the various elements above described, it was decided to make the steel to the following:—Carbon, 0.25 to 0.30; silicon, 0.15 to 0.25; manganese, 0.6 to 0.7 per cent.; sulphur, low; phosphorus, low.

This was produced in an electric furnace of the necessary capacity, and the resulting material analysed as below:—Carbon, 0.26; silicon, 0.18; manganese, 0.56; sulphur, 0.017; and phosphorus, 0.022 per cent.

Sand Preparation.

The main requirements of a moulding sand for such a casting as the one being considered are:—

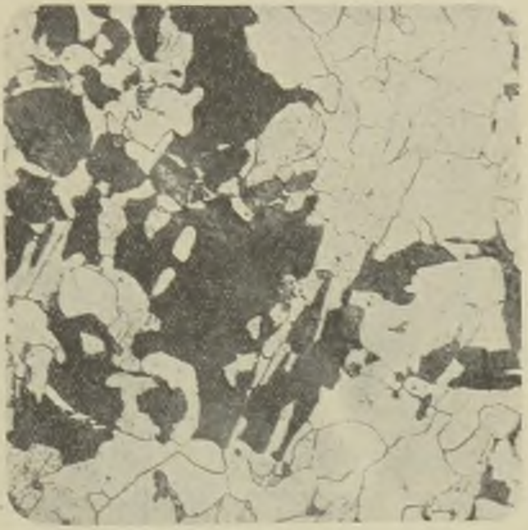


Fig. 8.—Steel Casting Annealed × 200.

(1) It must be sufficiently bonded to make a good, firm mould, able to resist the erosive action of the large quantity of steel which necessarily flows over it; (2) it must be sufficiently open, although strong in bond, to permit of the easy egress of gases produced during casting; and (3) it must be of such a composition that it can bear without serious fusion the high temperature of the steel with which it is in contact, bearing in mind the

length of time such contact takes place and the weight of liquid steel superimposed upon it.

The normal moulding sand, with a silica base, and bonded by any of the usual materials, does not, in the writers' experience, fill the whole of these requirements satisfactorily. The usual material for such heavy castings is some form of moulding composition. These moulding compositions can be obtained from many of the suppliers of foundry materials, ready mixed for use. In many cases, however, they are made up by the foundries themselves, from mixtures which are the result of many years' investigation and trial. Such mixtures are often very jealously guarded, and it must be accepted that such an attitude is quite comprehensible when the importance of the effect of composition regularity and the correct balancing of its various constituents to meet the above outlined requirements are recognised.

In the manufacture of large castings, the risk of failure involves such a heavy loss that too much care can hardly be taken to ensure a satisfactory moulding composition. Careful selection and examination of each and every one of its component materials is highly necessary. The accidental introduction of some material of easy fusibility, for instance, can be attended by such dire results as to make the after fettling of the casting a commercial impossibility.

The base materials of composition are more or less identical, the variations usually being in the nature of varying quantities. Burnt bricks of good quality—firebrick and silica, probably a proportion of used crucible pots—the requisite amounts of good sand, the whole being carefully milled and mixed, and then bonded with the highest quality fireclay, represent the usual schedule of materials from which steel moulding compositions are made up. The presence of a percentage of crushed coke to assist porosity is also common practice.

The Making of the Mould.

Many points require careful consideration before the moulding itself is commenced. It is assumed that all the necessary details on the character of the pattern have been satisfactorily settled, and that it is supplied ready to go into the sand.

The greater part of the mould for the job under discussion being in the floor, it is necessary to decide on the most suitable position in the foundry. The character of the floor, ease in handling and casting facilities, must all come up for the required degree of consideration. In some foundries pits are actually available permanently in the floor, and for some cases this offers decided advantages.

Where this is not the case, a hole of the required size is taken out, and the pattern, supported on loose brick pillars, is placed into it in the actual position of casting. The pattern is then removed and old sand is rammed into a bed approximately to the shape of the brick supports previously mentioned, but about six inches lower all over.

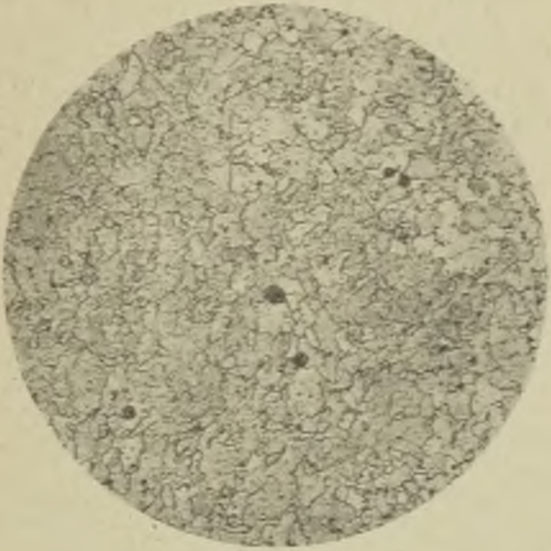


FIG. 9.—WELD METAL × 200.

On this sand bed old firebricks are then placed, covered with a layer of well burnt ashes. This ensures a free passage for the gases formed during casting, through the bottom part of the mould.

The ashes are covered by a layer of old sand; the pattern is then replaced allowing about 1½ in. clearance, which is rammed up with the prepared facing composition, previously referred to.

On a job of this character thorough drying is an essential, and during the moulding operations the getting of heat to all parts of the mould must be considered and allowed for. It was, therefore, so arranged as to allow of some parts of the mould being easily lifted out. This served a double purpose, as this particular mould was dried by the building of a fire actually in the mould itself, and not by one of the patent dryers now often used. The lifted-out parts arranged for, therefore, not only permitted of a suitable fire being used, but also opened out the mould so completely as to facilitate its removal and the thorough cleaning of the mould. The lifted away parts were, of course, taken away and suitably stove dried.

A decision being arrived at on this point, the sides and ends of the mould can be proceeded with. Facing composition to a thickness of one and a half inches, backed up by used sand, supported in turn by old firebricks, is rammed up in successive layers. The old bricks are carefully spaced, the spaces being filled with ashes, and suitable vents are led to these, as required. This progresses until the pattern is rammed up to the top, the drawbacks being suitably jointed and built up in the same manner. The joint for the top part is then made and the top rammed up in the usual fashion.

As with all castings, one of the most important points in this one is the position and manner of running. A reference to the photograph of this pattern will show that each end is much deeper than the centre portion. Casting from both ends simultaneously, therefore, will mean that the ends will fill first, during which time the steel is rapidly cooling. By the time these two portions are filled and meet one another, the probability is that the advancing edges of the molten steel are so cold as to introduce the possibility of an imperfect union. A weak plane will result, and such a casting being under severe contraction stresses, fracture is not at all improbable.

It was decided, therefore, to cast from one end only. Previous experience had demonstrated that the most satisfactory results were obtained when running was from the boss or larger end. This is in favour of satisfactory casting and feeding.

It will be noticed that the variation in section in this casting is in the form of a progressive reduction from the boss end. To ensure efficient feeding, therefore, one should aim at conditions which produce as nearly as possible a progressive reduction in temperature during solidification from boss end to the end of the palms. By running into the boss such a state of affairs is established; the last and hottest metal, when the casting is full, going into the large riser on the boss. A feeder head of sufficient size satisfactorily to feed this large boss is attached, and the efficient feeding of the boss being ensured the liquid pressure from the heavy end will be found sufficient to make it certain that satisfactory feeding of the rest of the casting takes place during solidification. It is, of course, essential that the riser is the last place to solidify, and it will be seen that in this case this state of affairs is almost ideally present. A reference to the photograph of the unfettled casting (Fig. 3) will still further emphasise this. In the casting shown, the head is approximately 36 ins. above the main level of the casting to ensure a satisfactory pressure and consequent feeding during solidification.

All these points being attended to in the manner stated and the mould and drawbacks being thoroughly dried, the latter are replaced in their respective position, cores inserted and the mould closed in the usual manner (Fig. 2).

In the light of previous experience, any tendency of the top part to lift during casting is counteracted by weighting it down to the necessary extent, and the mould is ready for casting.

After the pouring operation, it is customary in some foundries to attempt to assist contraction by liberating at as many points as possible. The writers are of the opinion that much of this only amounts to wasted effort.

Careful examination of a succession of what are known as contraction "pulls" convinces them that the defect takes place almost at the moment of solidification. Further contraction in the solid form may undoubtedly enlarge or extend such a defect, but it appears rare that a " pull " should take place at a later stage in the cooling period. A crack due to unequal cooling is a possibility, but this is usually due to a desire to hasten matters by stripping the casting too soon. These cracks or " clinks " as they are called, are more likely to occur in the harder types of carbon steels or in alloy steels than in the soft material used for the casting being discussed in this Paper.

Assuming that the writers' opinions are correct, that contraction "pulls" are a defect definitely originating at the moment of solidification, then it logically follows that the correct thing to do is to take such steps during the moulding and core making as will reduce the resistance of the cores and mould to a minimum, and not to rely on the after liberation of the solidified casting for this purpose. Judicious liberation to prevent possible distortion is quite another matter, and a lot can be done in this direction to assist the keeping of the casting in shape.

Annealing.

A sufficient length of time having elapsed to ensure the cooling of the casting to a point at which no danger of fracture exists, it is withdrawn from the mould and moved forward to the annealing operation. Before this operation, it is roughly trimmed and the greater part of the adhering masses of sand removed. Figs. 3 and 4 show the casting in this condition.

The annealing process is designed to perform two very important functions:—(1) By the complete recrystallisation of the steel from a point just above its upper change point, to remove the coarsely crystalline, and therefore weak, structure caused by its cooling from liquid temperatures in the mould; and (2) to remove as far as possible the various strains set up during cooling in the mould, both from the resistance of the mould and from the effects of unequal cooling due to varying section.

The performance of function (1) can be ensured by heating the casting to a temperature of 850 to 900 deg. C., and maintaining it at that temperature for a time sufficient to allow of equilibrium of temperature in all parts of the casting.

At this temperature the crystalline ferrite of the coarse "as cast" type, shown in micro-photograph Fig. 5, enters into mutual solid solution with the eutectic pearlite and on cooling is re-crystallised, but with a degree of fineness somewhat proportionate to the temperature to which it has been heated.

Function (2) is one associated with cooling and to remove strains in such a casting it is necessary that it should be cooled both slowly and evenly. Any departure from this may leave the casting almost as badly stressed as before annealing, strains being set up due to unequal speeds of cooling on parts varying in section.

Severe drop tests, to which such castings are subjected, may show up this disastrously. Careful support and packing in the furnace is found to be very necessary for such a job, and in every way steps are taken to ensure that distortion or sagging is prevented. Should such distortion appear in the casting as it comes from the mould. a great deal can be done by careful manipulation at this point to bring it back into the required shape again.

The influence of correct heat treatment on the physical properties of the material is very marked, and a reference to the table of tests will show that a great improvement is apparent. A comparison of the test figures with the micro-photographs Figs. 5 and 7 will make the reason for this improvement at once obvious. It will be seen that as the correct performance of function (1), *i.e.*, the re-crystallisation of the steel involves perfect solution of its ferrite and pearlite constituents, a time factor becomes operative. This is controlled principally by the size of the casting and the thickness of its section.

Violent heating up in the early stages of the annealing process may cause either distortion or fracture, or perhaps both, by the production of sharp variations of temperature between thick and thin sections. It is important, therefore, that the temperature is so controlled that all parts of the casting are heated as evenly as is practically possible. The temperature required being reached, it is then necessary to maintain it for such a period as will ensure the complete solution of the coarse "as cast" crystalline arrangement.

As previously stated, thickness of section is largely the controlling factor, and in such a casting as the one being considered, the soaking period is approximately 12 to 15 hours.

The influence of cooling speed is considerable, but in the case of a large casting, particularly with varying section thicknesses, it is not possible seriously to affect the metallurgical properties by quick cooling, owing to risk of fracture. In the case of smaller or plain castings very marked improvements are noticeable by subjecting the castings after reaching annealing temperatures to a quick cooling, either in air or some suitable liquid medium, with subsequent reheating to a lower temperature to remove any induced stresses.

In the case of the part forming the subject of this paper, however, efforts must be made to ensure, as far as possible, the equal cooling speed of its varying sections, and this can only be done by slow cooling. It is consequently cooled right down at a slow rate in the furnace, and is not exposed to the air until the temperature is so low that all danger of uneven cooling and risk of fracture is well past.

Fully to appreciate the effect and significance of the annealing operation it is necessary to study the physical properties before and after annealing together with the micro-photographs. The micro-photograph shown in Fig. 5 is at 50 dias., and shows the structure as cast. Fig. 6 is the same, but at 200 dias. Micro-photograph Fig. 7 is of the annealed casting at 50 dias., whilst Fig. 8 is the same at 200 dias.

The tensile test results before annealing were: Maximum stress, 29.8 tons per sq. in.; yield point, 15.0 tons per sq. in.; elongation, 14.0 per cent. on 3 in.; and reduction of area, 18.58 per cent. After annealing this became: Maximum stress, 31.2 tons per sq. in.; yield point, 16.6 tons per sq. in.; elongation, 26.5 per cent. on 3 in.; and reduction of area, 31.58 per cent.

The cold bends were respectively 87 and 180 deg. unbroken, before and after annealing.

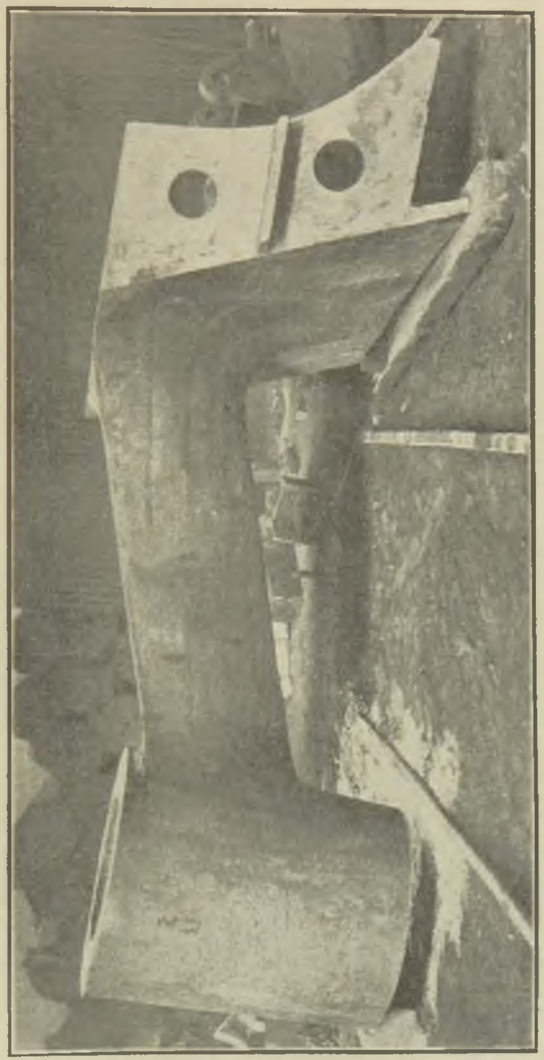


FIG. 10.—FETTLED CASTING.

As a matter of interest, and still further to demonstrate the benefits of the annealing process, impact test pieces were cut from both unannealed and annealed test pieces and broken by the Izod method. The results obtained were: *Unannealed*—18 ft. lbs. (average of two bars); *annealed*—32 ft. lbs. (average of three bars).

It will be seen, therefore, that the summarised effect of annealing on this casting is: (1) It has increased the yield point by approximately $1\frac{1}{2}$ tons per sq. in.; (2) it has raised appreciably the tensile strength of the material; (3) the ductility of the steel, as shown both by elongation and bend test results, has been practically doubled; and (4) the resistance to shock impact of the material, an extremely important feature, has been increased by about 78 per cent.

An examination of the fractures of the broken tests showed, as would be expected, that the as-cast samples were coarsely crystalline, whilst the annealed ones were fine and silky.

A comparison of micro-photographs Figs. 5 and 7 demonstrates that the coarse, strongly latticed and angular arrangement of structure associated with mild steels in their cast condition, has been replaced by a more even and finely-graded structure almost free from pronounced angularity.

Welding.

It sometimes happens that it becomes necessary on such large castings to obtain permission for the welding up of surface defects. The influence of this welding operation, and its value as a means of repairing or improving the external appearance of a casting, has been often discussed, and very often unfavourably. The progress of the art of welding, and the tremendous increase in its possibilities of application, due to this advance, have altered the situation, in the writer's opinion, to a great extent. It is now possible with modern plant to undertake very ambitious structural welding problems, and whilst welding, from a foundry point of view, is never likely to call for such big jobs, the progress along engineering lines does undoubtedly reflect itself on welding operations upon castings. The vast majority of welding cases occurring in a

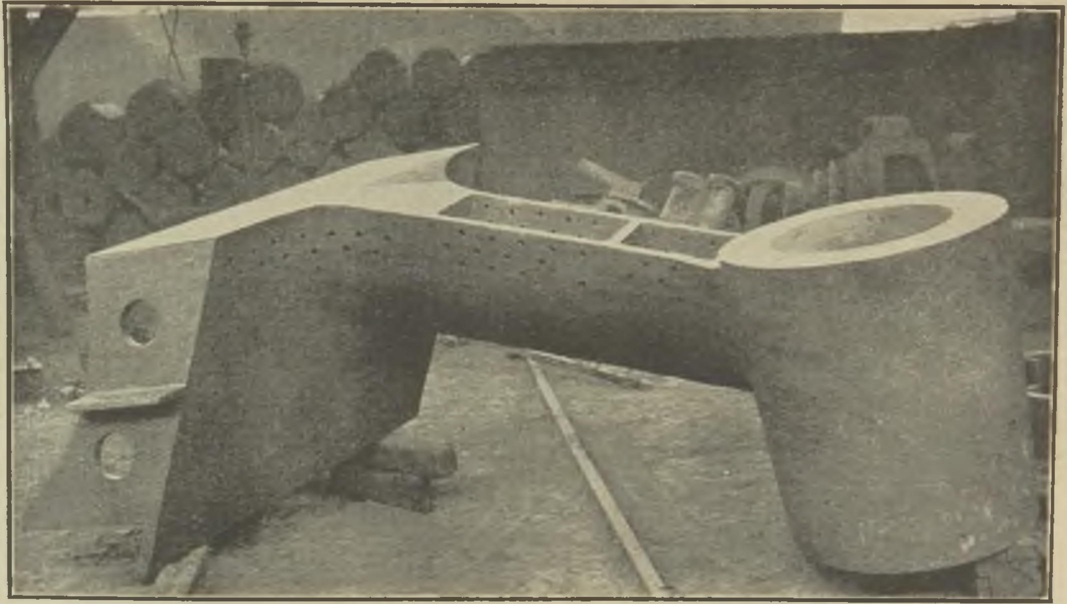


FIG. 11.—FINISHED CASTING.

steel foundry are purely matters which affect the appearance of a casting, and there appears no logical reason why such defects should not, by careful workmanship, be made perfectly good in this manner.

With a view to obtaining some actual data under workshop conditions, the writers have, on occasions, carried out observed tests on welding of cast steel. Bars have been taken representing normal foundry product, and after cutting into two, have been then welded together electrically, the resulting bar being machined and pulled for tensile strength.

They are satisfied that even under shop conditions a well-made weld possesses almost the strength of the original casting, together with a good degree of ductility. Two typical tests are as follows: (1) Maximum stress, 30.0 tons per sq. in. and elongation, 11 per cent. on 2 in.; (2) maximum stress, 29.5 tons per sq. in., and 13.2 per cent. elongation on 2 in.

Whilst admitting that very perfect welds are made by the oxyacetylene process, the writers are of the opinion that for steel foundry purposes electric welding possesses marked advantages. The welds are sound and very quickly produced, whilst the effect on the casting is more local and less likely to produce distortion.

For detailed information of a highly interesting character referring specifically to welding as applied to castings, the writers would refer the reader to a Paper given by Engineer-Commander Jackson before the Sheffield Branch of the I.B.F. on January 24, 1919. In this Paper a number of practical cases are quoted which prove both the value and efficiency of the process even eight or nine years ago. Since that time improvements have continually taken place, both in apparatus and the manufacture of welding rods, and it is safe to say that to-day welding is a most reliable and useful method of repairing steel casting defects, when such defects are of a type justifying repair.

The essential point which should be stressed is that of careful preparation. Absolute cleanliness is vital to the success of the weld, and any attempt to weld an unsound or dirty surface

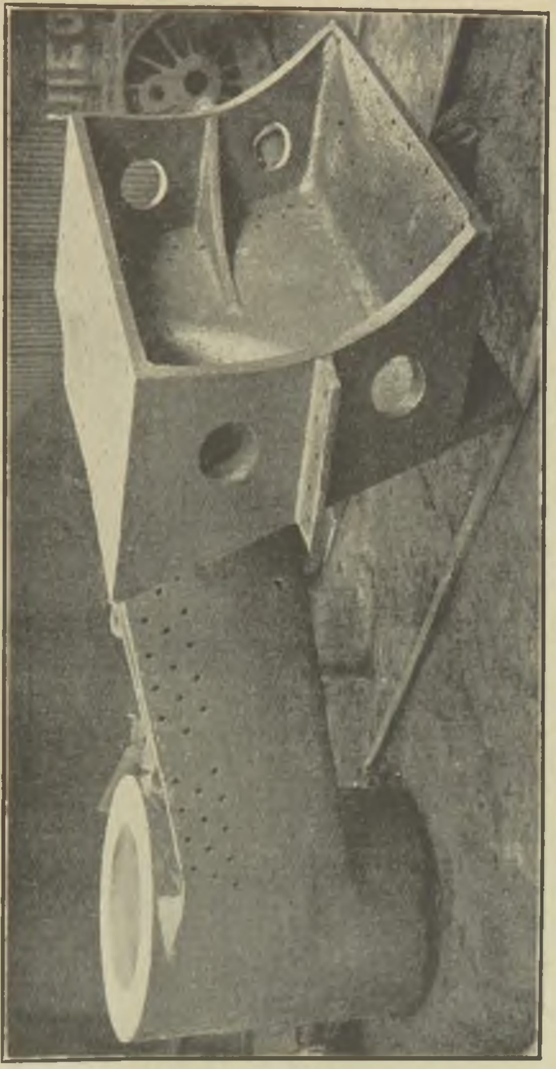


Fig. 12.—Finished Casting from the Opposite Side to Fig. 11.

merely results in a deposit of a porous and weak character.

Fig. 9 shows the actual microstructure of the weld metal in one of the test cases previously referred to, and is taken at 200 magnifications.

Inspection and Testing.

Such castings as the one forming the subject of this Paper are almost invariably under the inspection of one or more of the important testing authorities, and the final examination is of a very severe order. They must in all cases be free from external or internal defects likely to weaken the castings in any way, and the material specification must be rigidly adhered to.

The normal physical requirements are as follows: Maximum stress 28 to 35 tons per sq. in.; elongation, 20 per cent. minimum on 2 or 3 in.; and cold bend, 90 deg. minimum on 1 in. sq. bar over $1\frac{1}{4}$ in. rad.

In addition, a final drop test is applied in which the casting is dropped bodily from the specified height on to a sound floor. Such a test, by applying suddenly severe shock and vibratory stresses, is most likely to show up any hidden points of weakness which may have escaped previous notice.

Having withstood satisfactorily the various material tests and been pronounced free from distortion and visible defects, our casting is then ready for the machine shop. Fig. 10 shows the casting in this condition, and Figs. 11 and 12 illustrate its final appearance, machined and ready for despatch.

The writers, in concluding, desire to record their thanks to the directors of Messrs. Thos. Firth & Sons, Limited, for permission to submit material constituting the Paper, and also to the director of the Brown-Firth Research Laboratories for valuable assistance with the micro-photographs.

DISCUSSION.

Alternative Moulding Method Described.

Dr. P. Longmuir (Sheffield), who referred to the Paper as being of a type which was of very special interest to a Sheffield audience, heartily congratulated the authors on their very clear presentment of the making of a fairly heavy and intricate casting. The metallurgical part of the Paper was so good that one could have wished there had been more of it. As it stood, the description of the Siemens acid and the electric furnace were very effective, and, like the authors, he wished they had carried further their account of the differences which existed in the electric steel process when worked with one slag or when worked with two slags. The question of annealing was very effectively treated, and the microphotographs illustrated the point very well. Whilst he had nothing but praise for the Paper, he felt that the method of moulding was perhaps somewhat open to criticism, or, at any rate, that moulding practice on castings of this type was very much in advance of that given in the Paper. At one time it had been his good fortune to be interested in the production of similar castings, which at that time were made in phosphor bronze, and of weights equal to or exceeding the 8 tons 10 cwts. finished weight mentioned by the authors. He knew the inherent difficulties of steel castings as compared with phosphor bronze. Of course, there was the very much higher temperature, but, on the other hand, from the foundry point of view, phosphor bronze was far more searching into the pores of the mould than was steel, so that actually the moulding difficulties in the case of phosphor bronze were greater than in the case of steel. The mould was made in the floor, and the practice then—25 years ago—working from a solid pattern was somewhat similar to that described in the Paper, with the exception that the sides and ends of the mould were made as draw-backs, and were lifted away and stoved. By that means they were able to eliminate, or largely minimise, the very objectionable open fires in the foundry, and also considerably to cheapen the job and lessen the risks through excessive burning. The practice was, before bedding in, to have a plate, if possible one plate with suitable snugs on the outside, well off the sides of the job, or, if not, two or more plates were used bedded on girders. Moulding was followed as usual, the draw-backs lifted away and carried to the stove, the job was re-assembled, and—this was where they were in advance of the method described in the Paper—they never used a weight. No matter how interesting calculations of hydrostatic pressure were, a job of this kind should not be trusted to weights. After closing the mould, from the snugs in the bottom plates, wringers were carried up to binding bars across the top parts, and the whole bolted down. If the middle of the top part stood any chance of strain, that was wedged by a method very common at that time in foundries on the Clyde. Loose plates were put on the inside of the holding-down bolts and the space between rammed up as in a pit. Not even phosphor bronze, with its penetrating action, could possibly find an outlet, and the job was done far more safely than by merely weighting down.

Welding Steel Castings.

With regard to the preparation of sand, he fully appreciated the authors' reticence in the matter, and respected it, but he welcomed their frank attitude in regard to welding. The man who could produce a perfect, flawless casting every time was unknown to him at any rate. Something in the nature of welding was sometimes, though not often, essential, and when it was essential why hide the fact? It was no detriment at all to the casting, and the tensile tests given in the Paper constituted valuable support in this respect. Discussing inspection, he said they all had that to meet, and the kindest thing they could say about it was that it was just a very necessary evil.

Mr. E. Longden, referring to the fins in Fig. 3, said he supposed their purpose was to strengthen the casting and prevent cracking, but he asked if it were not the common practice nowadays to omit fins and use chills. The fin, of course, had a slight chilling effect locally. With regard to the method of moulding, it was to a large extent a matter of expediency; and also whether or not the floor was prepared for that method at the moment. It made a difference to the cost of moulding if one had to sink a pit and lay down girders, binders and plates, and so on. In an iron foundry one must make the casting where it was not always the best because the pits may be in use for other work. The determination of the hydrostatic pressure was not easy. That was why it was better to fasten down with binders if possible. Not only had one to consider static pressure, but pressure from the gases which were forming, and which acted curiously.

Size of Feeder Heads Criticised.

Mr. D. C. Lloyd said it appeared, from the photographs of the casting, that the heads were rather small, especially for steel, which he imagined was run fairly hot. He asked, therefore, whether the authors could get definite soundness underneath the heads, in view of the fact that they were rather small heads and that there were rather few of them for a casting of this size.

A Successful Welding Job.

Engineer-Commander Jackson, discussing welding, said that, if it were properly carried out by a competent man, he would have no hesitation whatever in accepting a casting which had been electrically welded. No doubt Mr. Brown would remember one very big job which was done at Messrs. Thos. Firth and Sons at the time he (Engineer-Commander Jackson) was serving in the Royal Navy. This particular casting was for H.M.S. *Hood,* and had a defect on a part of the steel casting subject to steam pressure, and although electric welding is not permitted on such surfaces, in this particular case permission to electrically weld this casting was given by the Admiralty. It was subjected to very severe and searching tests in the presence of the Deputy Engineer in Chief of the Navy, and as a result was accepted and put into service, and so far as he knew was still satisfactory.

Mr. W. H. Poole suggested that the feeding effect of some of the risers on the casting described might be improved, and asked if the authors really thought that the feeders used were of the right size and shape. He considered that the diameter of the necks in at least two of the three, was very small, and if it were much bigger one would get a better feeding effect with less height of metal.

Charging Electric Furnaces.

A member asked whether the scrap charged into the electric furnace was heavy or light scrap. The authors had said that they put the scrap in first and the turnings on top, in order to get better working, but he asked whether they did not find that the molten steeel dropping from the turnings tended to solidify on the bottom of the furnace, so that when the furnace was cast some of the steel was left behind on the bar.

Use of Brackets.

Mr. H. L. Turner, dealing with the use of brackets, said his experience had been that they were very useful in certain places, but in others they developed troubles of their own. He had found frequently that if one attached brackets running down the body of a casting, the contraction of the brackets—for they cooled very rapidly—set up tiny cracks at the ends of the brackets, and if the ends occurred in one straight line instead of being staggered there was produced a line of weakness right across the casting, which frequently, at the point of solidification referred to by the authors, developed into a hot pull right across the casting. He had also found that in certain instances where the bracket crossed the rib of metal one was trying to protect, it would set up a crack along the line of the bracket itself.

Mr. J. H. Cooper, referring to bracketing, said there were many different systems, but he had found that the chief difficulty arose when the brackets were made too large for the job. A bracket should be as thin as possible, so that when it was in a solid condition it was not sufficiently strong to tear the casting, and so as to allow the casting, although semi-plastiç, to draw the bracket slightly—which could happen. Referring to welding, he asked whether the authors had found that in arc welding there was an increasing carbon content locally. Also, he asked what electrodes they would use with the quasi-arc or other systems. Whilst he considered that the Paper was very convincing, and demonstrated that the authors had a great deal of knowledge of the subject, he did agree with Dr. Longmuir that some of the methods adopted could have been slightly improved.

AUTHORS' REPLY.

Mr. Melmoth asked that Mr. Brown might be excused from replying, inasmuch as he had been very ill for a month or so, but, with his usual pluck, had insisted upon attending the meeting for the presentation of the Paper.

Iron Oxide in Steel Thought to Increase Fluidity.

Replying to the various points raised, Mr. Melmoth, on behalf of Mr. Brown and himself, thanked Dr. Longmuir for his remarks. He himself was patricularly interested in obtaining more details of moulding processes. With regard to the difference between steels produced under single and double slags, for a good many years he had been producing steel from the electric furnaces almost entirely, and that steel had to be of a type which could be used to run castings very different from that described in the Paper. The weights of the castings varied from probably ½ lb. up to 15 cwts., and occasionally perhaps even more, and, naturally, the main thing, apart from soundness, was fluidity—the ability to run thin sections. He knew that he had been accused of labouring the question of fluidity, but in the present Paper there was no need to mention it, as with a casting of the type dealt with one did not require a very fluid steel in order to run it satisfactorily, from the standpoint of getting it all there. In the case of the other castings he had just mentioned, however, the proposition was a very different one. They had had to take a couple of tons of steel and "hand-shank" it round the foundry and cast these very small castings. After experiment and observations they had come to the conclusion that a steel made in the electric furnace under a single slag which contained fair amounts of iron oxide was definitely, so far as they could say from a works' standpoint, a more fluid steel than one under the more strongly reducing slags which were normal in the electric furnace process. From that they had evolved their present methods, and they were used almost consistently, always assuming that the scrap supplied was sufficiently good to justify it. He had been afraid that had that point been brought into the Paper it would have sounded almost like a repetition of a Paper which he had submitted to the Lancashire Branch some time ago, but it was certainly a point of very great interest that there appeared to be such a difference in the running properties of the material as produced by different processes in the same furnace. The explanation of it was not easy; in fact, he did not think it was known actually. It was put down, of course, to possibilities of dissolved oxide, and so on, but one was hardly able to say whether that was the exact explanation.

Moulding Methods.

With regard to moulding methods generally, he said it was obvious to everyone that the method adopted in any particular case was that which was most suited to the shop in which the job was being made. At the same time, he did not underestimate the value of the detailed description that Dr. Longmuir had given as an alternative to the method the authors had adopted, and Dr. Longmuir's description would be very helpful to them.

Use of Chills—A Warning.

Discussing Mr. Longden's reference to the use of fins, and the use of chills as alternatives, Mr. Melmoth referred again to the smaller castings he had handled some time ago, and said that the use of chills had been carried a very long way in connection with the production of fairly small castings, but one had to be very careful. There was no doubt that it was possible to produce, by the use of a chill, a state of affairs very much worse than would have been produced if nothing had been put on at all. A sudden cooling of one particular part, if a chill were a little over-effective, was almost bound to produce pulls in mild steels, and it was a very common experience to produce chill cracks in cases where chills were not very carefully thought out and designed. In the case of a fin or bracket the thickness must be such as would counteract satisfactorily the contraction stresses of the material and hold the casting together through its critical period.

Dealing with Mr. Lloyd's suggestion that the heads on the casting appeared to be rather small, he said that where steel castings were concerned the proof of the pudding was in the eating, or, in other words, in the fettling shop, and he assured Mr. Lloyd that he had not seen a cavity underneath a feeding head in any of these castings. If the heads had not been large enough, it was quite obvious, there would have been cavities there. Admittedly the question of the shape of head was a vital one, and one might criticise theoretically the shape of the heads, but the fact remained that the yield of casting was very satisfactory on this particular job, taking weight for weight and having in view the heavy machining allowances on it, and yet it was perfectly sound underneath the heads.

Melting Practice.

Replying to a member, he said the scrap used was the normal scrap such as was found in the works of the type of Messrs. Thomas Firth & Sons—crop ends and so on, and turnings. He had not found that in a continuously worked furnace the turnings on the top melted first, trickled down through the scrap, and formed solid on the bottom, so that their removal gave trouble. The furnace used was a Heroult furnace, and if any furnace was going to suffer from that trouble he was inclined to think it would be the Heroult, because none of the much-vaunted claims as to bottom heating effects were made in respect of it.

Brackets Need Study.

The point raised by Mr. Turner, as to the use of brackets, was one which Mr. Brown and himself had found of very great interest. Questions of the shape of the brackets, their thickness, where they ended, bringing them parallel in their effective ends and producing other pulls, were undoubtedly extremely important, and he agreed that if a rib or succession of ribs were put on in such a fashion as to pass on the contraction stresses to another definite line, it was quite probable that at that definite line a crack would appear. He gathered that Mr. Turner, when he had mentioned a bracket running down a body, had in mind a valve-like casting, having a rib running down the body and a large core inside. The authors' view as to that was that the rib, if too thick, caused a hot place, which, being delayed in its cooling by the presence of the rib, left the steel weak at one point and localised the contraction stresses at that spot. Consequently, the casting was liable to break down its whole length alongside the rib. He had seen cases in which there was such a rib, and in which it had been necessary to provide also smaller ribs in order to prevent the original rib cracking.

He agreed with Mr. Cooper that the brackets must be of the minimum thickness which would enable them satisfactorily to do the work they were intended to do. With regard to welding, he said he was not prepared to say, from memory, what was the thickness of the rods, but they were the ordinary quasi-arc rods, flux covered. Any rod of a similar type, flux covered, seemed to give similar results. The authors were of opinion that a flux-covered rod was necessary for fine welding.

THE INFLUENCE OF MANGANESE AND MANGANESE SULPHIDE ON WHITEHEART MALLEABLE.

By E. R. Taylor, A.R.S.M., D.I.C., F.I.C. (Associate Member).

Much has been written from time to time on the question of manganese, sulphur and manganese sulphide in cast iron and steel, but there is not a great deal of published information on the effect of these constituents on whiteheart malleable.

It is generally agreed that the injurious effect of sulphur in ferrous alloys may be neutralised very considerably by the presence of manganese. When manganese and sulphur combine to form manganese sulphide, 32 parts of sulphur combine with 55 parts of manganese to form 87 parts of manganese sulphide, so that one part of sulphur requires $\frac{55}{32}$ or 1.72 parts of manganese. It is well known, however, that the formation by manganese and sulphur of manganese sulphide is rarely, if ever, completed when iron and carbon are present, since other combinations may and in fact do take place. Assuming for the moment that in a particular case manganese and sulphur are present in an iron in the atomic proportions mentioned above, *i.e.*, 172 parts of manganese for every 100 parts of sulphur, not all the 272 parts of manganese sulphide would be formed, as some of the sulphur would combine with the iron to form ferrous-sulphide; alternatively some of the manganese may combine with carbon to form manganese carbide. According to the law of mass action, the tendency of a given amount of sulphur in the presence of manganese to form nothing but manganese sulphide will be assisted if the concentration of manganese (that is the amount of manganese present) is increased. If, therefore, it is desired to secure the greatest possible amount of sulphur as manganese sulphide, or as a compound sulphide containing the greatest possible amount of manganese, the amount of manganese must be increased much beyond that demanded by the theoretical ratio. In other words, an excess of manganese is required, and the greater this excess the larger will be the proportion of sulphur combined with manganese.

In ordinary grey-iron castings manganese is invariably preferred in excess of the theoretical ratio needed to convert sulphur to manganese sulphide. The excess of manganese over the theoretical demand of sulphur will be referred to as "excess" manganese, and clearly the greater the amount of "excess" manganese the larger the proportion of sulphur combined with manganese. The writer does not desire to refer, in connection with this Paper, to controversies with respect either to the precise influence of manganese on cast iron, the differentiation of sulphides under the microscope, or the possibility of sulphides of iron and manganese existing as compounds. He merely desires to point out that in cast iron it is generally recognised that sulphur exists best combined with manganese, and to ensure the maximum proportion of sulphur so existing, manganese is used in excess of that theoretically required.

In mild steel the sulphur is usually not over 0.05 per cent., and the manganese is ordinarily about 0.5 per cent. In the recent Report on the Heterogeneity of Steel Ingots,† it is stated that:— "When manganese is added to the steel in the bath, the distribution of the sulphur between the two elements iron and manganese is determined by the relative amounts of the two metals present and their respective affinities, and the sulphide is always of a complex character (FeMn)S. It is generally accepted that this complex is insoluble in liquid iron, and its distribution is governed by a different law from that of the other constituents. In addition, there is no doubt that this sulphide is of lower density than liquid iron."

Ordinary text-book literature repeatedly conveys the impression that an excess is preferred to a deficiency of manganese, and numerous references could be given to scientific Papers to the same effect.‡

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† "Journal of the Iron and Steel Institute." No. 1, 1926, p. 39.

‡ See E. R. Taylor, "Carnegie Scholarship Memoirs," Vol. 15, 1926, pp. 382 and 406.

Whiteheart Malleable Pig Iron.

In whiteheart malleable pig-iron the silicon content is low. Unavoidably, under present conditions of blast-furnace operation, therefore, the sulphur present is high, considerably in excess of what is obtained in foundry pig. The growth of cupola melting of whiteheart malleable naturally emphasises the sulphur difficulty owing to the absorption of sulphur from the coke. The chilling effect of sulphur is well known, and in the absence of manganese the sulphur would clearly retard the annealing operation. Furthermore, there would be practical difficulties in the way of securing a predetermined sulphur content, which would make any systematic control, by means of sulphur, difficult if not impossible, small changes in the sulphur content producing marked differences of the structure. The question of the desirable manganese content in whiteheart malleable is therefore of practical importance, as manganese in removing some sulphur takes from the metal a carbide-stabilising agent of great power. The intrinsic influence of manganese, apart from sulphur, on the carbide is still disputed, but metallurgical opinion as a whole takes the view that manganese also stabilises the carbide. Thus it would retard annealing, and if this view is correct the removal of manganese and sulphur deprives the metal simultaneously of two hardening agents. The problem would be simple if the formation of manganese sulphide were complete and non-reversible. An excess of manganese is necessary, and it may be assumed that this excess is present in the metal as manganese carbide. The question then arises—is it preferable to remove the maximum quantity of sulphur by excess manganese, or should the manganese be limited? In other words, which is the greater evil to the malleable founder, manganese carbide from excess manganese or ferrous sulphide from sulphur not combined with manganese, both of which may retard annealing? What middle course, if any, is open?

Purchasers of whiteheart malleable pig-iron have the choice of material from various localities, and the sulphur contents differ very widely. The writer has found such pig as high as 0.65 per cent. in sulphur, with traces of manganese, while at the other extreme irons with a much higher manganese content gave only 0.12 per cent. sulphur. In view of these variations there is therefore a good deal to be said for the practice of mixing and remelting these irons into so-called refined pig-iron before they reach the malleable founder, as this permits a predetermined ratio of manganese to sulphur.

The final question that arises, assuming that for whiteheart malleable a desirable ratio of manganese to sulphur could be fixed, may be stated as follows. Is there any difference between irons of differing sulphur contents? In other words, could a high-sulphur pig be utilised as satisfactorily by the industry (provided it contains its quota of manganese) as a low-sulphur pig with its proper manganese ratio? Can manganese sulphide be regarded as neutral from the point of view of its effect on the properties of whiteheart malleable?

Sulphur and Manganese in Black Heart.

In a Paper given by Professor Enrique Touceda before this Institute, at the Birmingham Conference in 1922, the question of manganese and sulphur in black heart was discussed. He said:—"The question, then, really resolves itself into what are the permissible limits for the sulphur and manganese. While it is generally conceded that these elements should be present in atomic proportions to form manganese sulphide, the author has seen many instances in which the product was excellent where this was not the case. Based upon data obtained from the testing of many test bars, the author would state that with a sulphur content between the limits of 0.05 and 0.08 per cent. it is safe to use a manganese content between the limits of 0.20 to 0.30 per cent., with recommendation to avoid using, coincidentally, the high limit for manganese with the low one for sulphur, and contrariwise. The manganese should be increased with increasing sulphur, and with the latter at 0.12 per cent. it should lie between 0.34 and 0.40 per cent."

Professor Touceda also refers to cupola-melted black heart in which sulphur averaged in the casting 0.25 and manganese 0.6 per cent., this being used for fittings in which superiority in quality is not essential. It was pointed out by him that this metal would show abnormal structure in heavy sections, and be low in elongation. It might fairly be concluded from these remarks that poor ductility may be attributed to the presence of manganese sulphide.

Dr. W. H. Hatfield,* in discussing black heart malleable, says:—"The manganese in the blackheart material is there to neutralise the sulphur, and this content should largely be determined by the content of the latter element."

Influence of Sulphur in Whiteheart Malleable.

The author first determined the influence of sulphur in whiteheart malleable. This material may be regarded as an impure iron-carbon alloy, and in order to ascertain the influence of sulphur in the absence of all elements other than iron and carbon, a Swedish iron base was used, to which 11 per cent. ferro-silicon was added to secure a uniform silicon content throughout the series, of 0.6 per cent., together with ferrous-sulphide to give varying sulphur contents throughout the series. At the same time a second series was made up, using as a base hematite iron of the kind commonly used in the trade, but of high sulphur and low manganese content, silicon being kept the same as before. Tensile and bend bars were cast in green sand, B.E.S.A. standard bars being employed.† In the chemical analyses sulphur was always determined gravimetrically. The details of the analyses of the original Swedish white iron and of the subsequent mixtures made up, before and after annealing, are given in the original Paper,‡ together with those of the series made from the hematite iron. The Swedish iron contained 3.10 per cent. total carbon, and 14 melts were made up, the sulphur varying between 0.019 and 1.49 per cent. The hematite iron con-

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* Journal of the Iron and Steel Institute, 1917, p. 319.

† See B.E.S.A. Specification 5022 (1923), on whiteheart malleable for automobile castings. The ultimate tensile strength specified is 20 tons per square inch with an elongation on 2 inches of 5 per cent., and a bend of 45 degrees round a 1 inch radius. The same figures have been proposed for the tentative specification for general whiteheart malleable, although there are slight changes in the test pieces and test conditions.

‡ See E. R. Taylor, "Carnegie Scholarship Memoirs," 1925, p. 131.

tained 2.9 total carbon, 0.70 silicon, 0.65 sulphur, 0.03 per cent. manganese, and 10 melts were made up with sulphur varying between 0.151 and 1.28 per cent., the lower sulphurs being secured by Swedish iron additions.

The bars were annealed under commercial conditions at the works of the Incandescent Heat Company, Limited, Smethwick, by courtesy of Mr. J. J. Fallon. The ore ratio employed was 1:3, the annealing period being 125 hours, of which 60 hours was between 890 and 960 deg. C. This annealing cycle is not ideal, being too short at the top temperature, and the cooling being too rapid. The influence of sulphur on tensile strength was shown to be wholly deleterious in both series. In the Swedish series the ultimate tensile strength fell from 24 tons per sq. in. for 0.1 per cent. sulphur, to 8 tons per sq. in. for 1.5 per cent. sulphur. The B.E.S.A. specified figure was maintained with sulphur under 0.5 per cent. The elongation figures for both series were disappointing, due to rapid cooling. In the hematite series the ultimate tensile strength was 23.5 tons per sq. in. at 0.15 per cent. sulphur,

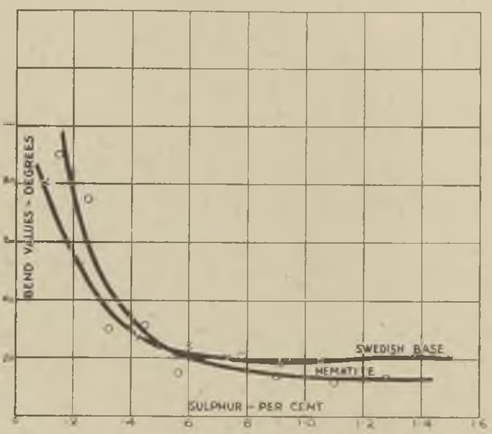

Fig. 1.—Influence of Sulphur on Bend Test in the Absence of Manganese.

falling to 10 tons per sq. in. for 1.28 per cent. sulphur. The B.E.S.A. figure was maintained under 0.7 per cent. sulphur. The influence on the bend test is shown in Fig. 1. For complete details of the mechanical tests the reader is referred to the original Paper.

With the adoption of a commercial silicon content, the main difference between the Swedish and hematite bases, in view of the low manganese content of the latter, was that of sulphur, which was, of course, varied deliberately in the melts made up. It might be anticipated, therefore,

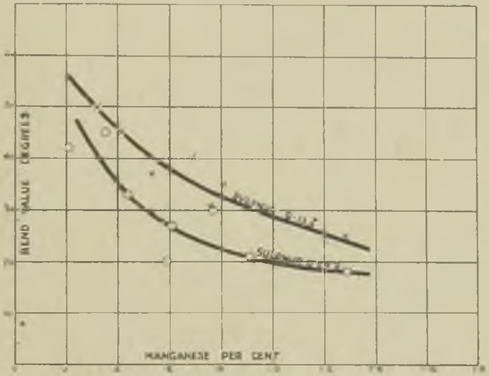

FIG. 2.—INFLUENCE OF MANGANESE AND SULPHUR ON BEND TEST.

that there would be little difference between the results of the two series, and this is confirmed by Fig. 1.

Conclusions.—For the Swedish series both tensile strength and elongation diminish with increasing sulphur. The elongation figures on this series were unduly low, doubtless owing to the rapid cooling from the furnace and short annealing. The bend test is below the specified figure at over 0.3 per cent. sulphur.

The hematite series afford a more satisfactory basis for comparisons with commercial material. Again mechanical properties diminish regularly with increasing sulphur, and the bend test shows that sulphur over 0.3 per cent. is below specification. Sulphur, therefore, exercises a wholly deleterious influence on the properties of whiteheart malleable when manganese is absent.

The Influence of Manganese.

The influence of manganese was then determined using ordinary hematite white iron as employed in the trade. Two series of melts were undertaken, the first having a sulphur content of 0.133, the second of 0.24 per cent., each with increasing manganese. There was ample evidence during higher sulphur melts of the combination between manganese and sulphur, the sulphide rising to the surface in a pasty, viscous mass, fusible with difficulty, and virtually precluding a series being made with sulphur above 0.3 per cent.

In each series the base metal, a hematite pig-iron of 3.09 total carbon, 0.60 silicon, 0.28 manganese, 0.133 sulphur, and 0.103 per cent. phosphorus, was crucible melted with increasing amounts of spiegeleisen to give increasing manganese, high-sulphur pig of similar origin being added in series 2 to give the higher sulphur contents desired. In the first series the manganese varied in 9 melts from 0.32 to 1.28 per cent. In the second series, in 7 melts the manganese varied from 0.21 to 1.29 per cent.. and in both series a little sulphur was lost through manganese sulphide rising to the top of the pot. This loss naturally increased as the manganese increased. In Series 1 the sulphur diminished from 0.133 to 0.10 per cent., and in Series 2 from 0.24 to 0.20 per cent.

For the analyses of the white and annealed bars together with full mechanical tests, the reader is referred to the original Paper.† The bars were annealed in a 1: 5 ore mixture after barrelling in a commercial gas-fired furnace at A. S. Smith and Sons, Walsall, by courtesy of Mr. G. S. Bayliss. The heating up took 50 hrs., and the cooling 60 hrs., the bars being kept 120 hrs. at 960 deg. C.

In Series 1 the ultimate tensile strength increased with manganese, and the elongation diminished, being 5 per cent. at 0.6 per cent. manganese. All the tensiles were over 20 tons in

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† E. R. Tayor, "Carnegie Scholarship Memoirs," 1926, p. 381.

both Series 1 and 2. In Series 2 the ultimate stress increases with increasing manganese up to 0.6 per cent., and then falls away again. The elongation does the same, increasing up to 0.45 per cent. manganese and then diminishing. The elongation was over 5 per cent. with the manganese between 0.4 and 0.8 per cent., with a peak of 8.5 per cent. at 0.45 per cent. manganese.

RS 8.

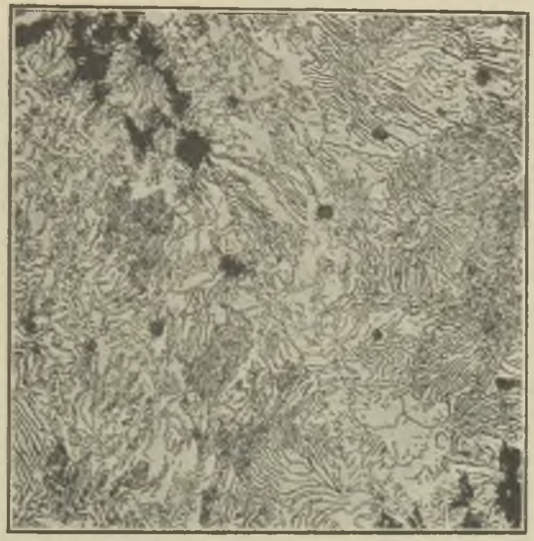

FIG. 3.—MN. 0.045 AND S. 0.014 PER CENT. ANNEALED. ETCHED WITH PICRIC ACID. × 200.

Fig. 2 shows the results of the bend tests, indicating the fall of bend value with manganese.

The bend and tensile tests taken together indicate that the best results for a given sulphur value arise when the manganese is not more than 1 to 2 times the sulphur. In the first series this occurs with the lowest manganese attained, as it was not found possible to go lower than 0.32 per cent. manganese. In the second series the best elongation is given by 0.45 per cent. manganese, the sulphur content being 0.24 per cent.

Conclusions.—It may therefore be concluded from these tests that in whiteheart malleable the best mechanical results are obtained when the manganese: sulphur ratio is not greater than 1: 2. When the ratio is much less than this, good bend tests can be obtained, but the elongation appears to suffer. Metal containing excess manganese is strong without being ductile, and anneals to finely divided pearlite instead of ferrite.

RS 20.

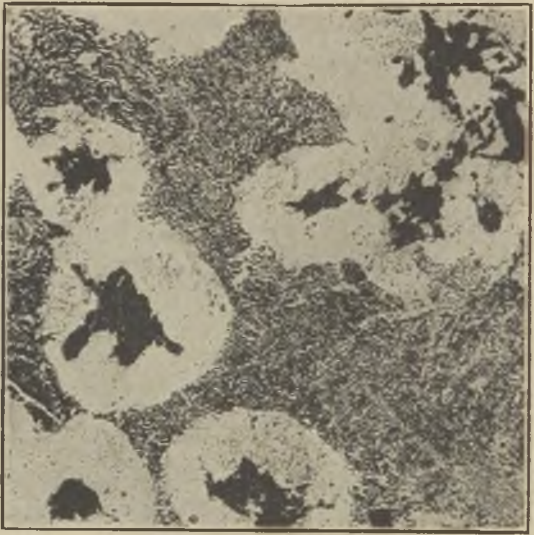

FIG. 4.—MN. 0.17 AND S. 0.131 PER CENT. ANNEALED. ETCHED WITH PICRIC ACID. × 200.

The Influence of Manganese Sulphide.

It was evident from the above-mentioned investigation that better mechanical results were obtained from a low-sulphur pig containing the proper quota of manganese, than from a high-sulphur pig with the proper quota of manganese.

Reference to Fig. 2 not only indicates a deterioration of bend value with increasing manganese, but it will be noted that the bend values for Series 2, containing sulphur 0.24 per cent., are uniformly lower than for Series 1, containing sulphur 0.13 per cent. For a given amount of excess manganese the former iron will contain a larger quantity of manganese sulphide than the latter. Since the mixtures, melting and annealing conditions are identical apart from this one difference, it may fairly be concluded that the ductility suffers if the amount of sulphide present increases. This result was generally supported by other tests irrespective of the character of the base metal, whether blast furnace or refined iron, but it was considered desirable to confirm it with further tests.

RS 2.

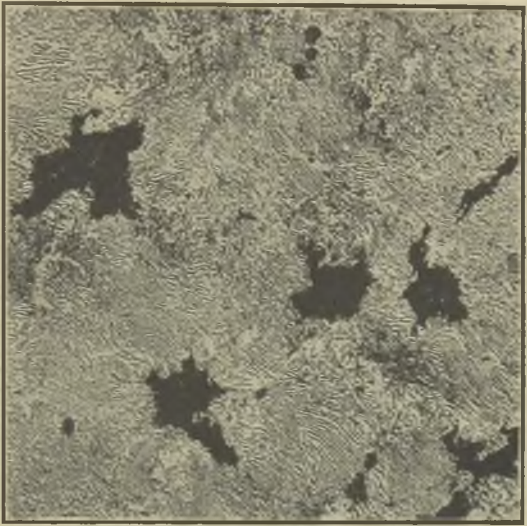

FIG. 5.—MN. 0.25 AND S. 0.17 PER CENT. ANNEALED. ETCHED WITH PICRIC ACID. × 200.

These were made on a Swedish iron base of the analysis:—T.C., 3.90; C.C., 3.90; Gr, nil; Si, 0.05; Mn, trace; S, 0.015; and P, 0.015 per cent.

Seven melts were made up of this base with 11 per cent. ferro-silicon, to give a commercial silicon figure of 0.6 per cent., and with calculated amounts of ferrous-sulphide and spiegeleisen to give manganese and sulphur contents varying between the different melts of the series, and yet being fixed in any one melt at the ratio 1.7 : 1. Three standard tensile and three standard bend bars were cast for each melt, being subsequently barrelled, packed in ore in the ratio of 1 part of new to 5 parts of old, and annealed in a commercial, producer-gas-fired oven for 120 hrs. at 960 deg. C. Cooling was slow, being at the rate of 15 deg. C. per hour until 650 deg. C. was reached.

RS 18.

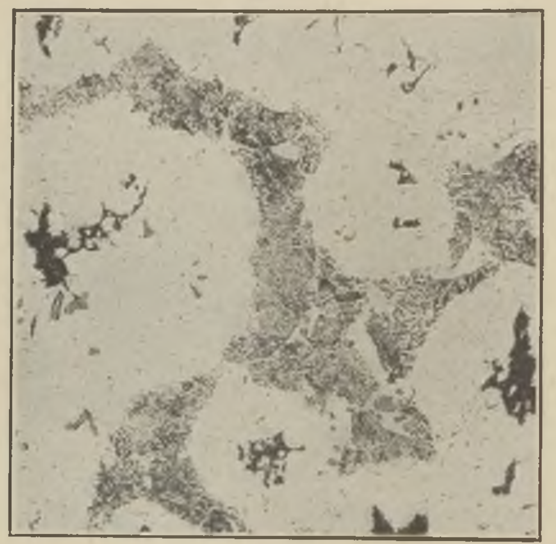

Fig. 6.—Mn. 0.386 and S. 0.187 per cent. Annealed. Etched with Picric Acid. × 200.

Table I gives the analyses of the white bars, and Table II those of the annealed bars, it being assumed that silicon, manganese and phosphorus remained unchanged during annealing. Table III gives results of mechanical tests, including tensile, elongation and bend tests.

TABLE I.—*White Bars.*

Cast.	T.C. %	C.C. %	G.C. %	Si. %	Mn. %	S. %
RS 8 ..	4.08	4.01	0.07	0.17	0.04	0.014
RS 22 ..	3.54	3.46	0.08	0.55	0.12	0.197
RS 20 ..	3.68	3.58	0.10	0.63	0.17	0.131
RS 2 ..	3.87	3.78	0.09	0.77	0.25	0.170
RS 18 ..	3.53	3.45	0.08	0.79	0.39	0.187
RS 17 ..	3.71	3.61	0.10	0.60	0.33	0.199
RS 9 ..	3.53	3.45	0.08	0.85	0.34	0.213

The phosphorus content remained constant at 0.015 per cent.

TABLE II.—*Annealed Bars.*

Cast.	T.C. Per cent.	C.C. Per cent.	G.C. Per cent.	S. Per cent.
RS 8 ..	1.98	0.65	1.33	0.038
RS 22 ..	1.96	0.74	1.22	0.203
RS 20 ..	1.87	0.66	1.21	0.151
RS 2 ..	2.13	0.83	1.30	0.197
RS 18 ..	1.97	0.52	1.45	0.181
RS 17 ..	2.01	0.66	1.35	0.244
RS 9 ..	1.98	0.69	1.29	0.239

Manganese, silicon and phosphorus contents are assumed to remain unchanged.

TABLE III.

Cast.	Mn. S. assuming all S. changed to Mn. S.	Slight excess of	Ult. Ten. Str. Tons/sq. in.	Per cent. Elong. on 2 in.	Bend value.
	Per cent.				
RS. 8 ..	0.038	Mn.	23.5	3.6	46°
RS 22 ..	0.193	S.	27.0	4.5	50°
RS 20 ..	0.269	S.	24.6	5.0	40°
RS 2 ..	0.395	S.	25.0	3.7	34°
RS 18 ..	0.509	Mn.	19.6	8.3	90°
RS 17 ..	0.527	S.	20.4	4.0	41°
RS 9 ..	0.542	S.	25.8	5.0	33°

It will be seen from the above results that, in a series in which manganese and sulphur remain related in the same way but in which the actual amounts vary, no definite decline or improvement is shown as the amounts of sulphur and manganese present increase. It is practically difficult to get melts in which the manganese and sulphur are present in a given ratio, even approximately, and the variations in silicon and carbon are quite sufficient to explain the differences shown. The high value obtained for bend in RS 18, in addition to the high elongation, is explained by the high silicon and the low combined carbon after annealing. This iron had annealed wholly to the blackheart condition. It is possible that some favourable condition in mixing or annealing resulted in a greater proportion of sulphur being

RS 18.

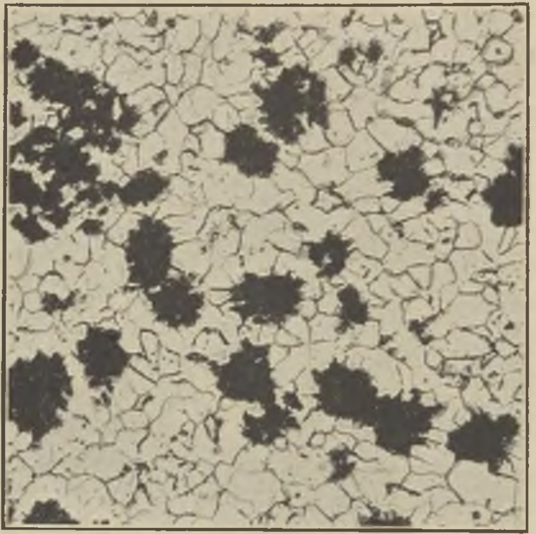

FIG. 7.—ANNEALED BAR ($\frac{3}{8}$ IN.). ETCHED IN PICRIC ACID. MN. 0.386 AND S. 0.187. × 100.

converted to manganese sulphide in RS 18 than in the other samples, and this would have facilitated annealing to the ferrite-graphite structure capable of yielding relatively good bend and elongation figures.

Generally it may be concluded that the presence of sulphide does not seriously affect the ductility of whiteheart malleable, and any harmful tendency is probably more than offset by the acceleration of the annealing due to the combined removal of both sulphur and manganese as sulphide. More reliance should be placed upon the bend tests in the above series than upon tensiles, as $\frac{5}{8}$-in. bars were used for the latter instead of $\frac{1}{2}$-in. diameter, and these proved in practice to be unsatisfactory on account of the greater difference in thickness between tensile and bend bars.

RS 22.

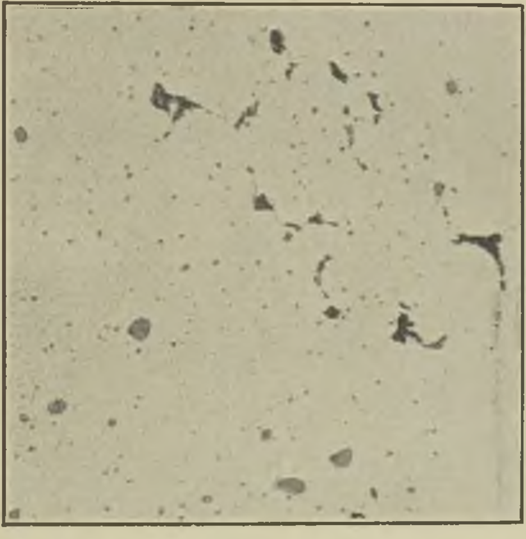

Fig. 8.—Mn. 0.122 and S. 0.197 per cent. Unetched × 200.

Five-eighths-inch tensile bars are proposed in the tentative malleable specification, and might well be reduced to the original figure unless a flat bar can be adopted.

Influence of Sulphide on Fracture.

It was noted that in RS 8 and RS 22 the fracture was crystalline and steely, whereas in the other casts the fracture is darker, RS 17 having a black centre with a steely rim $\frac{1}{4}$ in. thick. RS 18 annealed to a ferrite-graphite structure entirely, with a velvety black appearance. Reference to Table II, however, shows that there is no actual increase in temper carbon deposited as the sulphide increases, except in the one case of RS 18 mentioned above.

RS 18

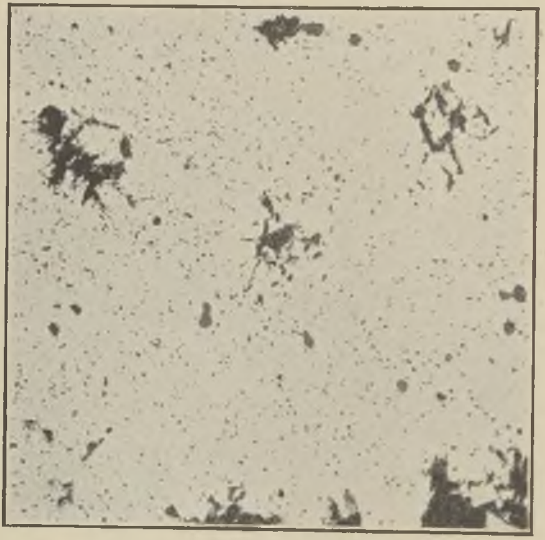

FIG. 9.—SAME SPECIMEN AS FIG. 6, BUT SHOWING HOW THE SULPHIDE HAS SHATTERED DURING ANNEALING. UNETCHED × 200.

The microstructure of the series in the cast state was normal, except that a little free graphite was present. Fig. 3 shows RS 8 after annealing, being mainly pearlitic. Fig. 4 shows RS 20 after annealing. Fig. 5 shows RS 2 after annealing, and Figs. 6 and 7 show RS 18 of $\frac{5}{8}$ in. bar and $\frac{3}{8}$ in. bar respectively, all these being etched.

Fig. 8 shows RS 22 unetched, showing a small amount of sulphide and temper carbon, and Fig. 9 shows RS 18 with a greater amount of sulphide, and a characteristic effect of the sulphide in very small particles. Fig. 10 shows RS 17 similarly.

Loss or Gain of Sulphur During Annealing.

Sulphur in the white iron castings appears to be affected during the anneal, largely depending on whether manganese is present or not. In the absence of manganese, the sulphur exists as the eutectic Fe – FeS freezing at 980 deg. C., *i.e.*, 200 deg. C. less than the melting point of pure iron sulphide.

In this case the author found that elimination of sulphur takes place during the annealing operation to an extent equal to 50 per cent. or more of the original sulphur present.

When manganese is present, however, more particularly over the ratio 1.7 times the sulphur, an absorption of sulphur takes place from the ore mixture, so that there is an increase in sulphur in the annealed castings over that of the white castings.

The following results were obtained as illustrating this:—

TABLE IV.—*Hematite Iron* (*Manganese absent*).

Original white iron bars. Sulphur per cent.	Annealed bars.	Percentage Sulphur eliminated.
Per cent.	Per cent.	Per cent.
0.151	0.071	53.0
0.25	0.153	38.0
0.324	0.296	8.64
0.65	0.51	21.5
1.28	0.65	49.2

TABLE V.—*Hematite Iron (Manganese present).*

Original white iron bars. Sulphur per cent.	Annealed bars.	Percentage Sulphur gained.
0.133	0.152	14.3
0.121	0.151	24.7
0.115	0.146	27.0
0.117	0.146	24.7
0.109	0.136	24.7
0.112	0.133	18.8
0.11	0.14	27.2
0.24	0.257	7.1
0.213	0.232	8.95
0.211	0.239	13.2
0.20	0.232	16.0

Also in the series in which manganese is present in a definite ratio:—

TABLE VI.—*Hematite Iron, Manganese present in Definite Ratio to Sulphur.*

	Sulphur in the white iron bars.	Sulphur in the annealed bars.	Percentage gain in Sulphur.
	Per cent.	Per cent.	
RS 22 ..	0.197	0.203	3.04
RS 20 ..	0.131	0.151	15.2
RS 2 ..	0.17	0.197	15.8
RS 18 ..	0.187	0.181	— 3.2
RS 17 ..	0.199	0.244	22.6
RS 9 ..	0.213	0.239	12.2

It is difficult to suggest a definite relationship between the manganese content and the behaviour of sulphur during annealing, but the general tendency is clearly indicated.

Conclusions.—(1) Sulphur in the absence of manganese is deleterious to the mechanical properties of whiteheart malleable.

(2) Manganese in the absence of sulphur is deleterious to the ductility of whiteheart malleable.

(3) Manganese and sulphur together neutralise the harmful properties of both, by the formation of sulphide. The manganese may be present in the proportion of 1 to 2 parts manganese to 1 of

sulphur, to offset the disadvantage of sulphur without incurring the disadvantage of undue excess manganese.

(4) There seems to be no reason why medium and high sulphur irons, otherwise suitable, should not be employed for whiteheart malleable provided the iron carries the quota of manganese not exceeding that given in (3) above, as the sulphide formed does not appear seriously to affect the mechanical properties. The lowest sulphur pig available, of course, is to be preferred.

RS 17.

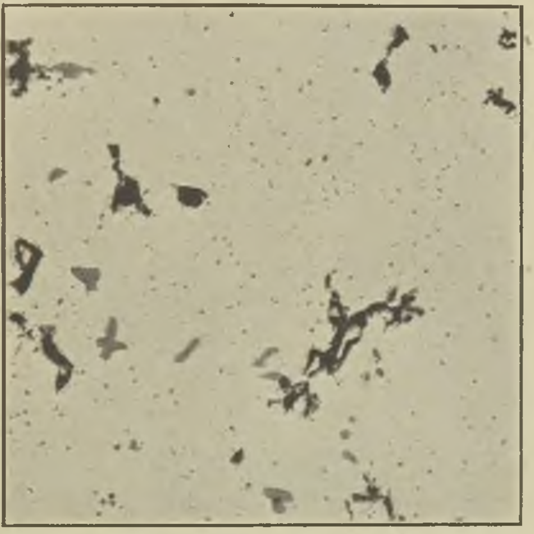

FIG. 10.—MN. 0.333 AND S. 0.199 PER CENT. ANNEALED. UNETCHED × 200.

(5) Whiteheart malleable bars appear to lose sulphur during annealing when manganese is absent, and gain it when manganese is present, *i.e.*, sulphur change during annealing appears to depend upon the character of the sulphide formed.

The author thinks it desirable to state that the work embodied in this paper was completed before joining the staff of the British Cast Iron Research Association, and has since been continued with respect to the influence of total carbon and silicon on the properties of whiteheart malleable. At the same time the paper could not have been presented without the facilities provided by the Association, and to the Director of the Association the author's grateful thanks are therefore tendered, and also to those gentlemen at the works of members of the Association in which the practical annealing work was conducted. The investigations on sulphur and manganese were carried out by means of Carnegie Scholarship grants from the Iron and Steel Institute. The work on the influence of manganese sulphide was undertaken by means of a grant from the Government Grant Committee of the Royal Society.

DISCUSSION.

Definite Field for Low Elongation Malleable.

Mr. F. J. Cook (Past-President) was of opinion that there certainly were commercial uses for an iron which would give very high tensile strength, say, of over 30 tons per sq. in., with a moderate elongation of 3 per cent., in such things as transmission gear, heavy conveyor work, cam levers for Diesel engines, and so on, where one wanted good strength and rigidity. A few years ago enormous elongations were obtained in America with malleable iron, and very great stress was laid on that point, but anyone who was familiar with the work carried out over there now knew that they had dropped a great deal of that. They had found that it was not a distinct advantage in many cases to have an iron with the same attributes as lead, but that they required a malleable iron of a stiffer nature, and he could quite conceive that the advantages, for such purposes as he had indicated, of a high tensile strength would be greater than the advantages of an abnormally high elongation. Therefore, one could quite truthfully answer Mr. Taylor's question in the affirmative. He referred to a diagram exhibited by

Mr. Taylor, which showed that, with manganese, the ultimate stress rose, then it dropped down, and later there was again a distinct rise. The tails of the diagrams for ultimate stress, yield and elongation took the same direction, and it appeared that Mr. Taylor had left off at a point from which he ought to have continued very much further, because it appeared, if he had, he would have got within the range of the results which had been shown by Prof. Piwowarsky. If that were so, there were two ways of getting at a material which would give similar results, and he suggested, therefore, that Mr. Taylor should carry the work a little further in order to see whether the rise in the curve persisted. The subject was full of possibilities; the Paper was well conceived, and the work had been very well carried out.

Mr. T. H. Turner asked what the figure was at the end, where the direction of the curve changed.

Mr. Cook replied that the ultimate stress was round about 26 or 27 tons. The manganese content at the point of change was round about 1 per cent.; above that, there was a distinct advance to such an extent that it looked as though it might go up considerably further.

Higher Sulphur in Skin.

Mr. W. H. Poole asked Mr. Taylor if he thought that a malleable iron of 30 tons tensile and 3 per cent. elongation was of very high grade, because he himself regularly tested malleable of 30 and 40 tons tensile, and from 7 to 12 per cent. elongation. He also asked why it was that there was more sulphur in the skin than in the remainder of the iron, and what, in Mr. Taylor's view, actually took place to cause that high sulphur content. He also asked that when Mr. Taylor carried out any further experiments he would keep in mind the practical casting results in the foundry, because when trying out casting results one often experienced a lot of trouble. If one cast a high-manganese metal and a low-manganese metal in the foundry one found an appreciable difference.

Mr. E. Longden asked Mr. Taylor if, in view of the importance of sulphur in the metal used for malleable iron castings, he had carried out any research into de-sulphurisation. In grey iron it was not so important as in malleable iron, but during the last eighteen months metallurgists had been somewhat confounded, because he had regularly produced metal with a sulphur content of 0.16 per cent., the sulphur having no damaging effect on the metal.

Migration of Sulphur in Malleable.

Mr. F. H. Hurren said that the Paper was very interesting and useful, inasmuch as serious research work on whiteheart malleable had been sadly neglected. Mr. Taylor had proved conclusively in his Paper and in the test results given in the Carnegie Scholarship Memoirs that high manganese was not a desirable factor, inasmuch as, although the tensile was increased, the bend test result was seriously reduced. He did not quite agree with the statement in paragraph 4 of Mr. Taylor's conclusions, to the effect that there seemed to be no reason why medium and high-sulphur irons should not be employed. Despite what Mr. Fletcher had said about the difficulty, with a blast furnace, of producing cast irons to specification, he did not see why the very high sulphur irons now put on the market could not be improved upon, and, with all due deference to the pig-iron manufacturers, he considered it was up to them to produce irons lower in sulphur and remove the trouble from the man who had to make the castings. Another interesting point brought out by Mr. Taylor was the fact that during annealing some castings lost sulphur and others gained. He himself had found that out in a number of tests, but had never realised what the explanation was until Mr. Taylor had proved it in his Paper, and he thanked Mr. Taylor for having given it.

AUTHOR'S REPLY.

Mr. Taylor, replying to the discussion, said that Mr. Cook's suggestion that the manganese content be carried further was a good one, because at about 1.25 or 1.3 per cent. manganese things did not seem to be going better. Those who wanted a high tensile malleable cast iron would get it with 1.25 per cent. manganese, but the elongation was only moderate, *i.e.*, 3 per cent. There must be many purposes in engineering for which such a material of high tensile strength and low ductility would be specially valuable, but such a malleable cast iron did not appear to achieve the popularity that perhaps it might. He would take the opportunity, when he could, of increasing the manganese in order to see what happened, because at 1.3 per cent., where he had finished, the tensile strength was soaring up to 35 tons per sq. in., and would perhaps have reached 40 tons. It might be that the properties of the material would coincide very closely with those obtained by Prof. Piwowarsky. Prof. Piwowarsky had indicated, in reply to the discussion on his Paper, that if he had lengthened the annealing period beyond a quarter of an hour he could have increased the elongation of 10 per cent., Presumably, however, in reaching an elongation of 10 per cent., the strength of the material would have been reduced somewhat. The action of the sulphur during annealing very likely explained some of the failures that had occurred in the past. He could not imagine that the properties of a malleable cast iron containing a large percentage of sulphur and no manganese, even if the sulphur were eliminated during annealing, would be so good as they would be if one started with a more select pig-iron and had no elimination of sulphur. It seemed probable that the elimination of a large percentage of sulphur would be detrimental during annealing. If one started with a pig-iron containing 0.5 per cent. sulphur, and perhaps eliminated half of that sulphur so that it was reduced to 0.25 per cent., the effect of having eliminated it would be to leave traces of injury. There were cases on record which showed that that was the case.

Correspondence.

In a written communication as promised by the author at the Conference, Mr. Taylor deals briefly with a few outstanding points raised in the discussion as follows:—

Mr. W. H. Poole spoke of high tensile malleable (30 to 40 tons) with 7 to 12 per cent. elongation as against the 3 per cent. quoted in the Paper. As high tensile strengths are inimical to high elongations it would be interesting to all concerned if Mr. Poole would publish a series of such results together with full analyses and tests. It must not be forgotten, however, that flat bars are known to register higher elongations than do round bars of the same material. It is understood Mr. Poole used flat test bars. The thickness of the test bar used, of course, also has a decided influence on the elongation observed. Experiments are, as a matter of fact, actually in hand to determine the relationship between the results obtained from both round and flat bars.

In regard to the concentration of sulphur in the skin of the iron, the cases of manganous and non-manganous malleable must be considered separately. In the former there is usually an increase of sulphur during annealing which must come from the ore. In the case of non-manganous malleable the sulphur migrates towards the skin and would appear to account for the local concentration.

In reply to Mr. E. Longden, Mr. Taylor states that de-sulphurisation of iron intended for malleable does not appear to be practised, although good results might arise thereby. At the present time the production of refined malleable pig-iron appears to be the result of cupola mixing rather than chemical treatment.

The author thanks Mr. F. H. Hurren for his remarks, and is interested to know that he is in general agreement regarding the effects of sulphur and of manganese.

Lancashire Branch.

EARLY HISTORY OF THE INSTITUTE.

By F. J. Cook, M.I.Mech.E. (Past President).

It is a remarkable fact that although the Association has been in existence since 1904, so far no attempt has been made to give an account of the circumstances which led to its formation or to tell the story of its early developments. It is important that these details should be given since the lapse of time has reduced the number of the foundrymen who formed the Association and set it on its forward path. It will be the object of this paper to detail very briefly the origin and progress of the Association up to the present time.

Incidentally, no better example of the power of the Press could be given, since it was in the pages of The Foundry Trade Journal that the first aspirations for an association found their expression. The first issue of The Foundry Trade Journal appeared in January, 1902. It is clear that at that time there must have been, although more or less lying dormant for lack of the means of expression, a desire for a foundrymen's association on the lines of the American one. For as early as the second issue of The Foundry Trade Journal two letters appeared under the *nommes des plumes* of "Foundryman" and "Foundry Foreman," both of which urged the formation of such an association.

These were followed in the May issue with a letter on similar lines signed "Foundrymite." After that time, no doubt owing to lack of initiative and pushfulness, the matter appears to have laid dormant, as no further letter on the subject appeared until May, 1903, when J. Ellis (Southampton), who subsequently became President of the Association, wrote under the *nom de plume* of "Foundry Manager," again urging the formation of such an association and suggesting that the first general meeting should be held at Manchester in connection with the forthcoming

Exhibition. In the next issue of June a writer signing himself "T.S.," whilst agreeing in principal with the suggestion, pointed out what he believed to be insurmountable difficulties, including that of cost. Just prior to this Mr. Finch, the present Treasurer, had been reading in the issues of the American journal "The Foundry" accounts of the American Conventions and was strongly impressed with the desirability of forming a similar association in Great Britain. At the same time he learned of the existence of THE FOUNDRY TRADE JOURNAL, and, with his characteristic energy wrote in the June issue giving a practical turn to the discussion by suggesting that if those interested in the formation would communicate with him he would take the initiative. At the same time he recalled a previous attempt he had made to form a foundry managers' association.

The First Meeting.

The discussion vigorously continued and in the July issue letters appeared from Mr. Finch and "Foundry Manager" both making light of the difficulties suggested by the correspondent "T.S." A further practical suggestion came from Mr. Finch to the effect that the Editor should provide space for the insertion of names and addresses of those interested. "Foundry Manager" again urged the holding of a general meeting in Manchester, suggesting that the seventy foundries in that district would no doubt combine to see the thing successfully carried through. More letters appeared on similar lines with Editorial notes in practically every issue. But still the matter flagged and in November, 1903, the Editor, in his notes was very despondent at the apparent lack of progress and emphasised the necessity of Mr. Finch's slogan "Wake up." In December, 1903, appeared an excellent article by Dr. Percy Longmuir entitled "A Foundrymen's Association, Its Possibilities and Advantages to the Foundry Industry." In the same issue appeared an enthusiastic letter from J. A. Phillips, some helpful Editor's notes, and a letter from a Scottish representative of the JOURNAL, stating that a suggestion for the formation of an association had been well received by the Scottish foundries.

Still the actual formation was delayed, until Mr. Finch, taking his courage in both hands, invited, through the medium of the Journal, all those interested in the formation of an association to meet him at the Cobden Hotel, Birmingham, on Saturday, April 9, 1904. This appeal resulted in the appearance of the following gentlemen, namely, R. Buchanan (Birmingham), C. Morehead (Rugby), J. Ellis (Southampton), F. W. Shaw and W. Vickers representing F. J. Cook (Birmingham) and F. W. Finch (Gloucester).

Nothing daunted by this poor response to the appeal, the handful of pioneers decided to take the bold step of forming an association. Mr. R. Buchanan was nominated President, Mr. F. W. Finch Secretary and Treasurer, and those present to form the Council with power to add to their numbers. It was also decided to make a special effort to obtain further support for the project by circularising all the foundries with more than five moulders. The details relative to the foundries were obtained for this purpose from the annual report of the Moulders' Society, and those for Scotland from Mr. Jack, the Secretary of the Scottish Union. Mr. Roxburgh (Kilmarnock) was very helpful at this stage in classifying the Scottish list.

First Results.

The second meeting revealed the fact that the special appeal had met with a fair amount of success; fifty applications for membership had been received, which was considered so satisfactory as to warrant the holding of the first annual Convention in Manchester during the August Bank Holiday week. Mr. J. G. Stewart, of Urmston, Manchester, who was present at the meeting, undertook to make the necessary arrangements for that Convention. By the time of the Convention 89 members had been enrolled of whom over 50 attended, and it can safely be asserted that no Convention has ever been more thoroughly enjoyed, and at none has a larger percentage of the members attended. Friendships were made on that occasion that have lasted until the present day. By the end of the year 1904 the membership had increased to 100.

Initial Objects.

The Council gave a great deal of thought and attention to the question of defining the lines on which the Association should be run, and though many ideas were never put into writing some of them have always been well understood and considered as unwritten laws. The primary object was considered to be purely educational—the education of the man actually at work in the foundry, such as workmen, foremen and managers. This was to be followed by educating those outside the shops who are more or less directly or indirectly concerned with it, such as draughtsmen, patternmakers, proprietors and works managers, etc. As an incentive to membership the subscription was placed at the absurdly low figure of 7s. 6d. per annum. It was also definitely decided that the Association should not countenance any discussion of Trade Union matters, whether appertaining to wages or conditions of labour. Further, the Association was not to be used in any sort of propaganda for business houses in the selling and advertising of their goods. The success which has followed the ideals set up in those early days proves that the Association was well and wisely governed from its inception.

The Official Organ.

In December, 1904, after discussion by the Council in conjunction with Major Cheesewright, it was decided to appoint THE FOUNDRY TRADE JOURNAL as the official organ of the Association. This step was considered an economical way of keeping directly in touch with the members, as at that time the Association funds would not allow of heavy expenditure. The members were allowed a rebate on the JOURNAL by the proprietors, who also undertook to provide space for reports or communications from foundrymen. In furtherance of this idea, and also for the purpose of drawing up a set of rules for the Association, a literary committee was formed comprising Mr. Buchanan and the author of this review, this committee promising to provide articles from time to time in the JOURNAL on points appertaining to the welfare of the Association. The first of these articles appeared in the March issue of 1905 over the initials of "F.J.C." (the author). In this article the writer pointed out the inadequacy of one meeting a year to such an Association, and suggested that until Branches could be formed (a policy which the Council always had in mind) it was desirable that wherever members of the Association gave papers to other Societies they should stipulate that invitations should be sent to all members of the Foundrymen's Association in the district. This article was followed by others from the pens of F. W. Shaw, C. Morehead and R. Buchanan.

The First Branch.

Manchester with her natural foresight and pushfulness may well be proud of the fact that in 1905 she received the sanction of the Council to form the first Branch, to be known as the "Lancashire Branch." Its first meeting took place in the autumn of that year when Mr. Finch addressed an audience of about seven. The first President was Mr. W. Russell, of Pendleton, and the first Secretary, Mr. J. G. Stewart, of the British Westinghouse Company, a man who did valuable work at the commencement of our history both in and out of the Council. Birmingham was the next to form a Branch, its first meeting being held on April 28, 1906, under the Presidency of R. Buchanan, and the author as Secretary. Mr. R. Mason, now in Australia, also helped to found the Birmingham Section.

Several meetings were held at Cardiff with a view to the formation of a Branch. They were organised entirely by the late Mr. Charles Jones, who not only did all the work, but paid the expenses out of his own pocket. But Cardiff seemed to lack the necessary enthusiasm, and this attempt gradually faded away. About eighteen months from its formation the Association was being run on lines which have proved most successful down to the present day. That in itself speaks volumes for the time and attention given by the members of the Council, and reflects credit on their admirable foresight and business acumen.

Milestones of Progress.

The Association now having been firmly established there only remains to enumerate some of the various milestones which stand out on the high road of progress. These have been very many, and the importance of some of them is probably hardly realised to-day. But they are destined to be of great value, particularly in our worldwide relations.

During the first few years of the Association's existence, and particularly after the formation of the Branches, it soon became clear that the annual subscription of 7s. 6d. per member was not sufficient to allow of developments which were so urgently needed. The Birmingham and Cardiff Branches, realising that headquarters could not afford to pay Branch expenses, both decided to pay their own. Up to that time Birmingham had met the difficulty by a subscription of 3s. per annum from each Branch member, and, as previously mentioned, Mr. Jones had himself paid the expenses of the Cardiff Branch. But the parent body continued to finance the Lancashire Branch, and this fact brought forth comment at several annual meetings when the statement of accounts came to be presented. This question, together with the desirability of printing a more extended annual copy of Proceedings, was considered by a sub-committee of the Association, with the result that the following recommendation was adopted at the Birmingham Convention in August, 1909:—

> "That a scheme of membership be inaugurated consisting of members at one guinea per annum subscription; associate member at half a guinea, and branch associates at three shillings, and all Branch expenses to be paid by headquarters."

This enabled the immediate commencement of enlarged Proceedings in their present form to be issued annually.

At the Convention in Glasgow, August, 1911, the Council put forward a scheme of Diplomas for the best paper of the year read before Branch meetings, believing that such a scheme would act as an incentive to members to write papers of an eminently practical character. It was also hoped to formulate schemes of awards for the whole Association.

Growth of Branches.

The number of Branches was gradually growing, and the inauguration of a Sheffield Branch in 1908 was followed by the Scottish Branch in 1910, London 1911, and Halifax and Newcastle-on-Tyne in 1912. The reading of papers before these Branches, the authors in many cases being eminent metallurgists, evinced a general desire among the members for a comprehensive "Glossary of Terms," to enable a better understanding of the purport of chemical and metallurgical phenomena. The sequel to this was a "Glossary of Terms" published in the Proceedings of 1911-12, this having been prepared by a sub-committee consisting of Dr. P. Longmuir, the late Mr. R. Buchanan, Dr. T. Swinden, and the author.

Another important educational question occupied the attention of the Council at that time, namely, apprentice training. A strong Committee, with Mr. Sidney A. Gimson as its Chairman and Mr. A. Hayes as Secretary, was formed, and, largely owing to the activities of these gentlemen, a comprehensive scheme was presented at the Convention in June, 1915. It was hoped and expected that it would be possible to expand this work still further, so as to formulate a definite curriculum for both shops and night-class training. But unfortunately the exigencies of the war cut short any further work on the matter.

In addition to services rendered in time by members of Council, some had furthered its interests by presentations, such as design and dies of crest for the Association by the late Mr. Charles Jones, of Cardiff, for use on the Association's notepaper. Badges were also made to be worn by members at Conventions, etc. But at the London Convention, in June, 1916, Mr. Mayer, of Dumbarton, the then retiring President, presented to the Association a valuable and beautiful President's gold chain of office, with links on which to engrave the names of the successive wearers. This was duly handed over, together with a properly drawn up legal deed of gift setting forth the terms of the present, and this chain was worn for the first time by Mr. J. Ellis, the incoming President.

Increased Fees Bring Prosperity.

In 1909, when the scale of members' subscriptions was increased, there were those who prophesied a great reduction in membership, and thereby a shrinkage in funds. This, however, proved to be unfounded, for both membership and funds increased rapidly, and by 1915 the Association had 1,047 members as compared with 448 in 1909, and the balance at the Bank in 1917 was such as to warrant an investment in War Loan to help the nation to the extent of £350.

International Connections.

The Great War of 1914 to 1918 militated against many things being done which might otherwise have been undertaken. Yet at the end of it an event took place which, though on the surface may appear to have little or no connection with the Association, bids fair to have far-reaching effects in our endeavours towards international relationship.

At the end of October, 1918, at the invitation of the British Ministry of Information, there sailed from America a party of American industrial Press representatives to inspect the battlefields, but who at the same time were specially interested in the industrial activity of Great Britain. Among the party was Mr. H. Cole Estep, of "The Foundry," who during his tour of inspection of plants got in touch, as far as time and circumstances would permit, with several members of this Association. His return was followed in the next year, 1919, by a visit from his colleague, the late Mr. A. O. Backert, and in 1921 by Mr. John Penton. The visit of Mr. Backert synchronised with his Presidency of the American Foundrymen's Association, and as such he was warmly received and entertained officially by members of our Association at Sheffield, Coventry and Birmingham. Mr. Backert, as many of you know, was a most charming man, who endeared himself to everyone he met, and he carried back to America a very keen appreciation of the position our Association held. This appreciation he soon turned to the mutual benefit of both the American and British Associations by suggesting that there should be an annual exchange of Papers between the two countries, these papers to be given at the respective Conventions. This suggestion was warmly received, and the first exchange paper was given by the late Mr. G. K. Elliot on behalf of the American Association at the Blackpool Convention of June, 1921. In the following year, 1922, Mr. Oliver Stubbs, then our President, and the late Mr. Thomas Firth, visited the States, together with the author, who attended the Rochester Convention and presented the first paper on behalf of the British Association.

At the Birmingham Convention in the same year, June, 1922, which immediately followed the return of these gentlemen from the States, Mr. Stubbs held a private luncheon at the Midland Hotel, Birmingham, at which representatives of America, France, Belgium and Britain were present in the persons of Mr. Stanley G. Flagg, Junr., U.S.A., P.P., A.F.A.; Professor Touceda, U.S.A.; Mr. E. Ramas, France (President of Foundrymen's Association); Mr. E. V. Ronceray, France; Mr. Leonard, Belgium (President of Foundrymen's Association); Mr. Varlet, Belgium; Mr. H. L. Reason, President I.B.F.; Mr. Frank Somers, Past-President, Staffordshire Iron and Steel Institute; Mr. F. J. Cook, Past-President, I.B.F. and Staffordshire Iron and Steel Institute; Colonel Cheesewright, D.S.O., of THE FOUNDRY TRADE JOURNAL; Mr. T. H. Firth, Past-President, I.B.F.; Mr. Cole Estep, Cleveland, Ohio; Mr. V. C. Faulkner, Editor of THE FOUNDRY TRADE JOURNAL; Mr. Oliver Stubbs, Past-President, I.B.F.

There grew out of this meeting a movement for closer cordial relations between Societies holding similar ideals, a movement of a wide and international character which has now become firmly established.

The Research Movement.

Coming back to the history of the Association, the need had been felt for a long time of an Information Bureau and of some sort of facilities for the carrying out of research work. There had been given to the Association the results of research work by Coe, and also those that had led up to the "Network" Formation of Cementite and Phosphide Eutectic and the action of Blast in Cupola Working. This data, however, had been the result of individual effort and not directly the outcome of the Association. The matter was considerably influenced by a paper given at the

Sheffield Convention in June, 1918, by R. Buchanan, entitled "A National Information Bureau for Foundrymen." As the result of this a special committee was appointed by the Council in August of the same year to deal with this matter. Great consideration was given to the matter from all aspects, and the committee were convinced that a body with a much wider scope than the Association was needed adequately to cope with the subject. Steps were then taken to form a Research Association under the auspices of, and in conjunction with, the Government Department of Scientific and Industrial Research. This Association came into being in 1920, and is an institution of which the Association is justly proud and in the working of which its members are taking a prominent and important part.

The Royal Charter.

At the same Council meeting, in August, 1918, a committee was formed to consider the question of applying for a Royal Charter This was a tedious and costly business. But largely owing to the untiring efforts and perseverance of the late Mr. Thomas Firth, the Charter was secured, and without any financial responsibility to the Association.

The expenses of the Association naturally grew with the expansion and wider scope of its work, and during the year 1920 expenditure outran the income by £165. It was considered essential that a paid Secretary with an office in London should be appointed, and for this purpose, together with a desire to see the Association on a sound financial basis, the Convention held in London in August, 1920, passed the Council's recommendation to increase the membership fees to Members two guineas, Associate Members one guinea, and Associates half a guinea. It was also decided to institute a new form of membership under the head of " Subscribing Firms " at five guineas per annum, and this action has added considerably to the prestige and scope of the Institute's activities.

Oliver Stubbs Medal.

At the Blackpool Convention in September, 1921, the President announced that the National Ironfounding Employers' Federation had been pleased to offer a sum of £200 to be invested in the name of the British Foundrymen's Association, the interest from which should provide for a gold medal called the Oliver Stubbs' Medal, in appreciation of the esteem in which that gentleman was held by both Associations and this medal should be awarded annually to a member of the Institute who had shown sufficient merit to warrant it. This gift was gratefully accepted, and a sub-committee, under the chairmanship of Mr. Carey Hill, of Coventry, formulated rules to be adhered to in making the annual award. The first recipient under this scheme was the author, at the Birmingham Convention in June, 1922.

Foundry Exhibition.

That Convention of 1922 was important in other ways, for it was in conjunction with that meeting that the first Foundry Exhibition supported by the Association was undertaken. It was there that Oliver Stubbs, as before mentioned, forged and welded the link of internationalism. The Exhibition was a great success, and at the Convention Papers were given by representatives from France, Belgium and the United States of America.

In the same year, 1922, W. Mayer again gave expression of his continued interest in the work of the Association by presenting funds, the interest from which would provide medals, to be called the "Surtees Medal," to be competed for annually by the Scottish and Newcastle-on-Tyne Branch members.

The international side of foundry work was steadily gaining ground, and in 1923 an international gathering was held at Paris, at which many of our members were present, as well as a large party from the United States, who previous to going to Paris, made an extended tour, and were officially entertained by our members in London, Sheffield, Manchester, Birmingham and Coventry. During 1926 the second international meeting took place at Detroit, U.S.A., when a fair number of our members attended. The exchange Paper was given by Mr. J. Shaw, and it is very gratifying to know that both he and Professor Turner were presented with gold medal awards by the American Association.

No account of the work of the Association could be considered complete that did not pay a special tribute to the loyal, enthusiastic work of the honorary secretaries. The Association has been most fortunate in being able to attract men to this position who have laboured for the good of the cause in a whole-hearted fashion.

Mr. Finch, the first secretary, held the position from the formation of the Association till August, 1907. In this year he was followed by Mr. J. E. H. Allbut, who continued to hold the office till he was relieved by Mr. E. A. Pilkington in 1913. In 1918 Captain Alexander Hayes was appointed to the office.

During this time the work of the Association had grown to such an extent that it became necessary to employ a paid secretary. A special committee was formed to consider the matter, and in 1920 it was decided to elect Mr. W. G. Hollinworth as secretary and open an office for the Association in London. Owing to ill-health, Mr. Hollinworth had to retire, and the position was occupied by Mr. T. Makemson, the present secretary, in December, 1926.

Looking back over the long years, one cannot but be impressed with the fact that the formation and destiny of this Association has been carefully and wisely looked after by men of outstanding merit and ability, both on the scientific and practical side of the industry, and to have been associated with such pioneers is a lasting delight to the author of this review.

DISCUSSION.

The Chairman (Mr. S. G. Smith) said the address by Mr. Cook had been delightful, and would be looked upon as a historical event. It was suitable for printing separately and sending out to the Branches. The address revived memories of the past. His first acquaintance with Mr. Cook began in 1908, when Mr. Cook persuaded him to give one of his earliest Papers at the Birmingham Conference of the Institute, and they had been in close association ever since. Mr. Cook had been actively interested from the beginning, and was one of the hardest workers for its welfare.

Future Progress Depends on Membership.

Mr. Oliver Stubbs said it was sometimes suggested that the conduct of the affairs of the Institute was carried out by too few people, and too little work left to other members of the General Council. The reply to that was that other members would not take up the work. There were Past-Presidents who, after they had closed their term of office, did not continue to take an interest in it as they ought to do. To a certain extent that remark applied to the Branches as much as to the General Council.

They were expecting the new General Secretary, Mr. Makemson, to undertake propaganda work, and to assist him Mr. Cook's address should be reprinted and distributed widely. It presented reasons why both firms and individuals should join the Institute. He believed the work done by the Institute had accomplished more to maintain peace in the foundry industry than the joint conferences specifically held for that purpose. But it had to move onward, and the only way to continue improving was by bringing in fresh members. Considering the hard times through which they had been passing in the last three years, the membership had kept up remarkably well. Indeed, when one saw the numbers who were passed for membership at each General Council meeting, it seemed surprising that the membership did not actually increase, but, unfortunately, the newcomers only replaced those who had resigned or dropped out through inability to pay the subscriptions. He sympathised with men who had to look carefully at a guinea or two guineas in such hard times. But in the near future the Institute would recover any ground it had lost. The first step should be to leave the meeting with their minds made up that they were going to get more members. Men of some education were wanted. Let them be given Papers of a character not too academic, so that they might feel they were making some progress, and the work would not be in vain.

Double Office.

Mr. H. Sherburn, after expressing his father's regret at not being able to attend and meet his old friends, with whom he became acquainted through the British Foundrymen's Association, said at one time his father was both President and Secretary of the Lancashire Branch. Happily those days were past, but for some years the position of the Lancashire Branch was full of difficulties, and anything but pleasant. One of the best men they had ever had was Mr. Kenyon, who, unfortunately, because of advancing years, could not now take the same interest in the work that he used to do. Perhaps that reason explained why some ex-Presidents of the Institute who were pioneers of the Institute were no longer active in its cause. Mr. Cook was a brilliant example to the contrary; he had been acting right through the piece, and still carried on with undiminished vigour. That afternoon he had contributed a valuable address to which the maximum publicity should be given.

Mr. Haigh remarked that he had been a member of the Lancashire Branch since 1906. All through the members had regarded men like Mr. Cook and the late Mr. Robert Buchanan as leaders and directors in the movement. But he wanted now to appeal to the young men in the foundries. At the present time it was difficult to induce skilled operatives to take an interest in it. The people in executive positions, the scientific people, the men who held administrative posts, had become interested; it was time the man on the floor or the bench was brought in also. In his opinion the Institute was suffering now through the practical not being linked up with the academic and technical.

Mr. T. W. Markland said the outstanding feature of the work of the Institute was that it was educational, and he thought the young men were beginning to realise that. Proof of his statement was given by the Junior Section. The conditions to-day were very different from those which prevailed thirty or forty years ago. Men were seeking knowledge, they wanted to be educated, and the Institute would help them.

Mr. T. Makemson said a history of the Institute was needed; the information available about its early days was very scanty, so they had reason to be glad that Mr. Cook had had the time and the inclination to prepare this address. No one was better qualified to do so, because he had himself taken part in most of the events of those early days of the Institute.

Mr. Cook had mentioned that after 1909, when the subscriptions were increased, the membership rose. A few years ago the subscriptions were again raised, and the membership again increased. However, he did not suggest the inference was that they should make a further increase in order to get additional members. But there were many people outside to whom membership of the Institute should be invaluable. Besides the educational advantages in the form of Papers, there was the great benefit derived by associating with other people engaged in the same industry. There was plenty of work for the Institute to do. The more members they had, and the more enthusiastic they were, the better it would be for all.

Vote of Thanks.

Mr. J. S. G. Primrose said if Mr. Cook would tell them something about the Conventions, it would be a most interesting sequel to the present Paper. He remembered seeing Mr. Cook at the Glasgow Convention in 1905, and had the privilege of showing Mr. Cook and other members something about metallography. The British Foundrymen's Association was the first society that met in the Royal Technical College, Glasgow. Mr. Buchanan gave his second presidential address. An appendix giving a list of the Conventions and the names of the Presidents, in addition to the Secretaries, would be a useful addition to the Paper. Mr. Cook might also favour them with a list of the honorary members. He moved that a hearty vote of thanks be given to Mr. Cook for this Paper.

Mr. R. A. Miles, in seconding the motion, remarked that some members of the Lancashire Branch had also interesting reminiscences.

Mr. G. Hall said he was a member of the London Branch, and, while expressing on his own account his appreciation of the address, he would suggest to Mr. Faulkner that he should induce Mr. Cook to repeat it to the members of the London Branch.

Mr. Cook said at one time there was trouble which looked like wrecking the Association, but it was grappled with. The first secretary was Mr. Finch; he was followed by Mr. Allbutt; then came Mr. Pilkington, junior. Those three were honorary secretaries. The fourth secretary, Mr. Hayes, had a certain amount given to him, but it was very small compared with the extent of the work done. A great deal of the success of the Institute was due to the work of those three honorary secretaries, and he did not know how they managed to get through that work. It had to be done at night, because they were engaged in business the whole of the day.

He had no hesitation in saying that the Institute was going to have a good time in the future. For some time past he had felt that propaganda work for getting in new members was lacking. In that respect there should be an improvement now, because they were on the right lines for getting such work done. That applied also to the men in the shops to which Mr. Haigh referred. It was a difficult matter, and he had given much time and thought to it. His conclusion was that they must try to get the foundry people when they were young; if they grew up with the Institute, they would not want to leave it. That great strides had been made since the Association was founded became apparent when one considered the state of knowledge in the foundry trade at that time. To the foundryman then pig-iron was pig-iron, and cast iron was cast iron; he did not trouble himself about the elements in it. In order to enlighten the people in the industry somewhat a glossary of terms was published. He did not think any association of an educational character in this country could claim to have progressed in its educational work to the same degree as the I.B.F.

London Branch.

PRESIDENTIAL ADDRESS.

By R. J. Shaw.

The London Branch of the Institute of British Foundrymen held the first meeting of its 1926-27 session at the Engineers' Club, Coventry Street, W.1, on September 23, when Mr. R. J. Shaw, the new Branch-President, delivered his Presidential Address.

Induction of New President.

Mr. Geo. C. Pierce (the retiring Branch-President), who occupied the chair at the opening of the proceedings, introduced Mr. Shaw. It gave him the greatest pleasure, he said, to do so, although Mr. Shaw was so well known to the members of the Branch that an introduction was really unnecessary. He felt that the Branch had made a worthy choice in their new President, and was confident that Mr. Shaw's year of office would be a very successful one.

Mr. Shaw then took the Chair, and was received with enthusiasm.

Presidential Address.

Mr. Shaw, expressing thanks for his election, said he appreciated the great honour conferred upon him. He was a very keen member of the Institute and had its interests very much at heart, and assured the members that he would do his very best to further the interest of the Branch during his period of office. He then delivered his presidential address.

THE PRESENT STATE OF OUR INDUSTRY.

Mr. Pierce and Gentlemen,—You will remember that last year the retiring President, Mr. Pierce, addressed you on "What is Wrong with Our Industry," and much that I have to say to you this evening can be taken as an extension of that address although it has a slightly different title, and is perhaps examined from another angle.

It seems to me that although a great deal of information concerning the metals and processes, which are in common use in our industry, is available, that for some reason we are not making the progress that we ought to.

Metallurgists, both practical and scientific, have enormously increased the knowledge available for use in the successful handling of the melting, casting and heat treatment of those metals which we, as founders, have to use daily. They have given us in the case of aluminium, stronger alloys with less liability to corrosion, and in the *silicon-aluminium alloy* one which has much less contraction—it has about the same contraction as cast iron $\frac{1}{10}$th inch per foot. This is an exceedingly important property where long, thin castings have to be produced. "Lightness," that quality which has always made *aluminium* so fascinating a material, has also received attention, and additionally there is magnesium, which is nearly 40 per cent. lighter, being used for the pistons of internal combustion engines, *but* we require in all these alloys less liquid shrinkage before routine work in the foundry will be performed with certainty. In the case of the brasses and bronzes we have been shown the importance of the analysis of the raw materials, *and* the powerful effect of very small amounts of impurities has been proved by physical tests and microscopical examination, and foundrymen will no doubt be called upon to supply gunmetal and bronze castings having higher physical tests than at present.

Steel.

Steel, as used for castings, has always been closely under the control of practical metallurgists who have been able to reduce to practice the results of years of research work by their learned colleagues, and therefore it is handled with much more certainty and retains its high place in the productions of the engineers.

Cast Iron.

Cast iron has of recent years been receiving a more reasonable share of attention and research than in the past; due mainly to the fact that it has been recognised as a very useful material, which is not too difficult to handle in actual foundry practice—a very important point indeed when some of the complicated castings of modern engineering designs have to be made; and progress in its improvement has been most marked, but I do not think the foundry industry can take much credit for initiative in this matter, as until Diesel engine makers, and other engineers demanded better material we jogged along producing very indifferent cast iron, but to-day we are asked for tests of 16 tons tensile in pistons, 13 tons in flywheels, and 12 tons in cylinders by automobile manufacturers, and for oil-engine work, material which, in addition to being strong has heat-resisting qualities, that is, will not "creep" or grow under the influence of high temperatures. These requirements are only being met to-day by those foundries where the foundry manager makes the fullest use of available metallurgical and mechanical aids, such as special cupola practice; treating the melted iron in the receiver; jolting it in special receivers; pouring it into heated moulds. All have the same object in view, namely, an improved material, and in this connection it has long been known that the state and quantity of the carbon had a great influence on strength, but though silicon, phosphorus, manganese and sulphur could all be controlled under works conditions within fair limits, carbon was a very different proposition, and the patented process which has been most discussed, and in which you have all been so much interested is a definite attempt to ensure that cast-iron castings have correct material in its best form of crystallisation. It seems here desirable to remind those who think mostly in terms of silicon, phosphorus, sulphur and manganese, when deciding on a suitable analysis for a certain casting, and who know by, say, lowering the silicon and phosphorus, etc., that they get a stronger material, that in so doing they were really adjusting these constituents in the cast iron, so that the carbon could take up its best condition. Now *if* in their attempts they had gone a little too far in the reduction of silicon and produced a casting, quite sound, but too hard to machine, it is conceivable *that* if they could have cast it in a hot mould they would have had a casting of grey cast iron and of machinable qualities, having the carbon so disposed that a pearlite structure resulted. Many of us who have used heated moulds for years on special castings must admit that we did not do it for this definite purpose, but for insuring against a blown or misrun casting, especially in the case of a casting of intricate design and thin section. I point out this to show how this one step forward from what was ordinary procedure when making good material, has resulted in that definite structure associated with greatest strength, being obtained with *regularity* under practical workshop conditions.

And now, having somewhat sketchily indicated to you that the scientific side of the industry is going forward, I would remind you that, although many of these improvements have been initiated by engineers in the foundries of their own establishments for their own productions, engineers generally will act on them and demand from all foundry men similar material. They are very much alive to the fact that a reduced weight with improved reliability and lower freight-charges are very great aids to selling their machinery, and the question arises, have we labour sufficiently skilled and well-directed, with the necessary metallurgical and mechanical aids to enable us to "deliver the goods"? If we compare the skill of our craftsmen, moulders and coremakers with other skilled workmen in the engineering trade from a handicraft point of view, it is at least equal or superior, but as to technical knowledge foundry workers are found lacking, and it is, as our American friends say, "right here" where the weak spot exists. I cannot see how we are to use the technical knowledge available at present if our workmen have not, for instance, the elementary knowledge of science to enable them to listen with understanding to a lecture on cast iron, or any of the other materials they use in their daily work. It is not fair that we should be continually asking that lecturers should speak in "foundry language." Scientific men, as a rule, are concise and exact in speech, though perhaps some of them may have a happier manner than others in presenting their subject, but I do not think the members of any trade should confine themselves to mere handwork, as so many of ours do. A good-looking mould is, of course, desirable, but it will not produce a good casting unless it has been planned to resist the scouring action and the pressure of the metal to be poured into it. I have often tried to interest young men in the metallurgical and mechanical side of their work, but with indifferent results. It seems to me that the trouble is that elementary schools are not very successful in teaching boys the relationship between some very simple scientific facts, and their application to everyday workshop processes, and so boys, when they arrive in works, have very little to interest them, and after a few weeks they drift with the rest, even those young workmen whose temperament and ambition lead them to aspire to become foremen want to be foremen first, and take a little mild technical instruction afterwards. If we are to go forward and make real use of the scientific information which is now available, our boys and young men will have to take advantage of our technical schools, lengthening their hours of work by study and shortening their hours of play, for there is no royal road to learning.

In addition to this, the industry does not seem to be able to attract to it sufficient apprentices, though I do not think it is much worse than other skilled trades in this respect. The trouble seems to be that parents nowadays want their sons to be salesmen not producers. It is so much cleaner and better paid. This latter point is becoming more prominent, and it seems probable that in the future the middleman will have to take a more reasonable share from the products of industry than he does at present.

Managers and Foremen.

Are those in control of foundries keeping up to date and able to translate into practical use the knowledge available? I think this extremely doubtful when it refers to men who have been trained as moulders, for in spite of some brilliant exceptions far too few deliberately aim at and prepare themselves for responsible positions. Foundries are such easy places in which to lose money that owners give grave consideration to the matter before entrusting their foundry to any applicant. The foreman who can "mix by analysis" is an improvement on the one who extracts his mixtures from his grandfather's notebook, but it is also necessary that he should know of the differing qualities required by engineers in their various castings and the best analysis to obtain them, though unless he has supplied to him the correct analysis of each parcel of pig-iron and scrap and can have his actual mixture checked by analysis I do not see how he can fully utilise this knowledge. It follows, therefore, that he must have the aid of a chemist, and I believe it to be beyond doubt that even a very young chemist capable of performing physical testing and routine analysis within reasonable commercial limits can be an economy in a foundry producing 20 tons per week of good-class engineering castings, but he can only be used to advantage when the manager or foreman knows his job. Consensus of opinion is that a chemist should be on every foundry staff, but in some cases he has not been a success, and I have heard a Past-President of this Institute express the opinion that a chemist would have to undergo a training in foundry practice before he would be of any use in the foundry. Now this can only be true if the young chemist has had thrust upon him duties and responsibilities which only years of experience of the various castings required by engineers would enable him to perform satisfactorily. I cannot suggest any other reason why the foundry chemist should not be a success, and you will note that the reflection is on the management. It is well to remember that the difference in cost between very mediocre cast iron and very good cast iron is negligible, when the analysis of the raw materials furnished by the chemist are utilised by one who knows what is required for a certain casting or types of castings, so that almost in a single step a foundry not only produces a material suitable for high-class castings, but at the same time eliminates a fruitful source of friction between the moulders and the management, as happens when good metal is given them with regularity. I ought perhaps to have made it clear that a great deal of what I have just said applies to the foundries of moderate size whose output is mainly jobbing castings. The larger foundries and those who specialise in light castings, rainwater goods or pipes are usually run by specialists, and are reasonably well organised and much better equipped with machinery than the foundry of moderate size.

Modern Plant.

Now this question of mechanical aids in the foundry is of the highest importance because although primarily their object is to enable men to produce good work with regularity so that results are more certain, yet up to the present they do not seem to have reduced the hard manual labour which is associated with foundry operations as they ought, and when we compare the small amount of energy expended by iron turners, milling and other machine operators with that of our craftsmen it is apparent that here we have another possible explanation of why we cannot attract a good type of boy to the trade or retain men when in it, for it is an undoubted fact that many are leaving it to take up semi-skilled work. Contrast starting time each morning as it affects the moulder and the machinist; the latter pulls the belt lever over and starts. The moulder has probably to assist in knocking out his boxes, prepare his floor, and if his castings appear satisfactory he is *only physically* tired before starting to make moulds, but if a few wasters have turned up during the knocking-out process he is also mentally dispirited, and not in the best form to proceed with his day's work. It appears obvious, then, that any mechanical aid which will spare our men undue exertion should be installed in our foundries. Sand-preparing plant which will clean the sand from iron, in addition to mixing it, ample crane units, runways, sand-blasting barrels, or those of the table-type form (I do not think those of the room type should be encouraged), and all the other apparatus, examples of which were to be seen at the recent Foundry Exhibition held in London. Foundry buildings also should be well lighted and fitted with plenty of plug connections for handlamps. This also applies to air supply for blowing out moulds, but what we require most is plenty of space. We might well consider the advisability of having our shop large enough to enable the men to work in one-half of it to-day and prepare the other half for to-morrow. Just think how orderly it would be for a man to pick up his tools and cross the shop to a floor all cleared and with ample sand ready, instead of having to start amid all the bustle of labourers knocking boxes out. It would all conduce to the production of sound, reliable and well-finished castings, such as would reflect credit on the industry.

Costing and Selling.

It would be pleasant to end on this note, but in this commercial age, when everyone seems to be interested only in the cheapest articles they can buy, we must "count the cost." It is this counting of the cost that adds so much to the worries of the managers and foremen, and while it is imperative that production cost should be taken very thoroughly, a better spirit might be infused into it if foremen were shown how the extra shillings mounted up when overhead charges are added. We are to have the pleasure of hearing a Paper this session by Mr. Bagshawe on this subject, and I commend this question of costing to your notice because as an industry we are hopelessly behind the times in this matter, and buyers of castings have, and cannot help but have, a low opinion of our business capabilities when they compare the widely different prices quoted for the same casting. It is impossible for foundries to price their castings at so much each, but *it is not impossible to draft a sliding scale of prices* which will be just and equitable to both the buyer and the foundry, not that buyers in the engineering industry evince any eagerness for a sliding scale, their idea is an all-round price per cwt., and this is one reason why we drag at the heels of the engineering industry. Yet they subject our products to the closest scrutiny, in the larger shops by inspection departments and in the smaller by the foremen in charge, and these do not take any risks, neither does the purchasing department. The last-named makes quite sure the price is right, and an all-round one per cwt. That slogan to which engineers stick so grimly and on which they have built successful businesses, leaving the foundry trade as an industry impoverished. I doubt if 10 per cent. of our foundries are making profits. How, then, can an industry so financially embarrassed afford up-to-date plant, clever staffs and a reasonable livelihood for all those engaged in it. I suggest to you that strong efforts will have to be made in the near future to impress upon engineers that we will meet what they are demanding in their castings, but that high-grade workmanship and regularity in quality of material cannot be maintained unless they are prepared to be more reasonable with regard to their methods of paying for it. At present when one undertakes the supply of castings to a new customer on an all-round price per cwt. basis, it is a sheer gamble, and when badly designed and badly made patterns are included the founder is a certain loser. I think most of the blame for this state of affairs rests with ourselves, and without doubt has been due to a lack of costing, for I cannot think that anybody would persist in supplying an article below cost if he knew the truth of the matter. It has been said truly that the finding of costs accomplishes two things. Firstly, it tells you what must be charged for your castings in order to make a profit, and secondly it tells just where the money goes.

Those who take costs are fully alive to the bitter truth of the second, and we have to thank those who *do not* take costs that we can make little use of the first.

Therefore, gentlemen, let us continue our efforts, both scientific and practical, to improve our product so far as our present impoverished state will allow us; but having done so, let us see that we get paid for it—the labourer is worthy of his hire.

DISCUSSION.

Although it is not usual to discuss Presidential Addresses, it was decided, with the Branch-President's permission, to follow the practice inaugurated last year, when the presidential address by Mr. Pierce entitled "What is Wrong with our Industry?" was discussed.

Mr. V. C. Faulkner (President of the Institute) opened the discussion, and said that the Branch-President had focussed the thoughts of the industry in the right direction, especially when he had emphasised the necessity for adequate costing. There was only one means of ensuring that proper costing methods should be adopted, and that was beyond the scope of the Institute, *i.e.*, by the formation of a very strong foundry employers' federation. There was just a danger that if we had in Great Britain an employers' federation of the strength of the German employers' federation, it would become the plaything of the politicians. The federation in Germany had 1,400 members, although there were only 1,600 foundries in that country. They had their own co-operative buying arrangements; they simply dealt with the pig-iron ring when buying pig-iron; with the coke ring when buying coke, and they had a selling price-fixing arrangement based on a unified costing system, with district modifications. They were so strong that they invited their best customers, such as the railway companies, to take costs for themselves and compare their figures with those obtained by the system they (the employers' federation) had evolved. At the Dusseldorf Exhibition they had shown curves based on their system and curves obtained by independent auditors, and it was very interesting to see the curves of the auditors lying between the synthetic curves of the founders.

The method adopted by employers in America was to appoint one auditor to put the same costing system into the works of one locality, and that seemed to be the only feasible way of tackling the matter in Britain.

A Proposed Junior Section.

With regard to the apprenticeship question, that was very much in the minds of the Branch Council at the present time. The Council had had a demand from some of the foundry apprentices for the formation of a section for them, similar to those in existence in other large centres, and a meeting was to be held during the following week to explore the possibilities. There seemed to be some prospect of forming such a section, and if they could get only 10 boys to attend, he was convinced that there were at least 8 or 10 members of the Institute who would be prepared to give one night a year to talk to them.

As to the equipment of foundries, he was very much alive to the fact that there were numbers of foundries in this country who knew exactly what plant they wanted, but were too poor to buy it. They knew also that they wanted better buildings, better lighting, and so on, but they were simply so poverty stricken that they could not afford it. The only way to save the founding industry from complete bankruptcy was to equip the foundries properly. The industry was in much the same position as the mining industry, except that the mining industry knew it was bankrupt, whereas the founding industry did not. He had been urging for a long time that foundries should be properly lighted, and, although some were properly constructed, no provision was made for cleaning the windows. He had seen something practical in that direction, however, at the foundry of the Esperance Longdoz, during a recent visit to Belgium, where they had fixed up a run-way alongside the windows, and had put an auxiliary machine on top of the crane to enable the roof windows to be kept clean. Finally, Mr. Faulkner proposed a hearty vote of thanks to Mr. Shaw for having focussed attention in his presidential address upon so many important points, which affected all the members in their daily business.

Mr. Horace J. Young, who seconded the vote of thanks, said he had heard a good many presidential addresses throughout the country from time to time, but he really believed that Mr. Shaw, in about a quarter of an hour, had delivered the best address he had ever heard. He did not say that merely for the pleasure of saying it, but because he really and truly believed that every one of the things he had said in such a clear manner—things which he himself would not have dared to have said (laughter)—was correct. He had never heard a President of any Branch say what was really true about the foundry trade. First of all, Mr. Shaw had said very plainly that we were ignorant. That was quite true. The chemists were ignorant; they knew practically nothing about cast iron, and yet one could go round the country and find people who thought they knew all about it. We were just on the fringe in regard to cast iron, and until the foundries supported inquiry into it we should remain in that position. The Branch-President was also perfectly right in saying that it was possible for science to save money in the foundry. During the last six months he himself had come across at least four foundries which were wasting an enormous amount of money on pig-iron and coke, and were turning out absolute rubbish, because they had old-fashioned mixtures. They were paying extravagantly for materials they did not know how to use. With regard to the engineers and their influence upon the price of castings, he assured the Branch-President and all concerned that nobody was rubbing it into the engineers more than he was. The foundry trade was simply a sweated trade, but he did not think the foundrymen had been able to help it; it was the fault of the engineer. On the other hand, very big first-class castings were needed, but as the result of the sweating, nobody was able to supply them; as the result of the sweating, foundries had not employed science, and now that it was required it was not available.

Training of Apprentices.

With regard to the training of boys, he referred to classes which he had conducted in the North of England, and said that the very great success which could be attained in that direction was surprising. One did not get any thanks, however, and if anybody in the London Branch started a Junior Section, or helped boys, and expected to get thanks, he was starting with an entirely wrong point of view. One's reward, however, was to be found in the results obtained. Several years ago he had had a class of 73 boys from the foundry and the engineering shops, and had started lecturing them in the orthodox manner, but soon became aware that none of them seemed to understand what he was talking about. Therefore, he had altered his methods, had supplied them with paper, and had asked them to write down the answers to various questions. In the first place he had asked what was meant by 5 per cent., what was 5 per cent. of 98, and what was 5 per cent. of 102. Out of the 73 apprentices, only three could answer correctly, and those three were premium pupils. At the end of three lessons, however, they were able to answer all sorts of questions. There was then a very great improvement, and it was possible, out of the 73 lads, to pick out 13 who were worth taking further. That was the point; it was useless educating the lot; we had to have working men, and he considered they were best left alone, but if we picked out the good ones and educated them, we should produce foremen and chargemen, and perhaps managers. If the London Branch formed a Junior Section, it would get the best, and there was no need to worry about the rest. With regard to the possession and application of scientific knowledge in the foundry, he did not agree with the Branch-President in blaming the working man or the foreman. His experience with the companies of this country was that if there were an intelligent managing director, whose word would go, it did not matter about anybody else. If the managing director had got the pluck or the knowledge to say that he was going to have a thing done properly, everbody else in the works—the works manager, the foremen and the rest—would gain the managing director's enthusiasm, and good results would accrue. Nearly all the managing directors were financial people, however, who neither knew nor cared anything about cast iron. Some years ago the question of cast iron had been raised in the British Parliament, but there was not one Member of Parliament who was able to say one word of common sense about it. (Laughter.) In a final compliment to the Branch-President, he said he had put so much truth into his remarks because he understood the problems of the industry. If there were more people such as the Branch-President in the foundry trade, we should do a great deal better.

Demarcation Disappearing.

Mr. A. H. Mundey, in his capacity of Chairman of the London Local Section of the Institute of

Metals—he is also a member of the London Branch of the Institute—offered the greetings of the former body to the new Branch President, and expressed the hope that the annual joint or corporate meeting of the two bodies was an earnest of the desire of both the practical man and the scientific man—two very much overworked and badly-worked phrases—to merge their interests. He could not, and would not, separate the two. He did not like putting the practical man into one watertight compartment, and the scientific man into another; if the practical man could not be a scientific man and the scientific man could not be a practical man, then the outlook was hopeless; but the sort of co-operation which was evinced between them was the surest sign that they were moving forward on the right lines. The Branch President, in his address, had indeed provided a a good deal of food for thought. In the first place, the Branch President had made the admission that foundrymen as a body were ignorant. If we started out with such an admission, it was one of the surest signs that we were going to learn something. There were men present who were old enough to remember the time when the foundry foreman and the foundryman thought he knew everything, when the man who went into the foundry as a metallurgist was considered a mere highbrow, who knew nothing, and who was only a general detective working in a laboratory with test tubes and so on, just to say how much carbon, or copper, or something else, there was in the particular charge of metal that was being operated on. It was at that time considered an impossibility for anyone but a foundryman to say anything about the characters of metals, their whims and fancies, their weaknesses and their strengths, and he was sure that foundrymen to-day would admit the truth of that.

Training Apprentices.

Dealing with the training of boys, he said, as one who, for twenty-five years, had been a lecturer in metallurgy to engineering and foundry students, that the position of the young men in London who wanted to know something about metallurgy was not so desperate as some people might think. One of the great reasons why we did not get good foundry apprentices was that it was a dirty, uncomfortable, ill-paid business and unless the young man could see some prospect of getting away from it pretty soon, and getting on to the actual carrying out of the work, he did not want to stay and serve out an apprenticeship. There was not sufficient inducement, and that was one reason why all engaged in the trade, whether foundrymen, foremen, or employers, ought to see to it that the work was made more acceptable to the young men, that it was better paid, that a young man should not be treated as an outsider because he worked in the foundry, but should be treated as well as, and should mix with, other young fellows, just as if he were employed in the office or in another part of the works.

Junior Sections.

He himself always took a tremendous interest in the boys associated with him, and he wished Mr. Faulkner good luck in connection with the Junior Section it was proposed to form in London. At the same time, he hoped that those concerned with the Section would not try to educate the boys too much; one could not teach them in a few monthly meetings all they would have to know, but one could get them interested sufficiently for them to seek out information. The boys must do a good deal more than attend a few meetings; they must pursue their education, but must be encouraged. Nearly all the members of the London Branch were in some authoritative capacity with them, and, therefore, should encourage them to pursue their education. There was the question of the boys' expenses, but surely employers and managers could pay something towards their expenses, as a means of encouraging them. He knew one firm who saw to it that all the boys had an opportunity of attending classes that were acceptable to the Directorate, and in cases of hardship the boys' expenses were always paid. Surely any decent, self-respecting firm would do as much as that. Finally, he wished Mr. Shaw a happy and successful year of office as President, and felt certain that, if that meeting were an indication of the enthusiasm he was able to infuse, then the year was going to be a very profitable one for the London Branch.

A National Foundry Certificate.

Mr. A. F. Gibbs was in agreement with the suggestion to form a Junior Section in London, if this could possibly be done, and added that, at the time of the Institute's Convention in Newcastle, two years ago, he had spoken to Mr. Young as to the possibilities of forming such a Section. He had had apprentices who had attended classes for two or three years, but who had no visible results of their training, in the form of a certificate, and he suggested, therefore, that very soon the Branch would have to ask the parent institute to provide for and arrange examinations for apprentices and to award a certificate. He had known students who, having completed their courses, were absolutely downhearted simply because they had no certificate or other visible reward for their success, so that he hoped the Branch would take the initiative and approach the parent body as suggested.

Foundry Economics.

Mr. A. W. G. Bagshawe (Dunstable) considered that the solution of the foundry apprenticeship problem was to be found in the direction of paying higher wages to foundrymen. He was no philanthropist, but the moulder must be paid wages higher than those of a skilled mechanic, and it was for the foundry management to find ways of doing it. That was bound up with the question of what castings could be made for, and what they could be sold for. He was to read a Paper before the Branch in January on the question of costing, and he was going to suggest in that Paper that the best thing the foundry trade could do for itself was to try to find and adopt a uniform costing system. There were hundreds of costing systems in existence, many of them good and many of them bad, and it should be possible to study them and to evolve from them one which was properly applicable to the foundry business. If foundry proprietors could sell at a price which would give them a margin over cost they would be able to equip their foundries properly. It was not enough, however, merely to put in machines to save labour and to do nothing else. They had first to put in machines which would increase output without saving labour, and, having increased output, they could look round and try to save labour. Most of them had tried to put in machines merely for the purpose of saving labour, but had found that they were no better off for it. If they could find a way to increase output and to pay the men more without making them do more work, they would be getting towards a solution of the problem. The foundry business would always be dirty and unpleasant, and in very many foundries, particularly the light foundries, where casting was carried out every day and sometimes all day, the men would be sent home sweating every night. Therefore, the problem had to be solved by better pay, and no apprenticeship system would ever solve it. Developing further his view that the foundryman should receive better pay than the machine hand, he said it was the foundryman who had to take all the risk. When a machine hand made a mistake, he knew it almost the second he made it, but if a foundryman made a mistake he might not be aware of it for a day, or maybe longer. Therefore, if the piece-work system were introduced—and, after all, he believed it was the best system—the foundryman was taking a big risk. Those in the foundry industry ought to try to adopt a uniform costing system, so that they would know the prices at which they could afford to sell, and could ensure a margin of profit sufficient to enable them to install proper apparatus, and so make labour in the foundry a reasonable occupation.

The "Ford" Ideal.

Mr. J. W. Gardom (Dunstable) said that everybody seemed to be anxious to increase the moulder's knowledge, but in his view they were going the wrong way about it. It would be agreed that foundrymen had got into the habit of looking at a pyrometer indicator and reading the temperature on it, never thinking for a moment that the reading was in milli-volts and not degrees Centigrade. If, when trying to improve the foundryman's knowledge, one talked to him in terms of money, he would understand. Mr. Gardom agreed with the Branch-President that the chemist was not always a success in the foundry, but one reason was that the management would not pay the salary which a good chemist could command. Therefore, they engaged an inexperienced chemist, and would not allow that inexperienced chemist to make a mistake. Commenting on the Branch-President's remark that the moulders started their day physically and mentally tired, after having shifted their equipment and puzzled over the mistakes of the previous day, he suggested the management might arrange to get all the moulds out the night before and write on the moulders' cards some indication as to why they had made those mistakes. That would relieve them of some of their worry, and enable them to avoid those mistakes in the future. As to the suggestion that each foundry should have two floors, he pointed out that that would cost money, and that the same result could be achieved by taking the sand out of the foundry and bringing it back again. The firm with which he was associated were doing their best to help their employees, on the principle that by helping other people they were also helping themselves. The castings made by other foundries were sold at certain prices, and his firm had to undersell them; other foundries paid certain wages, and his firm were going to pay more wages. That was an ideal they were trying to achieve, and he believed they were meeting with a little success, because they were getting better people and were educating them to produce really good castings.

Mr. Geo. C. Pierce (Past Branch-President), speaking as one who had come more closely into contact with the moulder at his work, perhaps, than most of the members, and who understood the moulder's point of view, agreed with Mr. Bagshawe that if the trade offered adequate remuneration there would be sufficient apprentices. He had not the slightest doubt that the solution of the problem would be found in the direction of better wages. He agreed that present costing methods in foundries did not constitute a business proposition, and that unification was necessary, but differed from the suggestion that the employers' federations in this country were not strong enough to remedy the position. He knew something of the strength of these bodies, and considered that one of the lightest tasks they could undertake was to ensure the adoption of a unified costing system. As to the apprenticeship question, it was all very well to say that the Institute could deal with the matter by establishing Junior Sections. Mr. Young, who was perhaps entitled, in view of his experience, to say most about Junior Sections, had put his finger on the spot when he had suggested that we should not bother so much about the working man, but that we should pick out the best of the apprentices and train them as foremen, chargemen, and managers. But it would not get the industry out of the hole it would be in very soon. If there were a boom in the industry, as he believed there would be, the dearth of skilled moulders would become evident. It was not so much a question of training chemists, foremen, chargemen and managers, because the shortage did not lay in that direction.

The vote of thanks to the Branch-President for his excellent address was then put to the meeting, and carried with acclamation.

Branch-President's Reply.

The BRANCH-PRESIDENT, after expressing his appreciation of the vote of thanks, replied to some of the points made in the discussion. He thanked Mr. Bagshawe particularly for his remarks as to the purpose of installing machinery, because they reflected his own views. What happened to-day was that when a new machine was brought into the foundry, the number of hands employed was reduced immediately. That created disquiet among the men, and it was altogether wrong. Something must be done to lighten the labour of the men, and, in addition, he did not see why a foundry should be very dirty. Mr. Gardom had rather misunderstood his reference to a foundry with two floors. What he had in mind was a big, broad, long shop, with a proper gangway along the middle—not one that varied from day to day—so that while work was in progress on one side, the other side was being prepared for the next day's work. When the work was finished on one side, the moulders could take their tools to the other side, where they would find their boxes ready for them. It would not entail much shifting of boxes. Again, he saw no reason why foundries should not have less sand and more concrete floors, and he had seen a foundry recently in which this policy had been adopted with pleasing results. Boys would not enter the foundry trade as apprentices when they could enter a comparatively clean trade, and one in which they were offered better opportunities. The boys must be treated better, they must have better shops, and so on, but this could not be done without money, and, having regard to the slump which the industry was now passing through, the money was not available. The difficulty was that investors would not put their money into foundries as they were not very attractive sources of profit. Unless the moulders were better educated, both technically and on the economic side, and appreciated what was involved in conducting a foundry, it would be impossible to get the co-operation between them and the management that was really necessary. One did find men occasionally, however, who had some notion that the position of the management was not always pleasant, and that very often they were scraping along and did not know where the next week's wages were coming from. After all, the men were always sure of their wages, but it was very difficult indeed, as a rule, to get them to understand how small were the profits, or how problematical. He was glad to find Mr. Bagshawe in agreement with him on so many points, and particularly on that of wages and conditions; somehow or other the foundry trade must be able to pay better wages and attract better people to the foundry. When that stage was reached they would be able to introduce more machines and to organise things better for the benefit of all; people would then work better and profits would accrue naturally. The saving which could be effected when everybody was happy and things were going all right was remarkable.

Finally, the Branch-President proposed a vote of thanks to Mr. H. G. Sommerfield (Branch-Secretary) for the enormous amount of work he had done as Hon. Secretary of the Institute's Convention, held in London in June.

The vote of thanks was accorded with acclamation, and after a brief response by Mr. Sommerfield the meeting closed.

East Midlands Branch.

A COMPARISON OF WHITEHEART AND BLACKHEART MALLEABLE CAST IRONS.

By A. E. Peace (Member).

Introduction.

The history of malleable cast iron commenced about 200 years ago when the Frenchman, Reaumur, made what is now known as whiteheart malleable cast iron. At that period there were only three kinds of iron known; these were wrought iron and cast iron—obtained by reduction of the ore—and blister or cementation steel obtained by heating wrought iron in charcoal. It seems probable that this cementation process was the germ of the idea of making malleable cast iron by substituting ore for the charcoal and thus removing carbon instead of adding it; this sprung up into an industry in Europe, the manufacture chiefly being confined to harness parts, nails, and similar small work. About 100 years later an attempt was made in America to produce malleable cast iron by this process. Boyden, in Newark, U.S.A., spent some years trying to make malleable cast iron, and was rewarded with success; but the fracture of his iron was blackheart instead of whiteheart. This was due to the different composition of the American pig-irons. The European irons were chiefly low manganese and high sulphur, whereas the American irons were the reverse; and thus, in addition to removing carbon by the action of the ore, graphitisation took place, producing the black fracture. It is thus seen that the two types sprung from the same idea and were at one time made by the same process, but owed their individuality to the difference in the local pig-irons. It is only comparatively recently that packing the castings with ore has been abandoned in the blackheart industry, thereby emphasising the metallurgical difference of the two products.

Method of Manufacture.

Pig-iron and scrap are melted to give an iron which when cast in sand moulds shall be free from graphite, *i.e.*, a white iron. The production of castings free from primary graphite is essential in making malleable cast iron, as during the annealing process any graphite flakes are subject to growth which so weakens the iron that in bad cases the metal is more brittle than ordinary grey cast iron. The white iron castings are subjected to annealing at a high temperature for some days with or without a hematite ore packing, when the product is rendered malleable.

Chemical Composition.

The essential difference in the two materials is due to the pig-iron used. The whiteheart industry uses white and mottled hematite, the compositions of which are not standard except in respect of phosphorus content, which is always low. The carbon, silicon, manganese and sulphur all vary within fairly wide limits, and this is probably the greatest difficulty the whiteheart manufacturer has to face. The carbon varies from 3.0 to 3.6 per cent., the silicon from 0.3 to 1.0 per cent., the manganese from 0.05 to 0.60 per cent., the sulphur from 0.15 to 0.40 per cent., and the phosphorus 0.08 per cent. and less. These figures do not cover all the pig-irons used in whiteheart manufacture, as some special refined irons of low sulphur and low carbon content are on the market, but the irons indicated form the basis of the whiteheart mixtures. The blackheart iron is made from grey hematites differing chiefly in their higher manganese content, which is 0.50 to 1.00 per cent., and low sulphur, which is usually not above 0.06 per cent. The silicon in these irons is generally higher, particularly where the melting medium provides a means of oxidation.

Melting and Casting.

Whiteheart is chiefly made from the cupola, though crucible melting is still practised. Blackheart is rarely cast from cupolas owing to the increase in sulphur obtained and to the higher carbon content of cupola metal. Air furnace, open-hearth, crucible, electric furnace, and a combination of the electric furnace, cupola and Bessemer converter are all used, but the most popular melting medium is the air-furnace. It will be readily understood that the melting of iron for the blackheart industry is considerably more expensive than for whiteheart. This fact tends to make the economical production of blackheart only possible when conducted on a comparatively large scale.

The only similarity between the hard iron before annealing is that it is in each case white fractured. The blackheart is lower in carbon than whiteheart, and consequently is stronger, less brittle, and not so hard in the unannealed state. Whiteheart, before annealing, contains from 3.0 per cent. to 3.5 per cent. of carbon, and blackheart from 2.3 to 2.8 per cent. In both cases the carbon is in the combined form. The structure of the irons both consist of pearlite and free cementite, but there is considerably more of the latter in the whiteheart than in the blackheart, which accounts for the difference in strength. The structural composition of whiteheart as cast is pearlite 60 per cent., and free cementite 40 per cent., whilst blackheart is pearlite 75 per cent. and free cementite 25 per cent.

Blackheart is usually cast at a higher temperature than whiteheart, this being necessitated by the higher freezing point of the iron, which involves a much higher temperature to get sufficient superheat to give the metal " long life " and fluidity. The usual melting furnaces employed in blackheart manufacture permit of higher casting temperatures than are common with the cupola.

Casting in both industries is usually done by hand or shank ladles, direct casting without transferring from a large ladle to a small one is the general rule, but in blackheart foundries using air-furnaces, open-hearth, or electric furnaces pouring very hot metal the iron is frequently carried in large ladles to the moulder's side. Crane ladles are in use, and a one-ton bottom pouring ladle is in use in at least one blackheart plant in this country.

The methods of moulding are similar, both irons possessing great liquid shrinkage and high contraction; the feeding and gating difficulties are common to both processes. The linear contraction of both irons is approximately $\frac{1}{4}$ in. per foot, but as there is about $\frac{1}{16}$ in. per foot for expansion on annealing, patterns are made to in. contraction.

Blackheart possesses a certain advantage in casting in that, as just mentioned, the furnaces used permit of obtaining longer life and greater fluidity than does the cupola.

Whiteheart castings in the hard state require more careful handling than blackheart on account of their greater brittleness. A certain amount of fettling is done on blackheart castings in the hard state, as they are strong enough to permit of knocking off flash without cracking.

Barrelling is largely used for removing sand before annealing in the case of blackheart, but this is generally too severe a treatment for anything but small castings in whiteheart, and sand blasting is generally adopted. The castings are, of course, inspected before going into the annealing ovens.

Annealing.

The great difference in annealing is due to the fact that all the carbide of iron in blackheart is decomposed by heat, but that the carbide in whiteheart is stabilised by the high sulphur content, and only yields slightly to heat treatment. In whiteheart red and black iron ores are used to provide oxygen for removing the greater part of the carbon.

Blackheart castings are packed in sand, slag, gravel or mill scale. This is done to prevent distortion during annealing. Blackheart anneals quite satisfactorily, however, without any packing medium. The annealing is carried out at 800 to 880 deg. C. for a period of from $2\frac{1}{2}$ to $3\frac{1}{2}$ days. Whiteheart castings require a higher temperature and a longer period, and are annealed at 900 to 1,000 deg. C. for 3 to 4 days. These times cover only the period at the annealing temperature. The time taken for heating up and cooling down depends on the size of the oven, amongst other things, and makes the total cycle in both processes from 8 to 14 days. Slow cooling is necessary to obtain the best results, and that malleable made on a short annealing cycle is generally inferior. To obtain perfect results with whiteheart necessitates slightly different treatment for castings of different section, the annealing under standard conditions being less and less complete as the cross section increases. The section which can be satisfactorily annealed in whiteheart is therefore limited by the depth to which decarburisation can be commercially effected. This limit is somewhere in the region of ¾ in. The section which can be made in blackheart, on the other hand, is limited not by the annealing process, but by the section above, which it is impossible to cast without getting primary graphite. This limit is somewhere around 3 in.

The cost of annealing is much higher in the case of whiteheart than blackheart. The use of ore and the greater time taken in packing the castings add to the expense. It is usual in the whiteheart trade to surround each casting with hematite ore, whereas in blackheart the packing material fills up the spaces left after the castings are placed as closely together as is possible. Thus a greater tonnage of blackheart can be packed in a certain space.

The chief item in the difference in annealing expenditure is fuel. From one to two tons of coal are required to anneal one ton of whiteheart malleable, but only ½ to ¾ ton will anneal a ton of blackheart castings. Owing to the higher temperature in the whiteheart anneal, the pans do not last so long. The pans used in both processes are usually made of a white hematite iron, the same type of pig-iron which is used for making the whiteheart castings being very satisfactory. The use of nickel chromium alloy pots has been tried out, but reducing atmospheres and the sulphur gases from the coal prevent them giving the life which one would expect from them, and in any case the initial cost is prohibitive. For example, the cost of equipping the plant with which the author is associated with nickel chromium alloy pans would be something like £100,000. The ordinary white hematite iron pans last from three to six anneals with whiteheart and about eight with blackheart.

Blackheart plants usually operate on a larger scale than the majority of whiteheart foundries, and as a consequence the annealing ovens are larger. From 10 to 30 tons capacity is common in the blackheart trade, whilst 4 to 10 tons is usual in whiteheart foundries.

After annealing, barrelling is often resorted to in order to remove any adhering packing material. This also gives a good surface to the castings, which is appreciated by a great many consumers. Grinding and chipping is adopted in both industries for fettling.

Straightening.

Present-day rapid machining methods call for accurate castings which can be set up in jigs. As the annealing process introduces distortion, due frequently to the irregular expansion of intricate castings and to sagging of the pots, it is necessary to straighten and set a large number of castings. Whiteheart malleable being annealed at a higher temperature, is subject to rather more distortion than blackheart. General practice is to set the castings hot, though there is a tendency to-day in both whiteheart and blackheart foundries to adopt cold setting wherever possible. Cold straightening means stressing the castings beyond the elastic limit to give them a permanent set, and this naturally weakens them, but there is always a danger in hot setting of heating above the critical temperature when, in the case of blackheart, the carbon will re-combine with the iron, rendering the casting more or less brittle, and probably useless. This overheating trouble is not likely to occur with whiteheart, as the amount of carbon present is low, and is usually all, or nearly all, present in the combined state. The lower critical temperature of malleable cast iron is about 730 deg. C., so that heating blackheart malleable in the neighbourhood of 700 deg. C., which is only a red heat, is decidedly dangerous.

Structure and Physical Properties.

The structure and fracture of the two materials are entirely different. The names whiteheart and blackheart were derived from the appearance of the fractures. Whiteheart is steely looking and is greyish on the edge, changing to bright coarse white crystals in the core; the line of demarcation is oftentimes well marked.

The microscope shows it to be ferrite on the surface, sometimes with a slight network of oxide of iron, and changing from the edge to the centre with gradually increasing pearlite, until in the centre there is frequently free cementite in sections of ½ in. and over. There is usually a small amount of free carbon in nodular form. Blackheart has a uniform black fracture, except for a slight greyness in the skin. The micro-structure is ferrite throughout, and all the carbon is present in the free state. The surface to a slight depth contains no carbon at all, due to the oxidising effect of the atmosphere in the annealing pots. This slight decarburisation is incidental, and is not sought after at all. The grain size is smaller than in the case of whiteheart, due to the lower temperature of anneal. The high temperature used in whiteheart annealing makes the structure coarse, and if any free carbon is found it is in larger particles than are found in blackheart malleable.

This description of structure of the two malleables is true of the general run of castings, but variations from what has been described are met with, particularly in the case of whiteheart malleable.

Owing to the nature of the annealing process in whiteheart, the section of the casting largely governs the extent of annealing. For example, a casting with a uniform circular section of, say, ¼ in. dia. might well have all but a trace of carbon removed, resembling in properties wrought iron or dead mild steel, whereas a larger casting with sections ¾ in. dia. would, under the same conditions, only be annealed to, perhaps, a ¼ in. or ⅜ in. depth, the centre containing up to 2 per cent. of carbon, practically all being in the combined form, and such a casting would possess no malleability, although being strong and resistant to shock.

It will be readily understood that there is a limit of sections above which the commercial annealing by the whiteheart process produces no malleability at all. There is, however, no limit to the size of blackheart malleable which can be annealed. The section in this case is, as stated before, limited by the size above which it is impossible to make the casting without getting primary graphite. It is essential in both processes, but particularly in blackheart, to produce castings which, before going to the ovens, shall be free, or practically free, from graphite; otherwise, on annealing, the flakes of primary graphite are subject to growth, and in bad cases the iron after annealing consists of a network of graphite, and is weaker than an open-grain cast iron. Primary graphite in whiteheart is not so subject to growth on annealing, owing to the restraining effect of the high sulphur content, and also to the fact that the carbon is largely removed by oxidation, but, in any case, a graphite flake is a source of weakness. To compare the physical properties of the two materials is very difficult, as will be understood when it is realised that there are somewhere in the neighbourhood of 200 firms in this country making malleable cast iron, and, since practice is not standardised, the quality varies very considerably. Not more than about half a dozen of these 200 firms are engaged in making malleable by the blackheart process. The physical properties to which most importance is attached are tenacity and ductility. The tensile strength is measured on the unmachined bar. The reason for this appears to lie in the idea that the removal of the surface of the test bar reduces the strength and ductility. In connection with whiteheart, there is some truth in this idea, as the metal is, as a rule, more thoroughly annealed in the surface than in the core, but with blackheart, numerous tests show no loss in elongation, or ultimate tensile values, after the skin has been turned off. However, the continued use of the unmachined bar is undoubtedly stimulated by the expense saved, and, as the material is ductile, the error due to the test piece not being mounted in the machine with its axis in a straight line with the direction of the pull, is negligible. The bar for the tensile test is by no means standardised, and it is a great pity that the latest British Engineering Standards Association's specification is not accepted by all consumers. The tensile value of whiteheart varies from 20 to as much as 30 tons per sq. in., but with the latter tensile strength the elongation is very low. Elongation values on 2 in. have been obtained up to 9 per cent., usual figures for good whiteheart being 23 tons tensile, and 4 to 6 per cent. elongation. Blackheart malleable shows a great superiority in ductility—most of the blackheart produced in this country having an average elongation of over 15 per cent. on 2 in. The tensile strength associated with this is 23 to 25 tons per sq. in. Good blackheart malleable should never show less than 22 tons per sq. in. tensile, nor 10 per cent. elongation. The yield point of both materials is about the same—namely, 14 to 16 tons per sq. in. All the results mentioned are what might be obtained on the British Engineering Standards Association's test piece "C," having a diam. of 0.564 in. The bend test is nearly always made on a bar 1 in. by $\frac{3}{8}$ in. Good whiteheart gives 45 to 90 deg. bend, and blackheart from 90 to 180 deg on such a bar bend round a 1-in. radius. The British Engineering Standards Association's specification for whiteheart is minimum tensile strength 20 tons per sq. in., and minimum elongation 5 per cent.; and for blackheart, minimum tensile 20 tons per sq. in., and minimum elongation 7½ per cent.

Specifications rarely call for tests other than these. The Izod impact value for blackheart is about 13 to 14 ft. lbs. on the standard Izod notched bar, whilst whiteheart is slightly less than this. A large amount of malleable castings are purchased solely on account of the easy machinability, and this quality is undoubtedly a very important feature of malleable cast iron. Good whiteheart machines more readily than mild steel, but is hardly as good as blackheart. This appears to be due to the presence of free carbon in the blackheart malleable which prevents clogging of the tool. It is claimed for blackheart malleable that it is the most readily machinable of all ferrous products.

The following figures indicate the machinability of blackheart:—Turning and facing a flange of 10 in. dia., a roughing speed was used of 108 ft.

per min.; the finishing speed was 182 ft. per min.; turning and facing cylindrical piece $6\frac{1}{2}$ in. dia., the roughing speed was 140 ft. per min., the finishing speed was 400 ft. per min. For the turning and given cutting of a light sleeve casting, the rough turning was done at 100 ft. per min., and the finish turning at 235 ft. per min.; the screw-cutting with a single point tool was done at 170 ft. per min. The latest British Engineering Standards Association's specification for malleable requires a machining speed of approximately 90 ft. per min.

An important point with users of malleable is uniformity—and this applies not only to the general malleability of the material, but to machinability. There are so many mass production methods adopted nowadays that it is common to find expensive lay-outs for machining. In such cases it is very important that the castings shall possess uniform cutting hardness, not only in each part, but in each and every batch. One hard casting, or even a hard spot, will sometimes upset a complete lay-out, and cause considerable expense.

Blackheart malleable undoubtedly possesses greater uniformity than whiteheart, due largely to the better knowledge of its metallurgy, and also in a great measure to its simpler annealing process. The manufacture of whiteheart is, however, rapidly improving, and the British Cast Iron Research Association is devoting considerable time and energy to the industry, and its research work in this branch is meeting with considerable success.

As might be expected, the resistance of malleable cast iron to abrasive wear is poor. Whiteheart shows some superiority over blackheart in respect to wearing properties.

Magnetic Properties.

Blackheart malleable cast iron possesses useful magnetic properties. It has high permeability, and very low hysteresis loss and coercive force. Whilst no magnetic data is available on whiteheart malleable, it seems, from a knowledge of its structure, that it would hardly possess the useful magnetic properties to such an extent as blackheart malleable.

It is interesting to note that both whiteheart and blackheart have a greater resistance to atmospheric corrosion than ordinary carbon steel and grey cast iron. This is probably due to the surface being practically carbon-free.

Applications.

It is not intended to enumerate the uses to which malleable cast iron is put, but rather to indicate jobs for which the two types are best suited. For years malleable has been the chief material in the construction of agricultural implements, and in this field whiteheart is quite as suitable as blackheart. A large amount of malleable is used in the chain belt industry, and here, again, there is little to choose between the two types. Amongst the heaviest customers cf malleable is the motor industry, where axle cases, differential carriers, dumb irons, hubs, brake parts, and all sorts of brackets are made in malleable. In this industry not only are high strength and ductility of vital importance, but easy machinability is an essential. There is no doubt that blackheart is the most suitable material for motor work from all points of view; hot-water and steam radiators are almost exclusively assembled with malleable cast iron nipples, and since easy and uniform machinability is the chief demand, blackheart is the better type to use. Tramway work, railway stock, and electrical machinery all make demands on the malleable trade. The shipbuilding industry also calls for numerous malleable parts. Malleable is sometimes used as a substitute for cast iron to obtain lightness, and here whiteheart is very suitable. Generally speaking, where strength without ductility, but with some fair resistance to shock, is required, whiteheart is better; particularly is this the case when resistance to frictional wear is a factor. Where high ductility combined with good tensile strength are the dominating requirements, blackheart is the superior material.

Occasionally castings are required which are to be subject to brazing or other heating operations, and in such cases whiteheart should always be used, as blackheart is embrittled if heated even momentarily above 730 deg. C.

For jobs where easy machinability is essential blackheart cannot be improved upon. At the present time blackheart malleable has the wider field of application, and this will probably remain so; but the scope of whiteheart will greatly increase when it can be produced with equal uniformity. Blackheart, by its uniformity, has established a greater confidence amongst users than is possessed by whiteheart. This uniformity of blackheart castings is perhaps the property in which it most differs from whiteheart. When pig-iron producers make more reliable irons, and when whiteheart becomes standardised on scientific lines, and is made from a more reliable melting medium than the cupola, then will it create a confidence amongst users, and be in a position to compare favourably with blackheart malleable cast iron, from the uniformity point of view.

DISCUSSION BY EAST MIDLANDS FOUNDRYMEN.

Dr. Bramley asked if the author would elaborate on his remarks as to the part sulphur played in the annealing of whiteheart castings.

Mr. Peace replied that in whiteheart malleable the sulphur is always unbalanced in reference to the manganese, this being practically essential to guarantee original hard iron castings free from graphite. Variations in sulphur content do not appear seriously to affect annealing of whiteheart providing the silicon is sufficiently high, but with low silicon-content increasing sulphur will appreciably retard the annealing.

Obtaining Low Carbon.

Mr. Russell said he was interested to hear of the difference in the pig-irons, and of the necessity for the carbon-content being kept low, and inquired if this was achieved by merely buying low carbon pig-irons, or was the carbon reduced in the air furnace melting.

In reply the author said the pig-irons purchased for blackheart manufacture are by no means low in carbon. Being low sulphur grey hematite irons the reverse is the case, 3.80 to 4.00 per cent. being common figures. As the charge contains about 50 per cent. of shop scrap which is low carbon, the actual carbon content of the mixture charged is around 3.00 per cent. On melting in the air furnace this carbon content is reduced to about 2.50 per cent. The loss varies with the furnace design and the blast which is used. Occasionally steel scrap is included in the charge to reduce the carbon content.

Mr. Goodwin said the author had stated that a ¾-in. section would be a thick section to make in whiteheart. He, personally, could not see any difficulty in annealing sections up to 3 in. He would, however, agree that there was a great difference in the "machineability." In his (Mr. Goodwin's) opinion, the reason whiteheart had not its share of the market was that the whiteheart founders did not appreciate the value of the works chemist to a proper extent, and a great number of firms making whiteheart castings left everything to the foreman.

Mr. Peace insisted that there was perhaps some disagreement as to what is satisfactorily annealed whiteheart, and whilst he agreed a 3-in. section could be annealed to an extent which would give it fair resistance to shock, it is doubtful if it would possess the property of "malleability" to any degree. Mr. Goodwin was undoubtedly correct in saying that the whiteheart industry is suffering from adherence to "rule of thumb" methods, and that standardisation and greater scientific control of the composition and of the annealing temperatures would, by producing a more reliable product, greatly increase the market for whiteheart.

Mr. Peace, in answer to a question by **Mr. Driver**, said that the "scrap" used in the manufacture of malleable cast-iron was the runners, gates and feeders and other shop scrap from the malleable foundry itself. Any annealed scrap castings are consumed and ordinary carbon steel scrap is used to a slight extent. The utilisation of ordinary scrap cast-iron is impossible in making malleable. Answering a further query by **Mr. Hammond**, the author stated that the steel is usually melted straight into the mixture when the quantity necessary is small, say not above 7 or 8 per cent., but in some instances it has been used alloyed with pig or other iron in the form of a low carbon pig-iron.

Heat Treatment Limitations.

Mr. Hammond said blackheart castings could not be double annealed, but a 3-in. section in whiteheart would stand three annealings, and inquired if it were possible to make a 3-in. section in blackheart perfectly sound, and also if, in blackheart annealing, a period for soaking was taken. He (Mr. Hammond) was sure that one of the reasons for the comparative shortcomings of whiteheart was due to melting in the cupola, as against melting in the air furnace, but if the cupola was properly run accurate results could be obtained indefinitely. If the whiteheart founders would take the proper scientific interest it would be found quite possible to get as uniform results from the cupola as from the air furnace.

Mr. Peace thought that if a section of whiteheart was annealed three times there would almost certainly be a penetration in the skin of iron oxide with possible peeling. It was quite possible with suitable gating and feeding to make a 3-in. section in blackheart perfectly sound. As regards the possibility of getting as uniform results from the cupola as from the air furnace—with carefully standardised cupola practice it might be thought that such a possibility could be made a reality, but experience shows that there are more variables in cupola melting than in air furnace.

In reply to **Mr. Driver**, who asked what was the most economical section for the designer to aim at—were there any thicknesses which would give the cheapest casting, **Mr. Peace** pointed out that there was no general economical section for the designer to adopt, each job would require consideration on its own merits. Uniformity of section is certainly a factor to be aimed at in designing malleable castings. Perhaps the most common section found in malleable is $\frac{3}{8}$ in. to $\frac{1}{2}$ in. In answer to a query by **Mr. Lucas** as to the best method of obviating distorted casting, **Mr. Peace** referred to his Paper, wherein it was stated that any method of heating blackheart malleable castings which cannot be carefully controlled pyrometrically was dangerous. A coke fire should not be used as carbon would be absorbed. Unless a furnace was available with pyrometric equipment, it was better to return the distorted castings to the manufacturer.

DISCUSSION BY LANCASHIRE BRANCH.

At the November meeting of the Lancashire Branch, held at the Manchester College of Technology, the Branch-President, Mr. S. G. Smith, in the chair, a Paper was read by **Mr. A. E. Peace**, of Derby, upon the " Manufacture and Properties of Blackheart Malleable Cast Iron." The ground covered was similar to that given by the author before the East Midlands Branch (pp. 327 to 338).

Mr. J. S. G. Primrose said to those among them who had the privilege a short time ago of visiting the works where Mr. Peace was engaged, it brought home what they then saw in a practical way and supplemented the information they then gained. When it was published it would be a standard to which they could refer. In the first place he should say that here they had an example of the careful and thorough control which was necessary in carrying out what was apparently a very simple operation. They had an iron with what might be called a perfectly white fracture made into an iron with what might be called a perfectly black fracture, by simply annealing and precipitating the carbon. It seemed exceedingly simple, but the composition and temperature must be controlled, and that was something to which the ordinary ironfounder was not accustomed. Would metal of the same composition be suitable for the production of both white and blackheart malleable? During the war period, when shell noses of malleable iron were produced very commonly, a Government inspector undertook to get both from iron of the same composition. The white iron selected was annealed in the usual way, but one half of the casting was packed in oxidising material, *i.e.*, ore up to a mark, and the other half was packed in non-oxidising material, *i.e.*, boneash. When the castings were fractured one half showed perfectly whiteheart steel fracture, and in the other half a perfectly blackheart fracture. It may have been a freak, but it was demonstrated that it could be produced.

From the samples he had received from America he considered that an essential feature which distinguished the American blackheart from the English blackheart described in the Paper, was that, when examined under the microscope, it was found to have, in addition to the black velvety fracture, a good deal of pearlite in what Mr. Peace would say was a normal ferrite matrix. That, of course, increased its strength, but very much diminished its ductility, its capacity for elongation, and also, in his opinion, reduced its toughness, that is to say, the amount of bending and shock that it would stand. From what the author had said, it would appear that there was a rather critical point in the further heat treatment of blackheart malleable castings. They usually had the pure ferrite and the nodular graphite or free carbon, as it might be called, but if this metal was heated up to a suitable temperature some of that carbon would go back into solution, that is, revert to pearlite. Was that detrimental in cases where heat treatment had to be used? For example, in heating to the dull red heat which Mr. Peace said was usual in straightening certain castings which had to be fitted into jigs.

Defects of Blackheart.

American makers sometimes had difficulties through what they called unaccountable brittleness occurring in blackheart malleable iron. It occurred in various ways. If they galvanised a piece of blackheart malleable it became brittle; or under certain conditions, if they ground off some of the runner ends, they got it very brittle. Quite close to the hottest part of the metal there was a white steel fracture which was detrimental to this material, but a little bit further back, beyond the range where the grinding affected it, there was a true blackheart fracture.

Another thing was that sometimes when they riveted a piece of strained blackheart malleable, like a bracket, on to a girder, it was brittle, and factured through the rivet hole on cooling.

As far as he had been able to gather these slight disabilities of American blackheart seemed to indicate that it was in the range of blue heat (so called because of the colour of the oxide scale produced at this low temperature) that this brittle defect showed itself sometimes, but not always, in blackheart. Investigation seemed to show that it only happened when a certain amount of stressing had been previously put upon the metal, and perhaps Mr. Peace might tell them whether he had experienced that, and how he overcame it.

Mr. Peace had told them that American iron was preferable to English iron for making blackheart. He had some recollection that when they were at Derby Mr. Peace told some of them the reason for that lay in the different chromium content of the two irons, but perhaps he would confirm that view to them.

Mr. Sherburn seconded the vote of thanks, and observed that it was a very valuable Paper, containing so much information that it was difficult to appreciate it fully on the spur of the moment.

Early Beginnings.

The **Chairman** (Mr. S. G. Smith) said the fundamental principles of malleable - cast iron were published by Boyden in 1822. Presumably it was whiteheart. Mr. Peace had referred to Boyden as an American, who first made this blackheart in America. Boyden was, in fact, born in Staffordshire.

A man called Matthews, of Sheffield, patented a process in 1782 or 1783, 40 years before Boyden started his American foundry.

He wanted to ask a question which was supplemental to the questions Mr. Primrose had put. What was the difference between the American blackheart and the British or European blackheart, leaving out altogether the question of whiteheart?

Moulding Troubles.

Mr. Evans (Derby) said the chief troubles were pretty much the same in malleable as in ordinary grey iron. For instance, wet sand would cause a great deal of trouble, even more so than it would in the case of ordinary grey iron. The sand must be dry; also, the use of large quantities of new sand would lead to trouble.

In certain cases they would apply red sand to act as a chill. They would appreciate, therefore, that if they used a large quantity of red sand in the facing and tried to make a casting with this material they were not likely to succeed. There were well-known castings, straight flat round discs from 15 to 20 in. dia., which were made in malleable. The material might be of the correct composition, they might get super heat, but they were in for trouble if the facing sand was not suitable. To run successfully they had to make a core, cut in two sections. Generally speaking it wanted more careful controlling than was required with ordinary grey iron.

Since the members visited the works at Derby they had changed many of the methods, so he hoped a little later they would be able to repeat the visit.

They checked the weights of the feeders and runners. That was a point which needed to be controlled in malleable iron where the percentage of iron used to weight of castings produced was much higher than in an ordinary grey-iron foundry.

Essentials.

Mr. Peace said Mr. Primrose had mentioned several points as essential in casting blackheart malleable iron. Careful control of the composition of the iron by careful analysis of the material used, very careful moulding practice, and, in annealing, pyrometric control of the temperatures. He understood Mr. Primrose to say that it was impossible to make blackheart malleable without those factors. He himself did not go so far; it was possible to make blackheart malleable without having any analysis or taking temperatures for the annealing. But he was convinced that without careful control it was impossible to make it as set out in the paper.

A Common Base.

It was possible to make whiteheart out of blackheart composition, but it was practically impossible to make blackheart out of whiteheart material. The reason was that the whiteheart always was high in total carbon and was nearly always very high in sulphur.

The Origin of the Black Fracture.

Mr. Primrose had made a point that the black fracture was effected by precipitating carbon when there was sufficient to make that fracture wholly black. They would see by the photographs that probably 75 per cent. of the material had no carbon; the fracture was black because the ferrite grains were so fractured that they did not reflect the light. It was possible to fracture blackheart so as to show a white fracture. This was accomplished by using a very heavy blow which shattered the crystals and they then had the ferrite crystals reflecting the light. He invited the members to inspect the fractures in the specimens exhibited.

The retention of pearlite in the skin, very close to the surface, he mentioned in the paper only casually, because at the present time they considered that they had practically remedied that trouble.

Effect of Subsequent Heat Treatment.

With regard to further heat treatment after annealing, it was essential to use pyrometric control. If they reached 730 deg. C. they would approach a brittle casting unless it was cooled at a rate not exceeding, say, 4 deg. C. per hour, which was hardly likely in works practice.

Mr. Primrose had referred to the embrittlement effect in galvanising, grinding and riveting. In galvanising it was purely a temperature effect, there was no question of strain. There seemed to be some critical point which had nothing to do with carbon content. Examined under the microscope it was just like normal blackheart, there was no difference. The fracture in this case was always intergranular instead of transgranular.

He thought it was a different problem from the grinding hardness Mr. Primrose mentioned, grinding embrittlement in this case being due to heating to 730 deg. C. In connection with riveting, the trouble arose from again a different cause. He had some malleable iron castings which had been riveted and split at the top. In his opinion that was due to excess of cold-working. Malleable was very subject to deformation, and if it was much cold-worked it would become brittle, but by re-heating it to 700 deg. C. and air-cooling or quenching it in water, that embrittlement could be remedied.

American and British Pig-Iron Compared.

In regard to the comparison of American pig-irons and English pig-irons, Mr. Primrose had said English pig-iron was not suitable. That was rather a strong statement. His firm used 2,000 to 3,000 tons per annum of English pig-iron for malleable. But they were not as useful as American irons if they were distined to be the sole pig-iron in the mixture. As far as his knowledge went it was due to the chromium content. He had never yet analysed common brands of English Hem. pig-iron with less than 0.02 per cent. chromium; in the American pig-irons he used the chromium content was never more than 0.01 per cent. The actual effect of that chromium content in the English irons was to restrain the decomposition of the carbide; and if put through the ordinary annealing process they found small nodules of free cementite which reduced the malleability.

He agreed with Mr. Smith that Boyden was an Englishman who came from Staffordshire, but he made his blackheart malleable in the United States by virtue of the fact that he used American pig-iron which had high manganese and low sulphur, and one could get this decomposition of the carbide of iron. He had heard of Matthews' process and had an idea that it was not a true blackheart process.

Essentially English and American blackheart were the same, as there could be only one good blackheart; and whilst the American foundries made it, and his firm made it also, he thought the Americans were rather casual in their methods.

In the paper he had not dealt with the size of the castings. The average size was probably about 10 to 28 lbs.

Oxidising packing materials were practically discontinued in blackheart making. There was no advantage to be gained from them. If a malleable casting were packed in sand it would anneal just as satisfactorily as if it were packed with other material.

Machine Fingers.

A MEMBER asked for Mr. Peace's opinion as to whether it was better to make agricultural machine fingers in whiteheart or in blackheart. He suggested that cracking might be prevented by heating up the mould and casting hot quickly.

It would be found there was a considerable reduction in contraction.

Mr. Peace said it was not his wish to compare the two materials whiteheart and blackheart. He could say, however, that his firm had made millions of mowing machine fingers in blackheart, and were continuing to do so.

Hot Moulds.

In connection with cracking, if a mould was heated and then cast with blackheart iron, they got a grey casting. It was impossible to use a mould which had been made very hot. They had found that cracking could be prevented by proper gating. Perhaps heating the mould would be useful in whiteheart with its higher sulphur content, which did not have a great deal of effect in preventing annealing, but did have a great effect in preventing primary graphitising.

Replying to another question, Mr. Peace said resistance to corrosion was not due to the carbon content, but was due to the complete absence of carbon of any type in the skin. It was a well-recognised fact that pure iron did not rust. There was a process in which pure iron was deposited on the casting to prevent rusting. The point about blackheart malleable was that it had a composition which was practically pure iron. It contained probably silicon in solution up to 1 per cent. and a low manganese content—perhaps 0.3 per cent., which was generally recognised to be favourable for resisting corrosion.

Mr. Cairns asked what would be (1) an approved composition of moulding sand for general casting, from a few ounces up to 2 cwt.? He knew that the temperature required with malleable iron was very much higher than with grey iron; (2) what was the difference between the running of a malleable mould and a steel mould? and (3) would not the same method of " feeding " apply to both?

The Chairman observed that by " black sand " Mr. Evans meant sand which had been used over and over again, but the bond had not been burned out quite. Whether dealing with heavy castings or with small ones, every precaution ought to be taken in each case to avoid those little " drawn " places.

Mr. Hopwood asked whether Mr. Evans had ever come across cases of hot spots—that is, places on the casting that are grey in colour instead of white, through the mould becoming locally heated by a large quantity of metal passing over that place.

Mr. Evans replied that he had, and the remedy was to chill the places affected. It was possible to get grey and white iron castings on the same runner.

Coal-Dust.

Mr. Sherburn said he was interested in Mr. Peace's statement that in the United States the consumption of malleable cast iron per head of population was ten times more than in this country. There must be some reason for that, and perhaps Mr. Peace would tell them what it was.

Perhaps the members of the Branch generally were not very competent to go deeply into the question of malleable castings, but it had struck him that the ordinary ironfounder could profit very much from hearing a Paper of this kind, and observing the processes to which attention was called. He might derive from it many lessons in regard to shrinkage and other difficulties which he was up against in his own practice.

He would like some information to be given with regard to the pulverising plant. When they visited the works at Derby, particulars were given of the size of grain into which the coal was broken up by the pulverisers, and it had occurred to him that machines of this type might solve the coal-dust problem for the foundryman, and ensure more uniformity in grain size than the methods at present secured. Coal-dust was a very variable article at present; those who had taken the trouble to test the grain size of samples from various consignments knew perfectly well that was the case. It impressed itself upon him that this method of pulverising coal might provide coal-dust of uniform quality in regard to grain size. Foundrymen were up against the lack of uniformity in raw materials, and it would be an advantage to secure some uniformity in this matter.

Another question he asked referred to the amount of breakage occurring in the cleaning process He believed Mr. Peace's firm rumbled their castings in the hard condition. Had they any special method of safeguarding against such breakages?

Consumption per Capita.

Mr. Peace said the greater consumption of malleable per head of population in America was, he believed, due to the fact that the qualities of malleable were not sufficiently recognised in this country, and people were rather chary of specifying material which they thought unreliable. It was quite reliable if properly made, and that it was properly made could be gathered from the list of rejections by customers which he had on exhibit.

The cleaning plant included sand-blast barrels, and also a hand-operated sand-blast. This was used on castings which were of such design that they had internal stresses set up on cooling. It was only the stronger section castings which were rumbled. Very little breakage occurred during rumbling; that was due to the iron being really strong, owing to its low carbon content. It was not like the ordinary white iron from the cupola, which was more brittle, due to higher carbon content.

Mr. Cairns asked whether Mr. Evans used any mould dressing in order to get a clear skin on the casting.

Mr. Evans stated that no dressing of moulds of any description was used.

The Chairman remarked that the temperature of the metal for malleable castings could not be compared with that of steel castings of the same size. The size made all the difference to the "eating in" or part-fusion of the sand.

Scottish Branch.

ALUMINIUM ALLOYS.

By. H. Hyman, Ph.D., B.Sc. (Member).

Most of the Papers which have been addressed to the Institute of British Foundrymen had been concerned mainly with cast iron and the heavier non-ferrous alloys, but this one dealt with aluminium or light alloys. There had been great developments in that branch of metallurgy in recent years, and it was hoped to give some idea of the scope of these developments.

Nature of Aluminium.

It would be seen from the graph (Fig. 1) that there had been considerable fluctuation in the world output of aluminium during the past 10 years. Since 1912 there had been a gradual increase, and this increase became very rapid during the War, when the output reached 200,000 tons. At the end of the War there was a rapid decline, but since 1921 the output had again increased. For the year 1924 the output was a little greater than in 1923, and in 1925 the record of over 200,000 tons was reached.

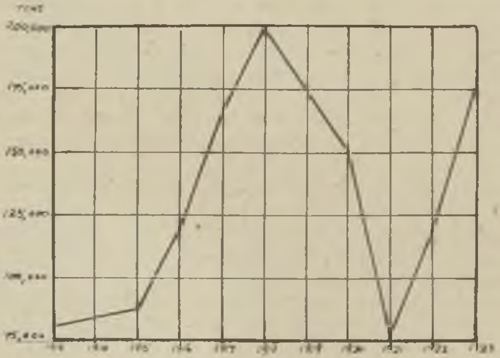

Fig. 1.—World's Output of Aluminium (1913-1923).

Aluminium as a pure metal was comparatively weak. It was much weaker than the well-known metals, iron and copper, which formed the basis of the iron and steel and heavier non-ferrous industries. For this reason aluminium found a limited application in industry, but at the same time it possessed many valuable properties. In addition to its lightness it was very ductile, and could therefore be drawn readily into wires, tubes, and sheets. In order to extend its application for industrial purposes, it was advisable to use the metal in the form of alloys.

Alloys of Aluminium.

The chief metals with which aluminium was combined in aluminium alloys were copper, zinc, magnesium and silicon, and the specific gravity of these metals were respectively 8.5, 7.0, 1.7 and 2.4; whilst the specific gravity of aluminium itself was 2.7. The weight of the alloy would of course depend upon the weight of the metals added to the aluminium. With copper and zinc they would all be familiar. Magnesium, on the other hand, was a comparatively new metal. It had been known for a considerable time in the form of magnesium ribbon, but it now came into the market in the form of rods about 1 ft. long and 1 in. in diameter. It was a very light metal, and for this reason it was employed in aluminium alloys where lightness was of extreme importance. Magnesium was not found in nature in as large quantities as aluminium, and on that account it would never displace aluminium from its position. Silicon, the remaining metal of those he had mentioned, was of more recent application than magnesium. It was steel grey in colour and very brittle in nature, and was produced chiefly in America. This metalloid was well known to the ironfounder as a constituent of cast iron.

These four elements readily dissolved in aluminium. The zinc, copper, magnesium or silicon was first melted, and the aluminium was then stirred in. In the case of silicon it was necessary to raise the temperature to about 900 deg. C. When preparing an alloy with copper, it was desirable to prepare an intermediate alloy of 50 per cent. copper and 50 per cent. aluminium.

Commercial Impurities.

There were many impurities present in aluminium as commercially obtained, and since the purity of the metal had a profound effect upon alloys, it was necessary, as they would readily understand, to know something about these impurities. Aluminium was obtained in two grades. In one iron and silicon were present in very small percentages (Table I), and there was a better grade in which these impurities amounted to about 1 per cent. At the present time, however, it was possible to obtain aluminium in a still better grade in which iron and silicon did not exceed 0.5 per cent.

Table I.—*Impurities in Commercial Aluminium.*

	Grade I.	Grade 2.
Iron	Not more than 1%	Not more than .6%
Silicon . .	,, ,, ,, 1%	,, ,, ,, .5%
Copper Zinc Manganese	,, ,, ,, .25%	,, ,, ,, .1%
Aluminium . .	98–99%	99% and over

In studying the preparation of aluminium alloys they could learn a great deal by comparing a series of alloys of aluminium and copper only, in which the percentage of copper varied by 10 per cent. Pure aluminium had a tensile strength of about 5 tons, and a very high elongation—about 30, as is shown in Table II.

Table II.—*Addition of Copper to Aluminium Sand-cast Test-bar Results.*

Copper %	Yield Point Tons per sq. in.	Tensile Strength Tons per sq. in.	Elongation %	Hardness (Brinell)
	1.7	4.8	28.0	
2	2.8	6.0	4.4	40
4	3.6	6.8	3.8	52
6	4.4	7.2	1.9	54
8	6.4	7.6	1.3	57
10	8.4	8.4	—	60

When they compared the different alloys with varying percentages of copper, they found that there was a steady fall in the elongation, until it became zero. At the same time there was a steady increase in the Brinell hardness. If they drew up similar tables for alloys containing zinc and magnesium, they would find the same tendency—a decrease in elongation as the percentage of combining metal was increased, accompanied by an increase in the Brinell hardness. Even when comparisons were made with alloys containing varying percentages of two combining metals, the same tendency was observed.

Effect of Alloy in Copper.

It might seem surprising that when they added to aluminium, which had such a high ductility, another metal like copper, also very ductile, they produced an alloy so brittle. The explanation was seen when they examined and compared aluminium and aluminium alloys under the microscope. Aluminium was built up of crystal grains. In commercial aluminium there were always present specks of impurities and minute cavities. Copper, iron, tin and other metals as commercially obtained, were very much alike in this respect. When they added 2 per cent. of copper to aluminium, the copper combined with the aluminium to form a chemical compound. This separated out between the grains of the metal as it solidified. Such a chemical compound was very brittle, and the material built up in this way was therefore itself very brittle. A similar effect was seen in cast iron. Cast iron was a mass of steel interspersed with brittle flakes of graphite. If these flakes were not present, the metal would have a tensile strength of about 30 tons, and an elongation of about 35 per cent. These flakes when present, however, broke up the metal, which then had a tensile strength of only 10 to 12 tons, and practically no elongation. Ductility in cast iron was of little consequence, because cast iron found its application in industry for its great strength under compression, and for this reason aluminium alloys would not displace cast iron from its important position as a foundation material in industrial structures.

Aluminium alloys used in this country contained from 4 to 12 per cent. of copper, or 3 per cent. of copper, and 12 per cent. of zinc, as shown in Table III.

TABLE III.—*Composition and Properties of Engineering Aluminium Alloys (Impurities included in Aluminium %).*

	Tensile Strength Tons per sq. in.	Elongation %	Specific Gravity.
Al 96% Cu 4%	7	4	2.8
Al 92% Cu 8%	8	1	2.9
Al 88% Cu 12%	10	—	3.0
Al 84% Cu 4% Zn 12%	9–11	2–5	3.0
Al 87% Si 13% (Alpax)	12	7–10	2.7
Al 82½% Cu 4% Ni. Mg 1½% (Y Alloy)	10–12	2	2.8
Do. (Wrought and Heat Treated)	25	25	2.8
Al 95% Cu 4% Mn ½% Mg ½% (Duralumin)	30	20	2.8

The structure of such an alloy is crystalline, a structure typical of these alloys. When such an alloy is examined under the microscope, it is found to show white and dark patches, caused by the unequal rates of solidification. There is not sufficient time in cooling under commercial conditions to allow the constituents of the alloy to reach a state of equilibrium.

Aluminium-Silicon Alloys.

Aluminium-silicon alloys, which had recently come into use, contained up to 12 per cent. of silicon. Silicon is always present in commercial aluminium to the extent of about 0.5 per cent. An alloy containing silicon was quite brittle, and the reason for this was obvious: silicon crystals were very brittle, and they broke up the continuity of the ductile material. It is found, however, that if the aluminium-silicon alloy is brought up to a temperature of about 900 deg. C. in the crucible, and then treated with some alkaline fluoride as a flux, the alloy changed in structure, which instead of being coarse and crystalline, becomes finely divided and emulsified. The structure is completely altered, and of course so are the mechanical properties of the alloy. It now had a tensile strength of from 12 to 14 tons, and an elongation of 7 to 10 per cent. No exact scientific explanation had been advanced for this change. These alloys are now being manufactured on a large scale. Their ductility is an advantage, because in certain castings it was possible to make use of such an alloy by bending within reasonable limits. It does not machine so well, however, as an ordinary commercial aluminium, and owing to the high temperature necessary in their manufacture, silicon alloys have a tendency to show a spongy fracture.

Commercial Alloys.

Aluminium alloys were comparatively simple in composition. The ordinary copper alloy contained from 12 to 14 per cent. of copper, while alloys containing a higher percentage of copper were used—particularly in America—for castings for pistons, and generally for castings which had to be close grained. Such an alloy, if it fractured, shows a fine silky fracture. Table III showed some comparison. The "Y" alloy, which has been developed by the National Physical Laboratory, has a tensile strength (wrought and heat-treated) of 25 tons, and an elongation of 25 per cent.—almost as good as mild steel. Duralumin, composed of 4 per cent. copper, 0.5 manganese, 0.5 magnesium, and 95 per cent. aluminium, had an even greater tensile strength, but its elongation was less by about 5 per cent. There were a number of proprietary alloys in the market, but it was found on analysis that their composition varied very little from that of the ordinary commercial alloys.

Improving the Properties.

Just as it was possible to improve the properties of certain other alloys by the addition of a small percentage of other metals—brass, for instance, was improved by the addition of small percentages of iron, nickel, and manganese—so also it was possible to get aluminium alloys of great breaking strength and ductility by the addition of small percentages of other metals. If small percentages of iron and nickel are added to a plain copper-aluminium alloy, a material was produced which has a tensile strength of about 11 tons and quite a good elongation—about 5 per cent. Such an alloy, if it is remelted, retains its good qualities. If its structure is examined under the microscope, it is found to be very close and silky. The nature of the fracture of any aluminium alloy gives one a very good indication of the properties of the alloys. If the fracture is coarsely crystalline, it indicated a weak metal.

If an attempt is made to further improve the properties of this alloy by increasing the percentages of the additional metals used, it is found that there were present brittle crystals of an iron-aluminium compound. The alloy is not improved therefore. The tendency is the other way, and the material is comparatively weak. This is common experience. Good results are obtained up to a certain point, but there is a limit beyond which results were far from good.

Corrosion of Aluminium Alloys.

The properties which were desirable in aluminium alloys for commercial purposes might be summarised as follows: (1) The metal must be capable of being easily handled in the foundry; (2) it must have reasonably good tensile strength and ductility; (3) it must be easily machinable in the shop; and (4) it must be capable of resisting atmospheric and sea-air corrosion. The author has had occasion to examine quite a number of alloys in regard to corrosion, and he has found that the following method of testing is the best: A steel bath is prepared in which the aluminium specimens are hung. Some salt water is put into the bath, and compressed air is then blown in. This forces the water up through fine nozzles, and as it meets the air current it was changed into a mist which fills the bath. This test is a very good index as to how an alloy would stand up to work as a fitment on board ships. It is important also to study the various conditions which arose when the alloy is in contact with other metals, and for this purpose holes are drilled into the specimen plate, screws made of other metals are inserted, and the changes occurring are noted. If a steel screw were inserted in the specimen plate, there was not so much corrosion as when brass or copper screws were used. Aluminium alloys which contained high percentages of copper corroded most quickly. It was found in the test which he had described that the "Y" alloy showed the best results for the first week or two, but the BS7 alloy ultimately proved the best.

Heat-Treatment.

In view of the comparatively low strengths of commercial alloys, some other method which would give better results is necessary. The heat-treatment process is employed. This process has been carried out for a long time in the iron and steel industries, and there was no reason why it should not be applied to aluminium alloys. They would get a very good idea of the effect of this treatment by comparing a series of alloys containing increasing percentages of copper. As the percentage of copper was increased it was found that the tensile strength increased from 6 to 8.4 tons, 11.6 with 10 per cent. copper, while there was a corresponding fall in elongation, as set out in Table IV.

TABLE IV.—*Addition of Copper to Aluminium. Heat Treated Sand Cast Test Bar Results.* 6 *Hours at* 500° *C. Quenched in Water. Aged* 6 *Days.*

Copper %	Yield Point Tons per sq. in.	Tensile Strength Tons per sq. in.	Elongation %
2. As cast	2.8	6.0	4.4
Heat treated ..	4.0	8.0	8.8
4. As cast	3.6	6.8	3.8
Heat treated ..	6.2	9.2	3.8
6. As cast	4.4	7.2	1.9
Heat treated ..	6.4	9.2	2.0
8. As cast	6.4	7.6	1.3
Heat treated ..	10.0	10.8	1.0
10. As cast	8.4	8.4	—
Heat treated ..	10.6	11.6	0.6

Under commercial conditions there was not sufficient time in cooling for the constituents of the alloy to attain equilibrium. But if the alloy were raised to a temperature of 500 deg. C., and maintained at that temperature for several hours, there was an improvement in both the tensile strength and elongation. In the case of one alloy the elongation was doubled by this process. But although improvement was effected, it was not sufficient—seldom more than 50 per cent.—to warrant such an expensive process, and one which, moreover, required so much time. Unless it could be made to effect a vast improvement, the heat-treatment process was not worth while. With steel it was possible to get more than 100 per cent. improvement in properties by this treatment, and if they could effect as great improvement with aluminium alloys, they would be taking a very big step.

In the case of steel, it was the presence in the metal of only 1 per cent. of carbon which made this vast improvement possible, and if they could introduce to the aluminium a constituent with analogous properties, a great advance would have been made. It was found that by adding to aluminium alloys a small percentage of magnesium an improvement was effected, but it was not the magnesium alone which caused this improvement. It was possible to draw up tables for aluminium-zinc or aluminium-silicon alloys, showing the same general tendencies when magnesium was added. Although magnesium has been used for a considerable time for alloys—notably in the case of duralumin—no scientific explanation of the change was advanced until recently. He had already mentioned that there was always present in commercial aluminium a small percentage—about ½ per cent.—of silicon, and it was found that when magnesium was added to the alloy it combined with the silicon to form magnesium silicide, and it was this compound, and not the magnesium alone, that caused the improvement in the properties of the alloy under heat-treatment.

Raising Strength Al-Cu Alloy.

The National Physical Laboratory had done a great deal of work in this direction, and it was found that by this process, after quenching in oil or water, the tensile strength of the alloy was increased from 7 tons to about 14 tons—more than 100 per cent. improvement could be effected. By rolling or forging, a stress of 20 to 25 tons and an elongation of about 20 per cent. could be obtained. It was interesting to note that the heat treatment of iron and steel had been carried on for centuries long before a scientific explanation was given of the changes which occurred. The same thing had happened in the case of aluminium alloys, and it was only within the past year or two that an explanation was furnished. If aluminium had always been produced in a high state of purity—that was to say, if no silicon had been present—then it would not have been possible to produce duralumin and other alloys of similar strength. It was only by reason of this accidental presence of silicon, for instance, that it had been possible to build up this industry which was so important in the production of aeroplanes. The heat treatment of aluminium alloys was now a commercial proposition. Such alloys were used for small castings—pistons and other light parts—very successfully. In the case of larger castings, difficulties arose, for they had a tendency to sag and bend, but it was possible to overcome some of these difficulties.

Ageing.

Closely connected with the heat treatment process was the phenomenon of ageing. This term was applied to the gradually increased hardening which occurred in these alloys during comparatively short periods after quenching. If the alloy was tested, a few hours after testing it was found to give higher figures of stress. In the case of duralumin rods, the tensile strength immediately after quenching was about 16 tons per sq. in. This figure rose in 24 hours to 25 tons, and the maximum value was reached in two days. No satisfactory explanation had been given of this change, but it was possible that some of the consituents separated out, and so produced a hardening of the alloys. With such results, there was a chance of light aluminium alloys displacing some of the other light metals. It should be noted, however, that if the temperature were too high, some of the constituents of the alloy would melt, and in this condition the material was quite worthless, being very weak and brittle. At the same time, if the temperature was too low, diffusion did not take place quickly enough, and good results would not be obtained.

Foundry Application.

In regard to foundry work with aluminium alloys, it was necessary in order to obtain good results to be guided by the same principles which applied in the casting of other alloys—irons, steels and the heavier non-ferrous alloys generally. It was important to pay careful attention to the metals, owing to their comparatively low strengths. One had to avoid over-heating, and temperature control had to be good. These light alloys, however, possessed certain peculiarities which made them quite distinct. They were comparatively weak at high temperatures—those temperatures which occurred immediately after the metal had solidified—and also they had quite a high contraction. Unless adjustments were made for uniform rates of cooling on heavy and light sections, contraction cracks would develop.

In the preparation of the metal for casting, care should be taken that it was not overheated in the furnace, and it should be poured at as low a temperature as possible—generally about 700 deg. C. The metal should be very carefully skimmed. This removed most of the oxides present, but a small percentage still remained in the alloy, and fluxes were used to get rid of this. The melting of aluminium was generally carried out in plumbago crucibles or iron pots. With the latter, it was necessary to line the interior with a coating of silicate of soda and whitewash. With plumbago crucibles it was found that the aluminium had quite a searching action on the material of the crucibles. It apparently dissolved some of the silicon present in the make up of the crucible, making the walls quite friable. The author has found that beneficial action of fluxes was more or less nullified by their bad effect on the walls of the crucible, which were liable to give way at certain points, forming a dust.

Some advocated the use of a small percentage of magnesium as flux, and it was said that the magnesium reduced any aluminium oxides that might be present in the metal. That, however, was not the case. Even if such an action did take place, the magnesium oxide produced would still remain in the metal. After the metal had been skimmed, the temperature should be read. The best temperature for pouring aluminium castings was the lowest casting temperature, say, 700 to 750 deg. C. In some cases, and especially with thin castings, it was necessary to pour above that temperature. The metal should always be poured in as quietly as possible.

Gating.

In regard to gating, the best type of gate was the branched type, with a number of smaller openings leading into the main casting, which could readily be cut off with a hack saw. If they started with a symmetrical casting and then attached a gate, the symmetry or uniformity of the casting was broken, because the gate was part of the casting. Not only so, but as the metal entered the mould it cooled as it reached the far end, which solidified first and set, causing contraction at one end of the casting, and tension at the other end. If the casting was unsymmetrical with one side thicker than the other, it was better to attach the gate to the thinner side. This produced uniformity in the casting and in the cooling, and inequalities were avoided.

Contraction in Aluminium Alloys.

With aluminium, contraction took place on the outside of the casting, and not inside as in the case of iron castings. It was better to have any contraction which might occur on the outside. The remedy in both cases was the same—the application of a chill of iron or brass to the heavier section. The use of chills was quite legitimate and could not be classified as a fake. Scientifically and technically it was a process which should be used wherever possible. The employment of a riser and a chill produced a sound job. With a riser, however, there was a large mass of metal which cooled more slowly than other parts of the casting, and the use of too many risers brought too many variations in the rate of cooling. It was quite common for a novice to apply a chill in the middle of a thin casting in order to avoid a crack. That was the wrong method. The correct method was to apply the chill at the heavier section of the casting, and at the same time to round off the short corners.

DISCUSSION.

Mr. Longden said he thought they should congratulate Dr. Hyman on his address, which had been very interesting and which had been given in a very helpful way. It was probably inevitable, when a lecturer covered so much ground as Dr. Hyman had covered, that he should touch upon points on which there was a difference of opinion. Referring to shrinkage of aluminium as compared with the shrinkage of cast iron Dr. Hyman had given the impression that cast iron in this respect was a dangerous material, and that in crystallising it always showed its shrinkage in cavities in the interior of the casting. That was not so. In many cases the shrinkage, if it occurred, took the form of an exterior cavity as in the illustration of aluminium. He did not agree with Dr. Hyman's conclusions as to the mechanism by which solidity was reached. Dr. Hyman had led them to believe that only the action of quick cooling due to the use of the chill in a heavy part of the casting was responsible for this. That was not the case. Quick cooling by itself was not the cause of solidity in either cast iron or aluminium. He thought, also, that the application of a chill probably increased liquid contraction. Quick cooling was merely the step which made the correction of the defect possible. In either case practically the same amount of shrinkage would take place, but in the one case solidification was speeded up just at the most effective moment, which would allow of the entry of new metal to fill the void consequent on quick cooling of the heavy part.

In regard to corrosion, Dr. Hyman had led them to believe that alloys of aluminium containing zinc were bad. He was not sure that the figures given were an entire proof of this. He thought that Dr. Hyman's strictures were a little too severe to be representative of the truth. The result of such a statement might be that people working with aluminium-zinc alloys might be afraid to proceed with the work. He did not know whether Dr. Hyman's test with the steel bath was a true test, because he should think that sea-spray was a very much more complicated test than that employed. He was inclined to believe that the organic constituents of sea water were very much more complex. He was sure that certain aluminium-zinc alloys had been proved to be superior to some of the others mentioned by Dr. Hyman.

Action of Chills.

Dr. Hyman, in reply, said that the action of a chill was twofold, and in this respect he agreed with the speaker that it hastened liquid contraction. He wished to point out, however, that it was really the rate of solid contraction just after the metal had solidified that had a pronounced effect upon unequal rates of cooling, and therefore upon any cracks which might develop. In the case of cast iron the chills were used chiefly to overcome liquid contraction.

So far as corrosion was concerned, his own work confirmed that of previous experimenters, and he should like very much to see any authoritative data of aluminium alloys containing zinc which behaved better than those in which zinc was not present.

American Practice Compared.

Mr. Williamson said he agreed with most of what Dr. Hyman had said. The Americans preferred a copper aluminium alloy, but they in Britain preferred an alloy (L5) with 13 per cent. of zinc and 3 per cent. of copper. Dr. Hyman had mentioned a figure of about 700 deg. C. If they raised the temperature of the aluminium, what effect would that have upon the casting?

Dr. Hyman said that the commercial alloys containing copper only were used chiefly in America, and those containing both copper and zinc were used chiefly in this country. He thought there might be two reasons for this. The first was that in this country we started with copper-zinc alloys. The industry got used to these alloys and did not like the change. In

America, on the other hand, they had been working with plain copper-aluminium alloys from the very beginning. The second reason was that the copper-zinc alloys were cheaper.

As to the effect of increasing the temperature—by, say, 100 deg., as the speaker had suggested—there was a danger when using a metal hotter than necessary of super-heating. The casting would therefore remain at a high temperature longer than necessary, and under these conditions there was a danger of cracks taking place.

Aluminium Alloys at Elevated Temperatures.

Mr. Williamson interrupted to point out that Dr. Hyman had evidently misunderstood him. When he referred to temperature he did not mean the temperature of the melting alloy. There was not much danger of over-heating the metal in the furnace, if they brought the temperature down before making the casting. Of course, it was better to be on the safe side, and bring the metal up to pouring temperature, rather than overheat and then cool it down. What he required to know was what effect the heating of typical British and American alloys in working parts of machines, say to 100 deg., would have upon the metal.

Dr. Hyman replied that as long as the temperature did not get higher than 300 deg. C. there was not much danger of anything going wrong with the casting. As a matter of fact aluminium castings like pistons, as used in the motor industry, had to withstand as high a temperature as 300 deg. C. There was one advantage in that case with aluminium—it was a good conductor of heat, and super-heating for that reason was less liable to occur.

Mr. Arnott said that with most of the Paper he was in agreement. It was perhaps a matter of interest to members to know the extent to which aluminium castings were replacing gun metal. Most people regarded aluminium castings as rather fiddling sort of things, but at the present time complete pump castings up to 4 cwt. had been made in aluminium. Such a casting made in gun metal would weigh about 12 cwt. Aluminium castings were really coming into ordinary engineering work to an extent which was quite unknown ten years ago. For some reason or other the Admiralty had awakened to the fact that there was such a material as aluminium. They were going into the matter now very wholeheartedly and quite a few of their own members were benefiting to some extent from that change of policy.

Wales and Monmouth Branch.

WASTERS.

By J. J. McClelland, M.I.Mech.E. (Member).

In collecting material for this Paper, the author tried to divide the responsibility for wasters under two headings, one the moulder and the other the management, but this proved to entail difficulties and appeared undesirable.

The various types of wasters found in foundries reach an almost astonishing number. To mention a few would be to include "runouts," "short pours," "scabbing," "crushes," "blows," "cold shuts," "misruns," "cross joints," "cores lifting," "cores breaking," "contraction cracks," "strains and swells," "dirt and slag," "hard spots," "warping," "bad feeding," etc.

A kind of court of inquiry or inquest is helpful in all foundries, and the foreman or some equally qualified person should be appointed to call at least the apprentices together to discuss the cause of all wasters, and instructions should be given on how to prevent their repetition. As an apprentice the author made castings for mechanical stokers for boilers, and one of the castings came out badly scabbed. The foreman, after lecturing him soundly, kindly reminded him that if he noted the cause of the trouble he would have learned more from the bad casting than he would have learnt from a thousand good ones.

Runouts.

In Fig. 1—an ordinary scullery copper—it is quite obvious that if there be a runout there is little chance of saving the casting, and it is perhaps advisable to let it go and not waste further time and metal on it. Being thin, the casting will set quickly, which would add to the chances of being able to save it. The joint, being at the lowest extremity, adds still further to the possibility of its being saved.

To prevent this trouble, the joint should be rammed sufficiently hard. No joint can be rammed too hard, and when the mould is open nothing should be done to disturb or alter the shape of the joint. If this be done, and sufficient weights or cramps are used when casting, runouts will be considerably reduced.

Fig. 2 shows a lead pot, and in this case if there be a runout there is a better chance of saving the casting, but some moulders have a careless habit of leaning on their joints, sometimes slicking them over with their tools and sometimes kneeling on joints, all of which have a tendency to disturb the shape and create gaps through which the molten metal can find a way. If it is impossible to avoid getting on to a joint, then something should be spread over it to avoid damage.

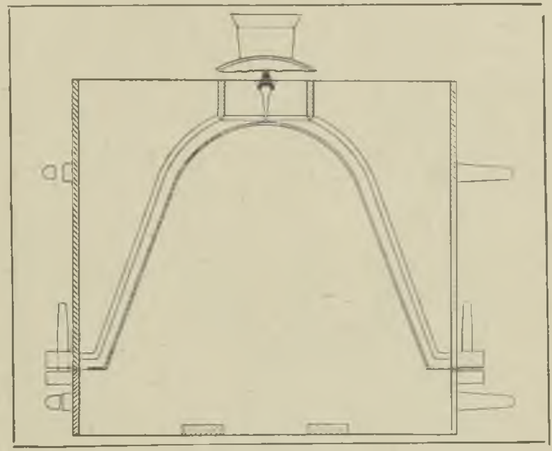

Fig. 1.

Short Pours.

These are nearly always inexcusable. There are ample means of finding out how to calculate the weight of castings and the capacity of ladles, with which information it would be well for every foundryman to equip himself.

Scabbing.

This is probably the most common evil in the foundry, and cannot always be attributed to faulty moulding. Materials provided by the management may sometimes cause a good deal of heart ache, and often a long time elapses before the true cause of the trouble is discovered. A personal experience might serve as a suitable illustration on this point. When visiting a certain foundry which was having considerable trouble from scabbing, the author was asked could he define the cause. He first inspected the sand, of which two kinds of sand were being used, namely, Mansfield and Southampton yellow, and upon examination it was found that the yellow sand contained large lumps of clear clay. The sands not being sufficiently well mixed, the clay lay in patches. When this trouble was eliminated scabbing ceased. Whilst clay is an essential in the foundry, it is an enemy when used indiscreetly.

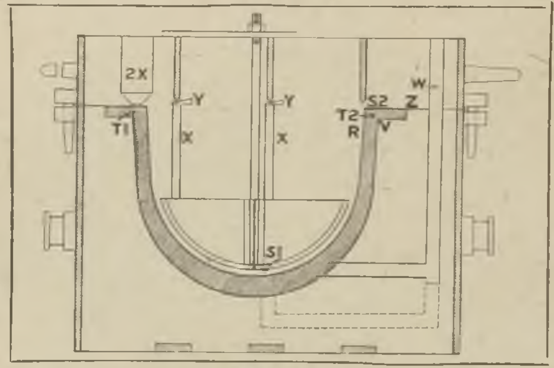

Fig. 2.

Figs. 1 and 2 are almost similar in shape, yet very few moulders would recommend making these two castings in the same manner. Fig. 1, being thin, the casting has to be run very quickly, usually with a thin flat gate on top (A). If an attempt were made to cast the other way up, it would necessitate two or three runners on the joint of the mould, and even then success would not be assured. Fig. 2, if made the same way, would probably scab because the gases could not escape sufficiently freely, and the casting, being so much thicker, contains more gases.

The internal portion of the sand is supported for lifting by the insertion of a four-winged grid or arbor. In the centre of the arbor is a screwed rod, suspended from a plate resting on two of the bars in the top portion, and to prevent the risk of screwing up too tightly distance pieces (X) are inserted, and a wedge (Y) driven in under the bar to ensure rigidity when lifting the top mould away for the withdrawal of a pattern.

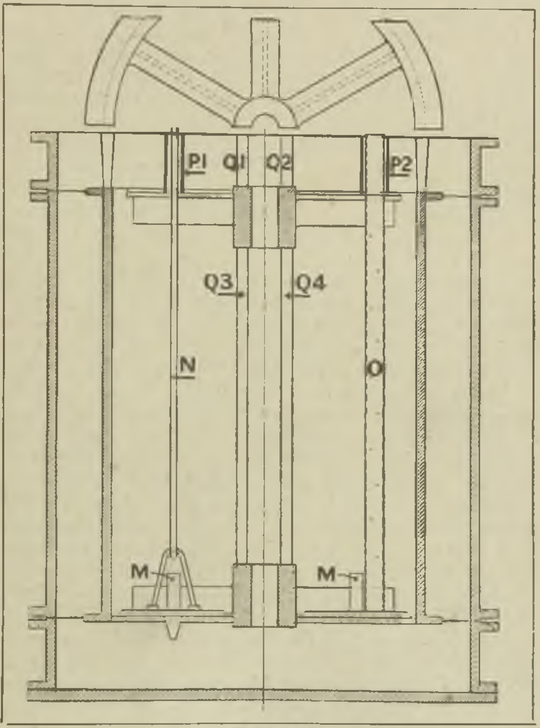

Fig. 3.

In Fig. 3 is an outline drawing of a winding drum with double arms set at each end. It is cast in green sand, where the risks of scabs are great. To the general founder it is well understood that a job of this description contains nearly all the elements to which a moulder is opposed. In the first place, the moulder cannot be given a complete pattern to work with, the drum itself being 4 ft. × 3 ft., he will probably have to work from a pattern consisting of a plain ring, probably 9 or 10 in. deep, with loose arms and flanges for top and bottom. Consequently, he would only be able to ram initially to the depth of the pattern ring. Then the ring would need to be drawn up 3 or 4 in. at a time with additional ramming each time, and all this adding to the difficulties of making the job safe. As it is the general practice to make this class of work for casting on end, it will be obvious that the mould must be very firmly rammed all over, and particularly at the bottom end. It will also be apparent that special arrangements are necessary for getting the air or gases away from the outer portion of the mould, as well as from the core. Every precaution should be taken to prevent the possibility of runouts at the bottom joints, for once the metal has started to make its escape in this vicinity there would be very little hope of saving the casting. Further, in connection with the core, it will be noticed from the illustration that the ordinary lifting plates as used for pulley arms are inserted, but for work of this description it is necessary that plates should be very securely attached to each other in the form of a stout bridge bar (M), or a similar arrangement for lifting the core when ramming is completed and for the extraction of the patterns. This being a six-armed drum, a lifting rod or eye bolt is shown at " N." There would be three such bolts distributed equally between the six arms. On the three remaining lifting plates it would be necessary to provide some means of preventing the pressure of the metal from lifting the plates. If these plates were allowed to lift, in consequence of the condensation which takes place in the mould they would be sweaty, and if the metal were to come into contact with this sweaty condition there would undoubtedly be a very serious explosion, causing extensive damage and probably injury to those in the immediate vicinity. To provide against this contingency, on the three lifting plates where there are no eye bolts, an ordinary length of core barrel " O " is inserted which protrudes just through the top, and when the mould is completed these plates are fastened down by the most suitable means available. Six pieces of gas barrel, " P1 and P2," are rammed up in the top part around the eye bolts and core barrel to prevent damage when being removed and replaced.

The method of running found most satisfactory will be as shown at Q1, Q2, Q3 and Q4, representing two runners fixed on the top boss, which are extended through the core to the bottom boss. One peculiarity about this system of running is that the runners between the bosses must be comparative in size with the section of material in the casting. Otherwise there would be danger of unequal contraction in cooling, and if the runners had the tendency of cooling more quickly than the main casting they would be likely to cause fracture in the arms. It should also be borne in mind that they should not be made heavier than necessary, owing to the difficulty in removing them when the casting is being trimmed. In some cases, where they do not have the effect of being unsightly, they are not removed at all, but are allowed to remain in the casting where they undoubtedly would perform the function of a strengthening bar and distance piece between the two bosses.

There is one important feature in connection with a job of this kind and that is the necessity of careful venting and ample provision for the escape of gas, especially in connection with the core, as all gases must be brought away through the three-core barrels which also function for holding down the lifting plate. It is also necessary with a core of these dimensions and shape to insert a fair number of stiffening rods during the ramming up of the core and at least at two or three intervals there should be a good layer of small coke or cinders through which the air could escape rapidly to the channel of exit, which in this case would be the small pieces of core barrel. Great care is also necessary in ramming. The point of the rammer should not be allowed to come closer to the pattern than from $1\frac{1}{4}$ to $1\frac{1}{2}$ inches. This practice applies to all classes of work in the foundry. If the rammer is allowed to come into close contact with the pattern, the result is a series of small shell scabs.

Crushes.

These are avoidable, and usually come from careless mending up or plastering on too much where it has been found necessary to patch a mould. To be on the safe side, every mould should be re-opened after closing, to ensure there is no trouble of this character. Blows also have several causes. They are chiefly attributable to gases in the metal. The moulder is not responsible for the materials used in metals, consequently he is not always responsible for blowholes. As is well known, cast iron naturally absorbs sulphur, and if a faulty supply of coke is obtained which contains more sulphur than it should, the iron will absorb some of the sulphur which might probably show, up later in the casting in the form of blow holes. The moulder is sometimes at fault with his ramming, or if he uses sand containing too much moisture, also improper venting, or the placing of runners and risers in the wrong position.

Cold Shuts.

Here the moulder can be responsible, and perhaps, also, the management, should the latter insist upon the use of metals unsuitable for the work in hand. For instance, Fig. 1 could not be cast with strong Scotch iron, and even in Scotland, where a large amount of work of this type is made, Middlesbrough iron is chiefly used, owing to its excellent fluidity allowing free running for thin castings. It is also not so troublesome from a contraction point of view. For Fig. 2 and Fig. 3 the lower phosphorus irons are more suitable. In the case of thin work, if the sand be too strong, it would have the tendency of hindering the free flow of metal, resulting in cold shuts.

Cross Joints.

These are also inexcusable. Faults of this description may be attributable to both sides. Where boxes are made to fit too loosely, there is a well-known practice of keeping them twisted in the direction of the travel of the sun, and if this is not possible, there are other methods for making sure that the joints meet properly. On the other hand, it is far better, and it removes the possibility of risks being taken, if the management will provide well-made boxes for use in the foundry, and thereby eliminate this class of trouble to a large extent.

Cores Lifting.

The moulder often has complaint against the pattern-maker on account of insufficient prints so often being put on patterns. Take an 18-inch cylinder, for example, probably from two to three feet long. A common practice would be for the pattern-maker to only put on an inch or an inch and a half core print on the pattern, leaving the moulder the difficulty of having to secure a core on prints of such dimensions. This is a system of false economy, and although it may mean the saving of a few pence in the pattern-shop, it necessitates additional work for the moulder, besides the added risk of losing a casting. The American practice is to go to the other extreme by providing ample core prints on all types of cylindrical or pipe patterns. They do not use core barrels as numerously as we do. Chaplets also prevent cores from lifting and the proper use of these accessories should be well understood.

Cores Breaking.

This may be more attributable to the core maker than to the moulder. Every core should be satisfactorily ironed and strengthened, and of course a good core cannot be made with bad sand.

Contraction Cracks and Warping.

These cannot always be attributed to the moulder, yet he should be conversant with the causes and remedies. By giving proper attention, some castings can be prevented from warping. Take a lathe bed for example. These are not designed of uniform section, and therefore part of the metal has completed contraction before the remainder. This means that the box portion of the bed, which is designed to be of sufficient strength to bear the anticipated load, is always thinner in section than the slide rails, which have to take the wear and tear of the saddle. A common practice when moulding this type of casting is to bend the pattern to the same amount as the anticipated warping. This is not the most desirable method, as a casting treated in this way always retains a strain on the structure, which is never released until fracture takes place. The more preferable custom is to mould the pattern straight, and immediately after casting, when the iron has solidified, the heavier sections should be stripped and made bare, in accordance with the dimensions of the bed being made, so that the heavier sections may be encouraged to cool down and complete contraction in the same period of time as the lighter section. This produces a casting free from strain, and is much more satisfactory to all concerned.

Strains and Swells.

These are usually the result of careless and unintelligent ramming and are nearly always avoidable.

Dirt and Slag.

These complaints very often arise from the unsatisfactory system of arranging runners. Fig. 2 illustrates a runner " W " carried to the base of the casting. It would be possible to run the same casting on the joint at " Z," but the results would more than likely be unsatisfactory. Firstly, there would always be a suction in the runner during the casting, which would naturally attract all dirt which got into the pouring bush, conveying it into the casting. Secondly, the flow of the metal over " V " would have a tendency to cause scabbing, and beating against " R " may also create the same trouble and the dirt which would accumulate from these two troubles might become apparent at points " S1 and S2." In all work of this description, it will undoubtedly be found preferable to carry the runner to the bottom if possible.

In the same illustration we get an example of the effects of sponginess and faulty feeding. Although the bottom of the pot is of a thicker substance than the sides or the flange, it is not usual to find sponginess in the bottom portion of the casting. It would be more likely to appear at

"T1" and "T2." This could be overcome by the introduction of a riser at "2X." This would act as the feeder, and it will be noticed that a riser has been made considerably larger in sectional area than the casting, the idea being that this is always preferable where possible. It is recommended that in casting a job of this description, pouring should cease immediately the metal has appeared in the riser. Probably a handful of charcoal would be helpful in retaining the temperature until it would be possible to bring along a fresh supply of hot metal from the cupola, with which the riser should be filled to the top. With the renewed rising temperature the riser would have a tendency to remain fluid until the main casting had completely solidified. If or when it is found necessary to resort to the use of a feeding rod, the operator should be very intelligently schooled in the use of same.

Discussion.

In opening the discussion, Mr. Galletly (President) suggested that an improvement might be effected in the system of running Fig. 2 if the method shown by dotted lines were used in place of the runner shown. This point was agreed, but it was suggested the introduction of such a runner might entail some difficulty. Mr. Galletly also confirmed the types of iron necessary for light and heavy castings, stating he had had an unpleasant experience owing to high-phosphorus iron having been used for a heavy casting.

Mr. Hird, referring to the question of clay in the sand, stated that there was clay in all moulding sand, and if it was eliminated, the sand would be useless for moulding. It was interesting to examine washed and raw sand under a microscope. The former appeared as a bright substance, whilst the latter had a little coating of clay covering it.

He asked for an expression of opinion on open and closed risers, the reply being that closed or covered risers should be used, particularly in connection with thin work, where it was necessary to rush the metal in as quickly as possible, which usually causes risers to roar, which in turn has a tendency to pull down the faces of the mould. Mr. Hird thought that for some classes of thin work there was an advantage in having an open riser. If it were closed there was pressure on the sand all the time. With regard to coal dust, he asked whether it was advisable to use none at all or a reduced amount for thin work, or should old sand be used.

In reply, **Mr. McClelland** said that for very thin work no coal dust at all was required. By way of illustration he quoted that when making thin, flat plates about 5 ft. by 3 ft., ¼ in. thick, with a 1-in. flange all round, it had been found that an equal proportion of new and old sand thoroughly mixed and a coating of plumbago on the face of the mould had been most satisfactory. Fig. 1, for example, would always be made without the use of coal dust.

Replying further to Mr. Hird, the speaker said that the elimination of coal dust helped to prevent seams on thin castings. For varying types of castings it was suggested that coal dust in the proportion of 6 to 1 should be used for heavy castings, 8 to 1 for light castings, and for very light castings no coal dust at all. For a casting as illustrated by Fig. 2, the proportion should be 6 to 1.

Mr. Hird thought it was very difficult to get a lathe bed straight by stripping, but thought that by putting in camber, although admitting there always was a strain, this was not a serious defect.

Mr. McClelland replied that whilst it might be all right to camber the pattern of a small lathe bed, he could not agree with the practice when making a large lathe bed, say, of 11 tons. Weighting moulds had been referred to in connection with runouts. The rough practice in many foundries was to use three times the estimated weight of the casting. A well-known moulding machine maker in America had advocated that there was a 3½-lb. to the sq. in. lifting pressure on all types of castings, no matter what their depth, but the more reliable formulæ was one established in this country of 1-lb. pressure to the sq. in. for every 4 in. of depth, *e.g.*, 8 in. deep would have 2 lbs. pressure to the sq. in. and 12 in. deep 3 lbs. pressure per sq. in., and so on.

Mr. Jenkins spoke of having seen a pot very similar to Fig. 2 made the reverse way, with disastrous results, the casting having a perforation in its base when the test was made with water.

Mr. Evan Davies asked what method would be adopted in extracting the pattern from the mould in Fig. 3. Also, whether it would help matters if the runners were put in on the slant to prevent contraction between the bosses. The reply was that it would be necessary to lift the middle part of the mould away and then withdraw the core to extract the pattern and make the necessary repair to the mould and also for convenience in blacking the mould. With regard to the slanting runner, this method might be an improvement on that shown.

Mr. Kinsman asked whether the runner in Fig. 3 was not liable to cool more quickly than the other part of the casting, the reply being that the runners should be of such proportion as to obviate this. At the same time, it must be remembered that by the flow of molten metal through the runners whilst the casting is being poured, the surrounding sand is raised in temperature to such an extent that it assists in retaining the heat in the runners so that the whole casting cools down more or less equally.

Mr. R. G. Williams stated that patternmakers did not like to take any blame, but preferred to refer to draughtsmen's errors and patternmakers' oversight. It was part of their duty to consider the economical use of their materials.

In proposing a vote of thanks to the lecturer, Mr. P. Leonard Gould offered congratulations, saying that he thought this was the type of lecture needed in this Branch. Mr. Marsh seconded, and the motion was supported by Mr. R. G. Williams.

Middlesbrough Branch.

NON-FERROUS FOUNDRY PRACTICE

By A. Logan (Member).

The first outstanding fact about brassfounding as compared with ironfounding which must strike everyone is that of purely commercial considerations, *i.e.*, the big difference in the cost of the metal going into the respective moulds. Whereas a pound of good-quality cast iron costs only a matter of three farthings, non-ferrous alloys may range from 7d. to 1s. 6d. per lb., or from 9 to 24 times as much. Assuming the same percentage profit in each case, castings in non-ferrous alloys will yield a much higher profit compared with similar castings in iron. A brass foundry of the same output as an iron foundry will therefore have a far greater commercial value per annum. Conversely, whereas a waster in cast iron may not amount to much, a similar waster in non-ferrous means a far greater loss of potential profit.

The following remarks are mainly concerned with some of the metallurgical considerations of brass founding, consequently there is little to say regarding actual brass moulding as compared with iron moulding. One thing is certain, however; a good brass moulder can go over to iron and produce first-class iron castings, but an iron moulder cannot produce successful non-ferrous castings without some previous brass-foundry experience or knowledge. Generally speaking, brass moulding calls for greater care and accuracy at every stage. Although non-ferrous alloys melt, and are poured at a very much lower temperature than iron, it is surprising how fluid and searching some of these alloys are upon the mould.

Solidification of Non-Ferrous Alloys.

In tracing trouble, it is necessary to understand the principles which govern the solidification of the particular metal or alloy in question. As alloys of the bronze type are greatly used, the equilibrium diagram of the copper-tin series should be consulted. The complete diagram is rather complicated, but the portion containing up to 20 per cent. tin (which includes all the commercial bronzes) is quite simple, and worth studying by the practical foundryman. Pure copper has a freezing point of 1,084 deg. C., and pure tin a freezing point of 232 deg. C., consequently none of the bronzes can have a freezing point as great as 1,084 deg. C., as the greater the amount of tin added, the lower the freezing point of the resulting alloy.

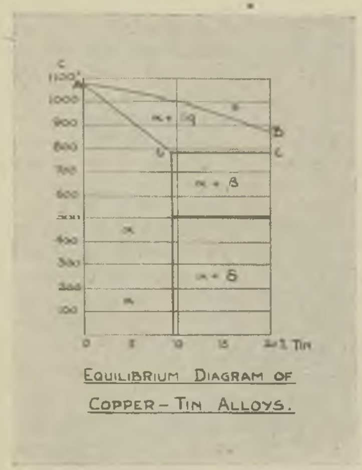

FIG. 1.—EQUILIBRIUM DIAGRAM OF THE COPPER-TIN ALLOYS, UP TO 20 PER CENT. TIN.

The line A—B (see Fig. 1) is called the liquidus, as at temperatures above this line the alloys are completely liquid. The line A—B—C is called the solidus, and at temperatures below this the alloys are completely solid. Between the two solidification takes place during an interval of time. Any line shown below the solidus relates to changes which take place in the solid material whilst cooling. Such a change is shown to take place at

500 deg. C. in alloys containing over 9 per cent. tin. To take an actual example: In a bronze containing 10 per cent. tin the first solidification commences about 1,000 deg. C. As can be expected with two metals having such big differences in freezing points, it is relatively pure copper which starts to solidify first. This shoots out in straight lines forming a sort of skeleton or backbone for the remainder of the alloy to solidify round. Solidification commences simultaneously throughout the alloy at all points at which the temperature is 1,000 deg. C. In the case of a casting, the metal which travels the furthest, *i.e.*, which is cooled the most, is the first to solidify, and this solidification naturally always commences at the wall of the mould, and proceeds inwards. The dendrites, as they are called, which have started to grow, soon find their progress checked by others round them, consequently branches are thrown out at right angles to the main axes, and when these meet with interference, branches again shoot out at right angles. In this way the crystals are gradually built up, and it will be seen that the shapes of the crystal boundaries are entirely haphazard, and are due to the interference one with another. The size to which the crystals grow depends upon the rate of cooling, which in turn depends upon the casting temperature and the size and section of the mould, and in a lesser degree on the ramming and thickness of sand.

When a waster casting is broken up, examination of the fracture (when guided by practical experience) will indicate whether the casting temperature was at fault. As the temperature falls, solidification proceeds and the liquid portion becomes richer in tin, as also does the material which is building up the structure, and which is known as the alpha solid-solution. At 790 deg. C. the alpha formed should contain 9 per cent. tin, and the remaining tin-rich liquid now solidifies. If a specimen of 10 per cent. bronze was quenched in water from just below 790 deg. C. it would be found to consist of two constituents. One, the heterogeneous alpha from almost pure copper up to approximately 9 per cent. tin, and a small amount of what is called the beta constituent, which contains approximately from 22.5 to 27 per cent. tin. This beta constituent is not stable, and when slowly cooled to 500 deg. C. breaks down into alpha and a third constituent known as delta.

According to the equilibrium diagram, a 10 per cent. tin bronze should contain only very small amounts of the beta constituent (or, as it finally appears in the casting, the delta constituent), but in actual practice, however, the rate of cooling is the most important determining factor. The slower the rate of cooling, the greater the amount of beta formed, and consequently the greater the amount of delta found in the casting. This has a very practical application. The delta constituent is quite different in physical properties and appearance from the alpha matrix in which it occurs, and it influences the physical properties of the casting containing it in proportion to the amount present and its distribution.

The lecturer then described a series of photomicrographs shown on the screen illustrating the structures of sound, strong gunmetal, and weak, unsound gunmetal. The chief outstanding difference in the case of the good gunmetal was that the strong interlacing dendritic structure was strongly developed, and this was always associated with a very small amount of the delta constituent and freedom from oxide films, etc. In the case of the weak gunmetal, the pronounced dendritic structure was replaced by a weak, loose arrangement associated with a large quantity of the delta constituent in a more or less network formation, and often considerable oxide inclusions and films. The importance of the delta constituent was shown when its properties were described. The delta is a hard, brittle, bluish-white compound of copper and tin in the proportion of one atomic part of tin to four atomic parts of copper (actually approximately 32 per cent. of tin). Being in itself hard and comparatively brittle, it imparts these qualities to the casting in which it occurs, reducing the tensile and elongation in proportion to the amount present. Foundrymen cannot always look at the structure of their castings through a microscope, but the fracture of the material does to some extent give an idea of the type of structure which the material possesses.

Fig. 2 illustrates the intercrystalline fracture of a piece of strong gunmetal when broken hot, whilst Fig. 3 shows the same piece of metal sectioned and etched to show the microstructure or crystal arrangement.

If a consignment of scrap gunmetal is being bought, and the fractures of the material resemble that shown, it can be fairly safely assumed that material of good quality is being obtained. On the other hand, if any pieces have fractures similar to that shown in Fig. 4 they should be rejected. Similarly any risers or runners broken from castings giving fractures of this kind indicate that the structure of the material is at fault, and a poor result can be expected from the casting. If subject to hydraulic test, it will in all probability prove porous. The physical properties of gunmetal are thus dependent upon the structure, and the practical question then arises as how best control the material in order to produce the right type of structure.

Fig. 2.—Fracture of Strong Gun-Metal. (Broken Hot.)

Fig. 3.—Macro of Gun-Metal.

Careful Melting Essential.

In many brass foundries the old-fashioned type of pit fired furnace is still in use, and although this type is far from ideal, yet it has a number of good points. Its first cost is low, and it is cheap to maintain. These advantages, however, are probably much more than counterbalanced by its low efficiency. It is also slow in melting, but except where mass production is in operation, this need not necessarily be a disadvantage. The slower melting probably leads to economy of crucibles, and these are an important item. Where care is taken, the crucible with natural-draught pit-fire melting is capable of giving the least oxidised material. Other forms of furnace used for brass melting are the tilting furnace, either coke or gas fired, or oil fired, as demonstrated at the recent Foundry Trades Exhibition in London. Where larger quantities of metal are required at one time, reverberatory furnaces are used. Generally the pit-fire type only take up to 300 or 400-lb. crucibles, and a number of units are built together. Where more than, say, a ton or 30 cwts. of metal are required for one cast, then a reverbatory furnace must be used, and these can be built to suit whatever capacity is required. Fig. 5 is a general view of a foundry, and shows a battery of 12 pit fires and one tilting furnace.

Fig. 4.—Fracture of Weak Gun-Metal.
(Broken Hot.)

Method of Making the Alloy.

The copper should be charged into the crucible, and, if scrap is being used, this should go along with it. A good covering of charcoal should be given, the fire made up, and the furnace cover put on. A good plan is to stand the crucible on a firebrick slab, then as the fire burns away the crucible remains undisturbed. The melting should

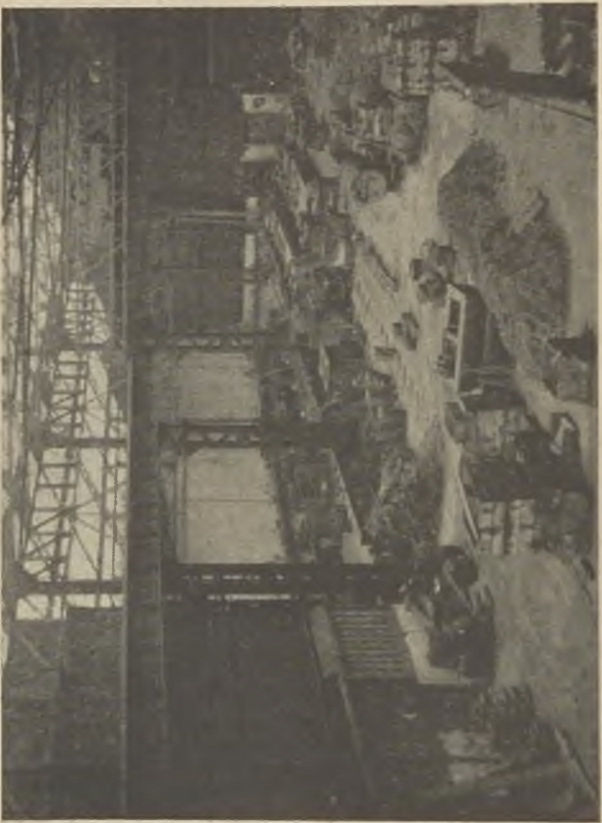

FIG. 5.—VIEW OF FOUNDRY WITH BATTERY OF PIT FIRES.

be as rapid as possible. When the contents of the crucible are just molten, the zinc is added, then the tin, and the right amount of superheat is attained as rapidly as possible. The mould should always be completely ready before the metal, so that the moment the right temperature is reached the pot can be withdrawn from the fire, and, after careful skimming, poured. These precautions are all with the object of preventing oxidation of the copper. A very large proportion of the troubles which occur in non-ferrous castings is a direct result of this one thing—oxidised material. When it is realised how readily and easily copper picks up oxygen when heated, and especially when molten, the importance of taking the utmost precautions against oxidation will be appreciated. A very simple object lesson, and one which should be brought to the notice of all furnacemen, is to take a sheet or piece of scrap copper and place it in the fire for a few minutes. If it is lifted out carefully and cooled down on a plate it will be found to be thickly covered with a black powdery scale. This is the copper-oxide which has been formed as a result of the combination of the metallic copper with oxygen from the air. At the temperature at which copper is molten this reaction takes place with great rapidity whenever the surface comes into contact with the air. If the copper-oxide so formed would come to the top of the metal it could be skimmed off, and the only trouble would be the loss of copper. Unfortunately, however, copper has the property of dissolving or alloying with its own oxide, and all the copper-oxide formed during melting goes into the alloy. If no steps were taken either to prevent the formation of oxide during melting, or to remove the small amount which is formed in spite of the greatest care, the resulting alloy would be sluggish and pasty, and castings poured from such metal would certainly be unsound.

In the case of Admiralty gunmetal, the composition is 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc, and the function of this small amount of zinc is to remove the oxide formed during melting. The correct time to add the zinc, therefore, is before the tin. If this is done, zinc unites with the oxygen from the copper-oxide, forming zinc-oxide, which is a light white powder, and is not soluble in the molten alloy. Zinc alone is not a perfect deoxidiser, for if the metal is badly oxidised it will not reduce more than a portion of the oxide present, and in any case, even with material which is carefully melted, it does not remove every trace of oxide. It is a good plan, therefore, where the highest quality material, giving the best possible results, is desired to add a further deoxidiser in the form of a phosphor-tin. Very little of this is required, the aim being just to add sufficient to deoxidise and leave practically none, or little more than a trace of phosphorus in the finished metal. The object is to get the metal as thoroughly deoxidised as possible before the addition of the tin, not only to prevent the loss of valuable tin by the formation of tin-oxide, but because tin-oxide once formed is very difficult to get rid of. Moreover, tin-oxide does not free itself so readily from the metal as does zinc-oxide, and it has a bad habit of crystallising in small crystals of tremendous hardness, which are detrimental to the material.

Casting Temperature.

Once the material has been carefully made and melted, there is still another point which must be attended to before even the perfect mould can be poured and a sound casting result. This is correct casting temperature, and neglect of this one point is quite sufficient in itself to bring about a waster casting. Fortunately, with the bronzes there is a fair amount of latitude. In the case of Admiralty gunmetal, the range of casting temperature extends from about 1,100 deg. C. for very heavy castings to about 1,220 deg. C. for light work. The rule to follow is to take into account the section and mass of the casting, how far the metal has to run, etc., and cast at as low a temperature as ever possible.

Wasters due to too high a casting temperature can be expected when " tin sweat " or segregation makes its appearance on the top of the runner, or wells up in the centre of the fracture when the runner is broken off soon after casting. Analysis and micro examination prove that the extruded segregated material is the beta constituent, containing up to about 25 per cent. tin. (See Fig. 6.)

According to the equilibrium diagram, a bronze with only 10 per cent. tin should contain only traces of this beta constituent, but in actual practice the rate of cooling has a very considerable influence; and unless the solidification is sufficiently rapid, then large quantities of tin-rich liquid will accumulate and form segregations in the portions of the casting last to solidify. In extreme cases some of this is actually squeezed out by the solidifying metal, and forms the "tin sweat," as it is called, seen on top of the runner.

Fig. 6.—Photo-Micrograph of Segregation from Top of Runner, × 50 diams.

The importance of correct casting temperature will be realised, for if the casting temperature is too high it means that the walls of the mould will absorb an undue and unnecessary amount of heat, which, owing to the poor conducting properties of sand, will be retained and retard the solidification of the casting. This is often the cause of trouble where castings have varying sections. The casting temperature must be high enough to run the thin parts without any fear of "cold shuts," yet if the thicker portions are very much greater in section there is a chance of segregation or "drawn" places resulting. In such cases it may be necessary to resort to chills to even out the rate of solidification. In this connection it should be mentioned that much can be done by means of correct gating and running.

Fig. 7 illustrates the different types of runner heads which indicate pouring too hot, correct, and too low. Castings with runner heads similar to A will probably suffer from oxidation films and pinhole unsoundness, and possibly show tin spots or segregation in heavy sections. The crystal size will be very large. Castings with runner heads similar to C will also be unsound, owing to the solidification taking place without proper feeding. The presence of blow holes is also almost a certainty, due to the fact that there is no time for gas to get free from the metal before solidification takes place.

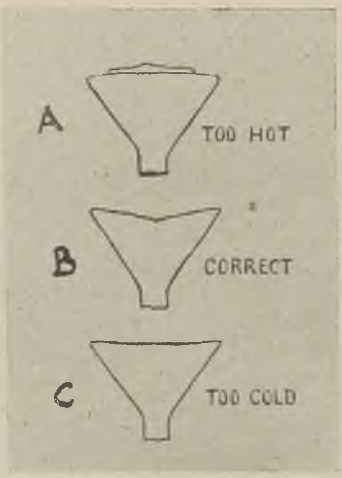

Fig. 7.—Effects of Extremes of Pouring Temperatures. (Gunmetal.)

There is generally a tendency to pour on the hot side, especially where a number of small boxes are poured from one crucible. The high-tin bronzes, and especially the phosphor bronzes, must not be poured too hot owing to the greater amount of "beta" which is normally formed, and which would segregate badly if the solidification was too slow.

Other Bronze Compositions.

Admiralty gunmetal is a high-quality general-purpose bronze, and as such is in general use for high class engineering. Cheaper and more easily handled alloys are used for ordinary engineering purposes. These usually contain less tin and more zinc, and often appreciable amounts of lead. An alloy such as 86 per cent. copper, 8 per cent. tin, 2 per cent. lead, and 4 per cent. zinc is in very wide use, and has been successfully used for pressure work.

When bearing bronze is required it is necessary to add more tin. Usually phosphorus is also added, not only to act as a deoxidiser, but to form the hard compound of copper-phosphide, which, associated with the "delta" constituent, assists materially the good wearing properties. Although the "delta" constituent is harmful in castings for ordinary purposes, making them weak and brittle, yet its presence is purposely encouraged in bearing metal, as its great hardness enables the metal to withstand a considerable amount of wear.

Lead is often added to bearing metals, a common composition for locomotive work being 84 per cent. copper, 15 per cent. tin, and 1 per cent. lead. Lead added to a bronze does not alloy, but is distributed throughout the structure in the form of small globules.

Brasses.

Although the usefulness of the bronze series is beyond question, yet the continual rise in the price of tin makes it worth while considering whether brass could not be used just as well in many cases. Brass is not suitable for bearings, nor is it suitable to take big pressures, nor to carry corrosive liquids. All constructional parts, however, can be more easily and cheaply cast with a brass of the Muntz metal type—that is, 60 per cent. copper and 40 per cent. zinc. If desired, both tin and lead can be added, and the physical properties still maintained about that of gunmetal.

Manganese Brass.

Muntz metal is really the base of all the high tensile brasses. By the addition of tin, iron, manganese, aluminium, and in some cases nickel, an alloy can be produced with quite distinct properties of its own. Different grades of manganese brass can be made, depending upon the purposes for which they are required, having tensile strengths ranging from 30 to 45 tons per sq. in. The medium strength alloys generally fall within the following range of composition:—Copper, 54 to 60; tin, trace to 1.2; lead, up to 0.5 per cent. (this is a criterion of the quality of zinc used, or may indicate the use of scrap in the manufacture); iron, about 1.0; manganese, trace to 3; aluminium, trace to 1; and zinc, remainder (approx. 39 to 40 per cent.).

Owing to their peculiarities, these alloys are rather difficult to handle in the foundry. The extra liquid contraction and shrinkage must be allowed for by means of risers and large feeding heads.

This alloy is principally used for pumps and propellers, and anywhere where resistance to corrosion is desired. It has been specified and used successfully for locomotive axle boxes. The best method of manufacturing this alloy is to make it in crucibles and cast into ingots, remelting these (if for a large casting) in a reverberatory furnace. The usual procedure is to place the iron (which can conveniently be in the form of wire nails) on the bottom of the pot, along with the cupro-manganese. The copper is placed on top and melted, then the zinc, tin, and aluminium are added. Manganese brass has a high surface tension, due apparently to the instantaneous formation of an oxide film on the surface. Attention should therefore be paid to gating and running, otherwise laps may be formed due to the fact that the two streams meeting may not unite perfectly.

The casting temperature range is very small, being approximately 1,000 deg. C. + 20 deg. C., so that pyrometric control is almost essential.

Aluminium Bronzes.

Another series of alloys which offer great possibilities as substitutes for tin bronzes are the aluminium bronzes. A plain 90 per cent. copper, 10 per cent. tin bronze, whilst having good physical properties, is practically useless as a foundry proposition, owing to the almost physical impossibility of obtaining sound sand castings. The addition of from 3 to 5 per cent. iron with a little silicon and manganese improves the casting qualities, but the alloy steel remains difficult to handle, being similar to manganese brass with its high shrinkage, etc. It is similar to the medium ranges of manganese brass (35 tons per sq. in. and 20 per cent. elongation), and has a good resistance to corrosion. There is no doubt that there is a future for this class of material, and it is being developed for propeller work.

The pure aluminium alloys for aeroplane and motor engine crankcase parts, etc., are also of great importance, and demand a foundry technique of their own. A recent development is the incorporation of light aluminium alloys into marine engineering practice.

General Considerations of Non-Ferrous Work.

Constant care and supervision of non-ferrous alloys is required whilst 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 casting temperature required for a particular casting. Although it is surprising how near a certain temperature can be judged by a man doing it day after day, yet it is better to be on the safe side for important work, and use a pyrometer. "Pinhole" unsoundness and liquation or segregation are a result of overheating and too high a casting temperature.

Another form of unsoundness, often accompanied by actual blowholes, is due to too low a casting temperature, and is caused by lack of feeding, and insufficient time liquid in the mould to allow gas to free itself. These troubles are avoided by casting at the correct casting temperature for the particular casting. The correct casting temperature is a matter of the section and mass of the casting, the distance the metal has to run, etc., in conjunction with previous experience. Correct casting temperature will not ensure a sound casting when the metal has been carelessly melted and is oxidised. Such metal, in addition, is nearly always poured too hot on account of its lack of fluidity.

Nowadays, it may be taken for granted that the possibility of chemical impurities giving trouble in ordinary brass or bronze is fairly remote. Chemical impurities can, and do, give trouble occasionally, as certain brands of copper have been found unsuitable for bronze making; but ordinarily, where good brands of pure metals are used, no trouble need be expected from this source. Of far greater importance is the damage which can be done in the foundry itself by unsuitable manufacture, careless melting, and incorrect casting temperature.

DISCUSSION.

Acid-Resisting Alloys.

Mr. Nisbet asked if the lecturer would state some acid-resisting alloys suitable for chemical work.

The lecturer replied that he could not claim to have had a great deal of experience with regard to acid-resisting alloys, but it would depend entirely upon the circumstances as to which particular composition would be most satisfactory. For actual chemical purposes, lead was often used alone, or, at any rate, lead-lined vessels; but if for constructional parts of machinery, then lead was obviously not hard or strong enough. An alloy of greater strength and hardness was obtained by adding antimony, and a composition of 90 per cent. lead and 10 per cent. antimony was used for pumps dealing with corrosive liquids. Where greater strength was required, then it was necessary to use a high nickel alloy. Monel metal, for instance, was an alloy of copper, nickel, iron, manganese, silicon, etc., and possessed a good resistance to corrosion. Other high nickel and chromium alloys were being developed for corrosion resisting purposes.

Removing the Delta Constituent.

Mr. S. V. Toy asked whether the lecturer could state whether the delta formation, the cause of the hardness in bronze, could be removed by annealing or even remelting, as he had understood him to say that scrap containing delta was useless for remelting.

In reply, **Mr. Logan** stated that the delta constituent was certainly removed by annealing. The correct temperature was approximately 700 deg. C., and the delta was absorbed into the alpha solid-solution, but whether it was advisable to anneal bronze in practice was another matter. In the case of bearing parts, the good wearing properties would suffer. As the delta constituent was mainly produced by slow cooling and prolonged solidification, it followed that remelting and more rapid solidification would eliminate it. He did not mean to imply that scrap containing delta was useless for remelting, but that often the presence of a large amount of this constituent was an indication of poor melting practice and oxidised metal, consequently scrap with such a fracture, as illustrated, was best left alone.

Etching Reagent.

Mr. N. E. Ridsdale asked what etching reagent was used for etching the specimens of bronze shown upon the screen, and whether phosphor-copper or phosphor-tin would be the most suitable deoxidiser for melting commercial pure copper, or would arsenic or manganese be equally or more suitable.

Mr. Logan stated that all the bronzes shown, with the exception of these heat-tinted, were etched with an alcoholic solution of acidified ferric chloride. The effect obtained was simply a matter of the time of immersion. Dealing with the question of the deoxidation of pure copper, Mr. Logan said that it was mainly the purpose for which the finished article was required which determined which deoxidiser was the best to use. For electrical purposes, for instance, phosphorus would raise the electrical resistance too much, and the most suitable deoxidiser in this case was cupre-silicon. Where phosphorus and tin were permissible, then probably the use of phosphor-tin would be the more satisfactory, as the addition of the tin would also aid the casting properties. The lecturer stated that he had not heard of arsenic being purposely introduced in the foundry for use as a deoxidiser. He did think manganese would be as suitable as phosphor-tin.

In a further question, MR. RIDSDALE asked what kind of plates were used in order to give transparent colour lantern slides, as he understood the autochrome process gave slides which were usually too dense for the lantern.

In reply, Mr. Logan said that the colour photographs of the heat-tinted sections shown were prepared by the autochrome and Paget processes. The main thing was to get the exposure correct, or, if anything, a shade on the generous side, in the first instance; then there should be no difficulty in obtaining a slide which was not too dense.

Melting Losses.

MR. CLAY asked if the lecturer could explain how it was that a copper containing silicon gave better results after the second melting, also how an addition should be made for the loss of spelter on the first melting of manganese brass.

Replying to the first question raised by Mr. Clay, Mr. Logan said that he was unable, offhand, to give a reason for this. With regard to the loss of zinc on melting manganese brass, this could be quite serious under certain conditions, amounting to as much as 3 or 4 per cent. As it was important to work to close limits of composition, this loss had to be made good. It was possible to take samples from the furnace at short intervals, and examine them under the microscope, and determine the quantitative position of the zinc. The best method was to make up the original ingots with a sufficient excess of zinc to allow for the loss which took place on remelting. With definite furnace conditions, further adjustment would then be very seldom necessary.

The meeting was concluded by a hearty vote of thanks to the lecturer, proposed by Mr. Smith and seconded by Mr. Clay, to which Mr. Logan briefly responded.

London Branch.

CONTRACTION IN ALLOY CASTINGS.*

By H. C. Dews (Member).

The volume of any substance depends on its temperature and its pressure. This elementary law of physics has an important bearing on the casting of metals and alloys, and this Paper deals mainly with some of the ways in which the soundness of a casting is related to the volume changes brought about by change of temperature. The effect of pressure, though not unimportant, will not be considered here.

At the outset it would be advisable to describe in a simple, scientific manner what is meant by the reference to "soundness" in castings. At any given temperature a certain mass of metal, if in equilibrium, occupies a definite volume, or in other words its density at that temperature is a specific figure. This density of the metal in equilibrium is known as its "real" or "true" density. The density at normal temperatures of a piece of cast metal, as determined in the ordinary way, generally falls short of its real density. The casting occupies more volume than theory demands. The difference between this "apparent" and the true density is due to the presence of cavities in the mass of metal generally supposed to be filled with gases which weigh considerably less than the metal which should occupy this space. The nearer the apparent and true density figures approach the less must be the internal cavities, and the more continuous and compact will be the material of the casting. In a perfectly sound casting—if such a thing exists—the two values will coincide. Careful distinction should be made between the apparent and real density when either of these values is mentioned subsequently.

The founder, strictly speaking, handles his metals in only two forms—the solid and the liquid. It is convenient, however, to study the produc-

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* A Paper read before a joint meeting with the London Section of the Institute of Metals, December 9, 1926.

tion of a casting in three stages—when the metal is all liquid, when both solid and liquid are present, and when the casting is entirely solid.

The Liquid State.

Mr. A. H. Munday, the President of the London Section of the Institute of Metals, in his address at the opening of this session, called attention to the serious lack of data dealing with the behaviour of metals in the liquid state. The present author would like to reinforce Mr. Munday's complaint, and to commend the subject to the research associations and institutions as one well worth their immediate and serious attention. A few reliable physical constants for common metals and alloys in the liquid, particularly in the range near the freezing point, would be a real help to those practical technologists who are wrestling with a correct understanding of foundry problems.

There are apparently no reliable published figures of the change of volume of liquid metal with change of temperature. Occasional attempts have certainly been made to determine these figures for some low melting-point metals and alloys, but even these researches are out-of-date. The figures for our widely used industrial alloys of medium melting point have been left entirely to conjecture.

It is well known that water has its maximum density 4 deg. C. above its freezing point. That is, it contracts when falling from 100 to 4 deg. C. and then from 4 to 0 deg. C. it expands again. Certain metals, particularly bismuth, have been suspected of similar behaviour, but confirmation is lacking. On the other hand there appears to be no reason why such anomalous effects should not occur in metals and alloys, and it certainly is a fact that the behaviour of certain alloys could be better explained by some other than a straight line volume-temperature curve. Failing definite data, however, one feels driven to assume that alloys contract regularly with falling temperature, and where quantitative considerations are involved it seems fairly safe to assign about 2 to 4 times the solid contraction to the liquid contraction. On certain deductions below such a simple relationship will be assumed.

The Solid State.

Much more data is available for metals in the solid, but here, again, the range of temperature very near to the freezing point has received less attention than it deserves. The profusion of data dealing with solid contraction falls into two classes—that which is expressed as inches per foot contraction and that which is expressed as coefficient of expansion. The former deals with the net contraction of a foot of metal falling in temperature from its freezing point to normal temperatures. The latter gives the increase in length suffered by unit length of the material during a rise of one degree. This figure applies only to a limited range of temperature.

The patternmakers' work is intimately connected with solid contraction. A pattern is always made a certain fraction bigger than the designer's dimensions, so that the casting which immediately on solidification takes the size of the pattern shall, on contraction with fall of temperature, eventually attain the desired size. The amount of this allowance for shrinkage is usually arrived at by deliberate experiment or by general experience based on a long series of checking various castings. In view of the intricacies of most modern castings, patternmakers are to be congratulated on the success they have obtained with these figures, compiled without much help from our scientific investigators.

One would expect that shrinkage figures could be obtained by multiplying the coefficient of expansion of the alloy by the difference between normal temperature and its freezing point. Calculated in this way the theoretical figures are all somewhat higher than those in practical use, and the difference calls attention to an important point. A casting is seldom in stable equilibrium in respect to volume and temperature. The low viscosity of the solid metal induces a hysteresis, and when the casting reaches normal temperature the volume changes are slightly incomplete. The residual energy necessary to complete the contraction is locked up in the form of strain, and contributes to what is spoken of as "casting strain." This strain may be liberated during the dressing of rough castings, or even during their later life, and will result in cracking and warping. Strain will be most severe in rapidly cooled castings, and it may usually be dissipated entirely by annealing when the volume changes will be completed.

The Pasty State.

The battle for successful castings is, more often than not, won or lost during that intermediate period when both solid and liquid are present together. It has been shown that change of temperature in the solid or in the liquid produces a fairly small and regular volume change. When the metal passes from solid to liquid—or *vice versa*—a sudden volume change of considerable magnitude takes place. The solid may occupy much more or much less volume than the liquid—that is the real density suddenly increases or suddenly decreases. In pure metals and certain alloys this sudden volume change takes place at a definite temperature, in other alloys it is spread over a small range of temperature.

The simple case of a pure metal or an alloy freezing at a constant temperature with increase of volume will be first considered. Bismuth is the classic example of such a case. Pure iron is another example, less often quoted, and certain alloys—particularly of aluminium and antimony—also show the same effect.

Imagine a casting in the shape of a ball made so that when the mould is completely full the supply of metal can be immediately shut off. Prior to casting, the mould, of course, is cold, and heat is therefore absorbed by the mould from the metal adjacent to the mould face. Assuming normal thermal conductivities, the interior of the ball will be considerably above the freezing point of the metal at the time that the walls begin to set. The temperature at the instant before the first skin freezes of each point through the casting may be shown on a curve such as that drawn at the top of Fig. 1. The thermal conductivity of the metal will be greater than that of the mould, and as cooling proceeds the temperature across the casting tends to even out until when the last drop of metal has frozen the temperature gradient will be similar to that shown by the second curve in Fig. 1. At the right hand side of the diagram is plotted the true density of the metal at each temperature. The true-density curve shows contraction on cooling in the liquid, expansion on solidification, and then contraction again in the solid. The change in apparent density, during the time that the temperature falls from the upper to the lower temperature curve may now be derived. At the beginning of this period the outside edge of the casting has density A. At the end of the period its den-

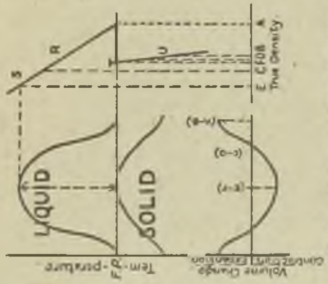


Fig. 1.—Volume changes in pure metal freezing with expansion.

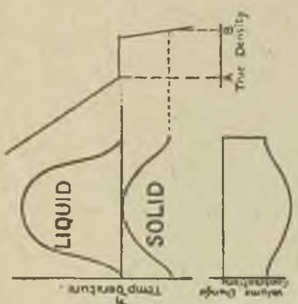


Fig. 2.—Volume changes in pure metal freezing with contraction.

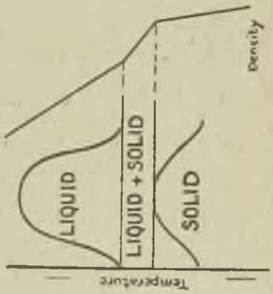


Fig. 3.—Volume changes in an alloy freezing with contraction.

Fig. 6.—Showing the occurrence of undercooling during the freezing of an alloy.

sity is B. It has thus changed in density to the extent of (A – B) which is seen to be positive. Expansion has therefore occurred proportional to (A – B). This is plotted on the bottom curve. Now take a point half-way to the centre of the casting. At the beginning of the period its density is C, at the end D. The change of density (C – D) is now negative. Contraction has taken place proportional to (C – D). This point is also plotted on the bottom curve. Similarly for the centre of the casting the change in density is (E – F), indicating a further contraction. If every point from the centre to the outside is treated in this way the apparent density curve can be completed, as shown in the figure. The area enclosed by this curve above the zero line is proportional to the gross expansion of the casting, and the area below the zero line is proportional to the gross contraction. In the particular case illustrated, the latter area is larger than the former, showing a net contraction of the casting proportional to the difference between these two areas.

Suppose this particular casting were made in a rigid mould, the unyielding face of which would retain intimate contact with the first skin of the casting. The net contraction would then cause a cavity to be formed somewhere near the centre of the casting. If a soft sand mould were used the first expansion of the skin of the casting would make the mould a little larger, and the internal cavity would be therefore greater.

If the liquid contraction is less than that shown in Fig. 1, the point E will move nearer to F and the gross contraction correspondingly diminished, until when the point S is vertically above T no contraction will occur at all. The same result would be obtained if the difference in temperature between the centre and the outside of the casting at the beginning of freezing were less than shown in Fig. 1. In this case the gross contraction will disappear, when the highest point of the temperature curve falls below the level R. This could be brought about by a low casting temperature.

The thermal properties of the mould material and the metal also affect the contraction. If the mould has a high conductivity the point U will move lower down the density curve and the gross expansion will be diminished. If the metal has a high conductivity the point U will move up the density curve and the gross expansion will be increased.

Also, if the slope of the solid contraction curve is greater than is shown in the diagram, the gross expansion will be diminished.

Summarising these points, one can expect that in a metal which freezes with expansion at constant temperature, the volume of any internal cavity will be increased by using a soft mould material of high conductivity, by using a metal with a high coefficient of expansion in the liquid and solid and with a low-thermal conductivity, and by casting at a high temperature.

The majority of metals contract on freezing, but the same line of reasoning as the above may be applied. The temperature gradients across the casting at the beginning and end of freezing are shown in Fig. 2 exactly the same as before. The true density curve on the right-hand side of the diagram has the same slope in the liquid and solid ranges as before, but instead of a decrease in density on freezing an increase is now assumed to occur. Consider first the outside skin. When the first layer is just about to freeze it will have density A; when the casting is entirely solid it will have density B. The difference (A – B) is negative, indicating contraction. Every point to the centre of the casting on the top curve has density less than A, and even point on the bottom curve has density greater than A. Every layer to freeze, then, adds to the net contraction, and the total contraction is shown on the curve at the bottom of the diagram. As in the previous case, the contraction cavity will be increased in volume by increasing the slope of the liquid density curve, by increasing the height of the initial temperature gradient and by increasing the slope of the solid density curve. A high thermal conductivity in the mould and a low thermal conductivity in the metal also increase the contraction cavity.

What Happens when Alloys Freeze.

The general rule, then, can be laid down as follows:—When a mass of metal or alloy freezes at constant temperature undisturbed in a mould it will usually develop a contraction cavity, and the volume of this cavity will be increased by (a) a high thermal capacity of the mould; (b) a low thermal capacity of the metal; (c) a high coefficient of expansion in the liquid and solid metal; (d) an algebraically high contraction on freezing; and (e) a high casting temperature.

By controlling these factors, then, it appears that the contraction cavity should be considerably reduced, if not entirely eliminated. Unfortunately, all these points are not always controllable, as considerations other than eliminating contraction have to be taken into account when making castings. The properties of the metal, for example, when one is compelled to use that particular metal, have to be accepted willy-nilly.

The common metals have a fairly wide range of thermal conductivities. A few values are given in Table I. All the values quoted are for temperatures near the freezing point of the metal, as it is only in this range that the thermal conductivity affects the contraction. It has been shown that a high conductivity is desirable, and on this basis aluminium and copper are favourably situated, whereas lead and nickel have unfavourable values. The low conductivity of nickel is probably greatly responsible for some of the difficulties experienced in casting this metal.

TABLE I.

Metal	Temp. deg. C.	Thermal Conductivity
Nickel	1,200	0.06
Lead	200	0.08
Tin	200	0.14
Zinc	400	0.22
Copper	1,000	0.70
Aluminium	600	1.01

The volume change on freezing has been determined recently for a number of pure metals and a few alloys. Some of the values are given in Table II, from which it can be seen that there is a considerable variation from one metal to another, which may necessitate considerable modification of general foundry practice. The high value of aluminium is worthy of notice. This high figure is in keeping with the excessive "drawing" experienced when casting pure aluminium.

The paucity of data on the volume changes in liquid metals has already been referred to. In the solid the volume change is relatively low, and its effect on the extent of the contraction cavity is probably only slight.

TABLE II.

Volume Change on Freezing.

Pure Fe.	5.5	Expansion.
Bi.	3.32	
Sb.	1.40	Contraction
Sn.	2.80	
Brass 60/40	2.89	
Pb.	3.44	
Al-Si. (12%)	3.41	
Cu.	4.05	
Zn.	6.50	
Al.	6.26	

There remains, then, of the points enumerated above only the heat capacity of the mould and the casting temperature as being capable of control.

The somewhat loose expression "heat capacity of the mould" has been chosen to cover the property of the mould for cooling the adjacent cast metal. This property depends mainly on the thermal conductivity of the mould, and also on the specific heat of the mould material, its temperature, its degree of contact with the metal, and so on. Considering the common mould materials, such as moulding sand, cast iron and steel, one finds that dry silica sand has the lowest thermal conductivity. The presence of clay materially increases the conductivity, and the presence of moisture increases it still more. Moisture also increases the specific heat of the sand mixture. The conductivity of iron and steel is considerably higher than any sand mixture, iron having a slightly higher value than steel. The specific heat of iron and steel is of the same order as dry sand. The great difference in the conductivity between a sand and a chill mould is slightly off-set by the more intimate contact obtained in sand than in a chill mould. In general, then, a pure metal casting will show the greatest contraction cavity when made in a cast-iron mould, and the least in a dry silica-sand mould.

From the curves on which these notes are based it is seen that the magnitude of the influence of thermal properties of the mould is dependent on the magnitude of the solid contraction, which is relatively small. The extent to which the last remaining controllable factor—the casting temperature—influences the piping is governed essentially by the liquid contraction, which is usually much greater than the solid contraction. The danger from a high casting temperature is therefore serious. The general rule will be that a metal or alloy freezing at a constant temperature should invariably be cast at the lowest possible temperature at which the fluidity of the metal will allow the mould to be properly filled.

Location of Contraction Cavity.

Having now by these various means reduced the net contraction to the lowest amount compatible with the exigencies of the work in hand, one can turn attention to controlling the *location* of the contraction cavity.

In the simple casting—the sphere—chosen to illustrate the above principles, the whole of the outside freezes first. As each succeeding layer sets it will attach itself to the gradually thickening solid skin until no liquid is left, and the whole of the contraction, great or small, will be localised in the centre of the casting. In this particular case the location of the cavity is in that part of the casting to solidify last. It is probably the thought of such a simple case that inspires the constant repetition of that popular slogan which says that a casting will draw at the last place to solidify. It only needs the examination of a few complicated engineering castings to show how misleading such a statement may be. Some of the contraction will certainly be located at the point which freezes last, but draws may also be found at places which freeze early in the making of the casting. At all these points it can be shown that the solidifying metal has been cut off from the liquid. Drawing can only be avoided, then, by ensuring that a supply of liquid metal is available to every part of the casting as it solidifies.

Equal Section Not Desirable.

Another product of loose thinking is the frequent request to the drawing office for an even section all over the casting. In actual fact the casting with an extensive even section is often the worst type of casting to produce really sound. The foundryman who asks for an even section generally gives as his reason that he wants the whole of the casting to cool at the same time. This is exactly contrary to what is required to secure soundness. If the whole of a casting cools together, the contraction cavity will be distributed all over the casting, and the result will be general unsoundness and weakness. If, however, the casting cools directionally, the contraction cavity is, as it were, gathered up as each layer freezes, and it may finally be brought to a place where feeding can be applied. Indeed, it is in arrangement of this directional cooling and the concentration of the contraction at a suitable point for feeding that the foundryman may most usefully exercise his art and ingeniously apply his experience.

Castings are of such a diversity of shape and size that one can only apply the principle of directional cooling and feeding by giving each individual casting individual attention, but a few general remarks may be mentioned by way of illustration.

The point where one expects to localise the contraction must obviously communicate with a riser or a runner, and this riser or runner must contain liquid metal after the casting is solid. The latter point seems self-evident, but the meagreness of many runners and risers suggests that it is often overlooked. Feeding may be accomplished from runners, or risers, or both. If no risers are used, feeding from the runner may take place in two ways. The runner may be joined to a thick section, in which case it must be a very big runner, so that it remains liquid until all the thick section is solid. Alternatively, the casting may be run on its thinnest section. In this case thick sections must be cooled very quickly, generally by chilling, or the casting must be poured very slowly, so that thick parts are fed before the thin section solidifies. If risers are used they will generally be placed on the thickest parts of the casting. The most useful application of a riser is to feed any part of a casting isolated from the main wave of freezing. Risers must always be larger than the section they are intended to feed.

Alloys with Freezing Ranges.

The arguments so far have been based on the supposition that the metal or alloy freezes at a constant temperature. It has been shown how the extent of the contraction can be minimised by certain moulding and casting details, and how, by contriving directional freezing, the residual contraction can be fed. Most engineering alloys, however, freeze through a range of temperature, and this property modifies some of the above conclusions. To appreciate this, it is necessary to discuss some metallurgical theories.

When a metal has passed its freezing point it begins to solidify from a number of isolated points. At each of these points a tiny crystal of metal is formed, and in line with each axis of the crystal new crystals attach themselves. In this way arms of solid are built out into the liquid, and from these small branches grow at right angles, until the well-known fir-tree pattern is obtained (Fig. 4). Each dendrite grows until it meets dendrites growing from other centres, and in this way the whole of the metal eventually solidifies. The location of the shrinkage cavity is governed by the position and number of the original crystallisation centres, and by the rate of growth of the dendrites.

Below a certain distance from the freezing point the centres of crystallisation form spontaneously in the liquid, the number forming being a constant for the particular conditions. Between the freezing point and this temperature of spontaneous crystallisation—that is, in the metastable range—nuclei are only formed by the influence of extraneous conditions, such as the presence of solid particles, mechanical movement, etc.

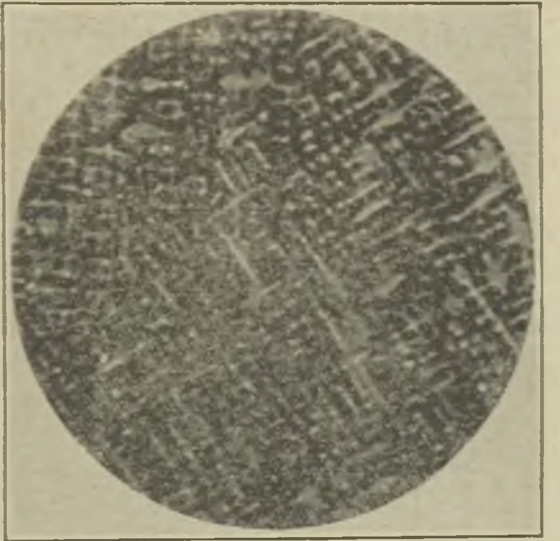


FIG. 4.—TYPICAL DENDRITIC GROWTH IN ALLOYS. COPPER-NICKEL ALLOY × 30.

Consider first a pure metal or alloy which freezes at a constant temperature. If the rate of cooling is sufficiently slow, crystallisation will proceed entirely in the metastable range. This is independent of how or at what temperature the first nuclei are formed, since the vectorial force of crystallisation will be sufficiently great to follow close on the heels of the falling temperature, and the liquid will have no opportunity of reaching the labile range while crystallisation is proceeding. A columnar microstructure will generaly result. If the cooling is rapid, the labile range will be reached a short distance in advance of the crytallising solid, and new nuclei will be quickly formed. Crystallisation from these new nuclei, however, will not have time to spread very far before the dendrites from the advancing solid behind have caught up, owing to their greater degree of super-cooling. An equiaxed structure will result in this case. In either case, however, the liquid-solid interface will be fairly distinct, and will closely follow the temperature gradient.

In alloys which freeze through a range of temperature, conditions arise which tend to destroy an even solid-liquid interface, and to leave islands of liquid isolated by solid formed in advance of the true-density contours. Alloys which consist of solid solutions invariably show coreing in a normal "as cast" microstructure. This is due to each succeeding layer of solution to be deposited being richer in the lower freezing-point constituent and failing to diffuse into the solid mass. Where more than one constituent is present in the normal alloy it is quite common to find more of the second constituent than equilibrium conditions specify. In the microstructure in Fig. 5, showing a 90 : 10 pure copper tin alloy, the ground mass consisting of α solid-solution is seen to be distinctly cored and there are also considerable areas of α-δ eutectoid, which under equilibrium conditions should not appear in alloys containing less than about 13 per cent. of tin. The slow diffusion then in such an alloy brings about during freezing a continual shift in the effective composition of the alloy towards the lower freezing-point side of the equilibrium diagram. When a casting made in such an alloy is freezing there will be near the solid a layer of liquid of a composition which, under equilibrium conditions, would belong to a lower freezing point alloy. Beyond this unstable liquid is liquid of the true alloy composition. If the temperature difference between the two places is small, one can see the possibility of the stable liquid becoming considerably more under-cooled than the liquid adjacent to the solid, so much so that it may reach the labile range and commence to crystallise. This may be illustrated by a diagram such as Fig. 6 (page 399). Freezing is assumed to have been proceeding from the left-hand side of the diagram, and as freezing has proceeded a layer of liquid has been formed, with a lower freezing point than the normal alloy. The thick line shows the freezing point of the liquid, and the dotted line the temperature of spontaneous crystallisation. Suppose the temperature gradient to be as shown by the thin line. All to the left of A is solid. At the point B is liquid, which is still a little above its freezing point, but further on at C there is liquid which has reached the labile range. Crystallisation will therefore set in at C, with the result that the area B will be isolated and left to freeze out of contact with liquid—that is, beyond

FIG. 5.—PURE 10 PER CENT. BRONZE × 250, SHOWING COREING AND ALPHA-DELTA EUTECTOID.

the possibility of feeding. That is, a cavity will develop at C. As the same conditions are formed around every crystallite, the casting will be generally unsound. This type of unsoundness can only arise with a low-temperature gradient, as one can see from Fig. 6 that if the temperature gradient is tilted so that it passes under X and over Y, directional freezing is bound to occur. An example of an alloy showing " drawing," due to a flat temperature gradient, is shown in Fig. 7. The cavities are dispersed over the whole section, causing extended unsoundness.

Now revert to the type of diagram which was used to illustrate density changes in pure metals. A similar diagram drawn for alloys freezing through a range of temperature was shown in Fig. 3. Exactly the same reasoning as before may be applied to this diagram, and the same conclusions as applied to pure metals will be arrived at for alloys. Amongst these conclusions was the desirability for a low-temperature gradient in the liquid casting at the moment of freezing. From a metallurgical point of view it has just been shown that a high temperature gradient is desirable. Alloy casting then resolves itself into discovering the happy compromise between a too flat and a too steep temperature gradient. The longer the freezing range of the alloy and the greater must be departure from a flat temperature gradient. In practice temperature gradient is generally most conveniently controlled by casting temperature. It follows, then, that alloys with a long freezing range must be cast at a higher temperature than alloys with a short freezing range. A simple illustration is found in 2F cartridge brass and Admiralty gunmetal. Both alloys commence to freeze at approximately the same temperature, but gunmetal has a freezing range about twice that of brass, and it is found that similar castings have to be poured much hotter in gunmetal than in brass to secure soundness. A very rough working rule for medium melting point alloys is to add the freezing range to the temperature of commencement of freezing to get the approximate casting temperature for average work.

With high melting point alloys which have a fairly long freezing range, an inconveniently high casting temperature would be necessary to obtain a sufficiently steep temperature gradient. This can be avoided somewhat by using a low-conducting mould-material, such as dry silica sand. On the other hand, with lower melting-point alloys, such as those of aluminium, the correct temperature gradient can be best obtained by using a chill mould.

It appears, then, that by a critical control of the steepness of the temperature gradient, and by manipulating the moulding practice so that the temperature gradient slopes evenly from the remotest points to a feeding point, sound castings should be obtainable in most alloys, and the bogey of a long freezing range need not be feared.

FIG. 7.—UNSOUNDNESS IN A BRONZE CAST AT TOO LOW A TEMPERATURE.

The benefits from theoretical reasoning, such as much of the above, can only be obtained by very careful translation into foundry practice, and meetings which encourage co-operation between foundrymen and metallurgists appear to be ideal occasions for defining the conditions and discussing how to comply with the conditions necessary to securing sound castings.

DISCUSSION.

Mr. A. H. Mundey (Chairman of the London Local Section of the Institute of Metals) returned thanks to the London Branch of the Institute of British Foundrymen—of which he is also a member—for having provided such an excellent lecture, which contained much food for thought for the members of both bodies. Dealing with the behaviour of liquids, he recalled experiments which were made to produce a non-freezing liquid which could be put into the buffer cylinder of a gun, so that it could be used in districts where the temperature was very low without fear of preventing the gun firing. Glycerine and many other things had been tried. Alcohol and water had been used mostly, and oil also had been used, but someone had suggested experiments with sugar and water. Many wonderful things were discovered with regard to sugar and water, and he was reminded of them when watching the way in which the low temperature metals which had rather long ranges of solidification crystallised out. If one had 10 lbs. of sugar and a gallon of water and dissolved the sugar in the water, one would have about 1¼ gallons of fluid, and it was not saturated then. In these experiments the liquid was frozen, and some particularly curious curves were obtained, and those concerned with the experiments were anxious to see whether it was going to impose any very particular stresses on the cylinders.

Contractions and Small Castings.

Thus the question of solutions and the alteration of the co-efficients of expansion and contraction due to the amount of material in solution was really rather striking. Only that day he had been trying to find out why a very small flat casting, just over 5¾ in. long, 4 in. wide, and about 0.2 or 0.15 in. thick, had shrunk 0.033 in., when, by all calculations, it should have shrunk only 0.01 in., because, when dealing with certain castings which received no machining whatever it was very necessary that they should not shrink to a greater extent than had been calculated. Frequently one had to adjust moulds in such a way that the castings, which had not to be machined, should not be smaller than required, and calculations had to be made with very great accuracy. Fortunately, one was able to cast to within 0.001 in. in die casting moulds, and to get as nearly as possible perfectly rectangular castings, but one could do that only with alloys which were very easily studied and which could be very carefully manipulated—alloys which froze at about 230 or 240 deg. C. It would be realised, therefore, that those concerned with die castings, which had to be so accurately cast, and were sometimes cast in iron moulds with cores of sand, or with one side of the mould made of *papier maché*, had much food for anxious thought whilst carrying out their work.

N.P.L. Researching on Liquid Metals.

Dr. Walter Rosenhain, F.R.S., expressed his sincere admiration for the clear manner in which Mr. Dews had dealt with a very complicated and difficult subject. He had dealt with it in a strictly scientific way by simplifying the problem as far as he possibly could and analysing it out accurately in the simplified form, and he had also done what was very necessary when adopting that form of treatment, *i.e.*, he had warned his hearers that it was not always possible to apply in full detail all the conclusions arrived at from a simplified analysis of that kind. That was inevitable because the conditions of practice were never as simple as those one had to postulate if one wanted to arrive at exact conclusions with the limited knowledge available. He agreed that it was desirable that we should know more about the properties of liquid metals. For the last two or three years one man at least at the National Physical Laboratory had been devoting himself entirely to that subject, and had been measuring the solubility of gases and surface tension, but not densities, which latter involved many complications. Much work on volume changes on freezing had been done by Endo, of Japan, and that encouraged one to think that the problem might not be so insoluble as it appeared at first sight.

Alloys Expanding on Freezing.

Incidentally, the question whether there are many alloys which expand on freezing would have to be settled rather more definitely than it had been up to the present. That property had been ascribed to many materials which did not possess it. With some of the aluminium alloys, such as aluminium manganese, aluminium-iron, and so on, if one cast a little ingot one would find that after a certain stage of freezing a little aperture was forced in the surface skin and liquid metal came out; this was of the eutectic composition. It was not, however, due to expansion on freezing, but had been conclusively shown to arise from a totally different phenomenon—a phenomenon which entered very largely into the matters with which Mr. Dews had been dealing, namely, the liberation of gas from the solidifying metal. That was a phenomenon with which we were only gradually becoming fully acquainted, and it was so important in the production of sound metal—not only of sound castings, but of sound ingots which had to be rolled afterwards—that it required the closest attention.

The Importance of Gas in Liquid Alloys.

In ordinary foundry practice no attempt was made to eliminate gases. An attempt was made sometimes to minimise their presence by special methods of melting, but he doubted whether those methods were successful. Liquid metal had a higher power of dissolving gases than the solid, and during the process of freezing gas was expelled. The casting produced never had the theoretical density of the metal, and even if it were compressed mechanically afterwards it was very difficult indeed to get to the full theoretical density. That could be determined by X-ray analysis and knowledge of the atomic weight. One could get fairly near it in some cases, but the difference was due, at any rate, to a large extent, to gas, for the presence of gas altered the contraction conditions immensely. There occurred a localisation of small cavities in the crystal boundaries, which altered the stresses set up by contraction and the differential diagrams which Mr. Dews had shown, so that the whole matter was very much affected.

Liquid Metal Never Still.

Another point which should be mentioned was the fact that the theoretical ideas which Mr. Dews had so clearly developed depended upon the assumption that one had liquid metal at rest in the mould before solidification commenced, or, at any rate, during the major part of the process of solidification. He himself believed, however, that such was never the case, for two reasons. First, the cooling was never so even that one did not get differences of temperatures in the liquid, leading to convection currents. If one could avoid convection currents one would get no dendritic crystallisation at all, but would get crystal layers. The growing up of the dendrite was affected by the convection currents. Then there was another phenomenon, the fact that the liquid was agitated by the act of pouring it into the mould. On the whole, therefore, the phenomena of the freezing of a casting were really very complex, and the astonishing thing was that the foundryman met with as much success as he did. It was not astonishing to find that castings contained pores, draws, and all the other ills to which they were heir, but we should get beyond that, and he believed we should get beyond it particularly by learning how to eliminate gas, or, at any rate, the greater part of it, from our liquid metal. A great deal of successful work had been done in that direction, with the result that many of the casting difficulties, in cases where drawing was particularly prevalent, were being overcome in practice. It applied to copper, to certain nickel-iron alloys, and to aluminium alloys, and he had no doubt it could be worked out equally elsewhere.

Temperatures Gradients and Nature of Crystallisation.

There was one point in Mr. Dews' address in regard to which he must differ. Mr. Dews had suggested that one obtained radial crystallisation, *i.e.*, acicular crystals, if the temperature gradient was small; that when the gradient was small no part of the liquid became under-cooled to the labile stage, and radial crystallisation extended to the centre. In the first place, in experiments with lead, copper or aluminimum, if one poured the metal into a chill mould one would get a deep formation of chilled crystals; the dendrites, from the mould wall, would reach nearly to the centre. If, on the other hand, one used a graphite mould, or still more a sand mould, the depth of the dendrites was very small, and equi-axed crystals predominated throughout the whole section. Those were the facts as he knew them. In his laboratory they had repeatedly prepared ingots of various metals, and of various sections, deliberately to show that those were the facts, and had succeeded in doing so every time. He believed that the labile stage was not so important in metals as some people were inclined to think, and that nearly always the conditions were such as to precipitate crystallisation almost immediately the true liquidus was passed; consequently, whether or not one obtained acicular crystals or equi-axed crystals depended upon whether the flow of heat was sufficiently rapid to determine the rate of growth of crystals. When the rate of growth was high the crystal grew definitely against the flow of heat, but where it was slow the iso-thermals were very wide apart, the directional effect was very slight, and growth took place more or less in all directions. He had yet to be convinced that there was any objection to that view; in fact, he believed the experiments rather supported it. However, he did not think that really altered the facts very much, because on that view one still obtained the results that Mr. Dews had said were obtained experimentally, that with a lower temperature gradient one was more apt to get enclosures during the growth of the dendrites than with rapid cooling. One would at first sight have been inclined to believe that the ideal state of affairs was one in which the whole of the crystallisation was radial, because that would push the cavity to the centre. That was not true, because the gas was trapped by the growing dendrites and there was a tendency for weakness to exist between adjacent dendrites; one had a concentration of these little gas cavities there, and possibly also shrinkage cavities, lying in rows, whereas in an equi-axed structure they were much more scattered and did not produce localised weakness.

Density of Liquid Metals.

Professor T. Turner (Past-President, Institute of Metals) said that a good deal of work had been done under his direction in recent years on the density of liquid metals. That work had not been published, but tin, lead, zinc, antimony, aluminium and copper had all been studied, and the line above the melting point was practically a straight line in all those cases; therefore, knowing the coefficient, one could pretty well estimate what the density of the liquid metal was. The attempt had also been made to arrive at the density of liquid cast iron, but that, of course, involved considerable difficulties, on account of temperature and other circumstances; the results obtained were anomalous, and he had been afraid to publish them until they had been confirmed. Mr. Dews had very wisely divided the subject of his lecture in such a way as to make it more or less simple for consideration. Taking first the case of a pure metal, Professor Turner pointed out that it changed very abruptly at the solidifying point. It was very limpid above that point, *i.e.*, its viscosity was very small, and it ran quite freely, and, with the exception of bismuth—to which he did not think any great attention need be paid, because it was not very much used, particularly as a metal—it contracted during solidification. One point to which Mr. Dews had not referred in connection with a pure metal was what might be called the skin effect in determining the shape and size of the ultimate casting; there was on the outside a rigid envelope while solidification was proceeding inside. According to the character of the metal or the alloy, that outside skin would grow in a characteristic way and behave in a characteristic manner.

Contraction of Bars of Varying Diameters.

One could illustrate this by casting four bars, in cast iron, for example, of different thicknesses, but in a mould of the same length and measuring them. One would find, of course, that the smallest diameter bar had contracted in length the most, whilst the largest diameter bar had contracted the least. On the contrary, if one cast in the same way copper or brass or a number of other alloys, one would find that the smallest diameter bar contracted the least and the largest diameter bar contracted the most. He was not prepared to explain why that was so, but different alloys behaved differently, and it was certainly attributable in part to the skin effect. In the case of iron, it was due partly to the chilling effect and the prevention of the separation of graphite. In cast iron one had a substance which was anomalous, and yet it was the most important of all the ordinary metals cast.

Two Types of Contraction.

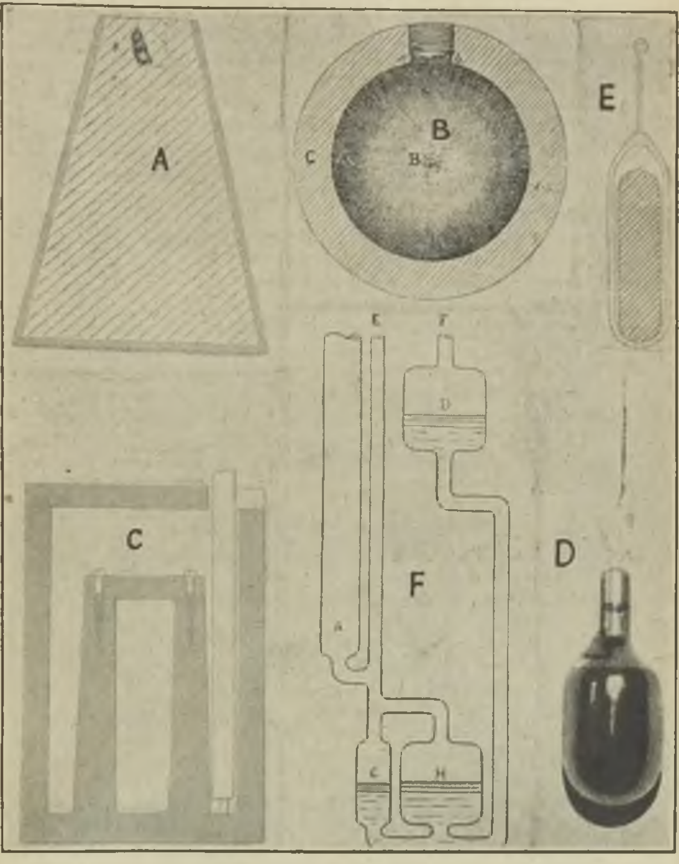
Generally, we divided the contraction which took place into the liquid contraction and the shrinkage. The liquid contraction was practically uniform. Then we came to the expansion that took place during or after solidification, an expansion which in white iron was very small, but which in grey iron might be considerable—over 5 per cent. of the total volume in the case of a very grey iron, and that was quite a large proportion. From the moment of solidification until the time when the casting attained the temperature of the room there occurred what we commonly called shrinkage, as distinct from liquid contraction. The term was applied first by Keep, and was measured by his well-known shrinkage apparatus.

Defective Nomenclature.

Unfortunately, the term "shrink" was also applied to the cavities that were met with in castings, and therefore there was some vagueness as to the meaning of the term as it was commonly applied. When alloys and mixtures were allowed to cool, however, they did not necessarily shrink uniformly; in fact, it was the exception rather than the rule to find that they contracted uniformly.

Volume Changes in Cast Iron.

The reasons for that, it might almost be said, were manifold, but in the case of cast iron there were three reasons, which were perfectly clear. In the first place, one had graphite absolutely



Figs. A to F illustrate the Various Apparatus used for the Determination of Densities of the Liquid Metals.

separated, and instead of having a density, like the carbide from which it was formed, of 5 or 6, it had a density of something in the neighbourhood of 2. Not only was that the case, but the graphite occurred in the form of irregular flakes, which prevented the close packing of the cubic crystals of iron. Hence, the larger the flakes of graphite, the more difficult would it be to pack closely, and the more graphite present, the greater would be the decrease in density. In other words, the greater would be the expansion of the casting—the actual increase of length, thickness and width of the specimen—over a range of temperature, and part of that expansion was permanent. There was another expansion, when the iron carbide was thrown out of solution, at a temperature of about 700 deg., which, though much smaller, was quite perceptible on an extensometer. Between these two expansions there was a third, which took place when the phosphide of iron was thrown out originally as iron-carbon-phosphorus eutectic, which then decomposed in grey iron and threw out some more graphite, both actions of which led to expansion. Hence, we could tell the character of the cast iron which was being poured into a mould if we attached to the end of that mould a suitable pointer.

Germans Appreciate Extensometer.

That method was used in many foundries in America, and he had been very interested to hear, in connection with visits paid by representatives of the British Cast Iron Research Association to Germany lately, of the large number of foundries in Germany which had this expansion apparatus or extensometer in use. It was a small apparatus, in which was cast a bar, about 1 ft. long, at the end of which was attached a pointer, and by means of a pencil and a drum it recorded the expansions of the casting while it was solidifying in the mould. Anybody familiar with the curves could see at once whether the casting would prove to be hard, soft or strong. One could predict with certainty the character of the metal by noting the changes in volume which took place while the metal was cooling. In connection with other alloys, such as brasses, bronzes and so forth, one found that there were expansions corresponding roughly with the crystallising interval. The longer the crystallising interval, the greater the expansion recorded on a bar at certain definite temperatures during the progress of solidification.

Piano Frame Volume Changes.

One would see the importance of this in connection with many designs. His attention had been drawn to the matter more than twenty years ago in connection with cast iron frames for pianos. The frames were sometimes heard to crack in the mould; in other cases the frames were placed on one side in the foundry, and one could hear them crack there; in other cases they cracked months after casting, and in still other cases they cracked while in the possession of the purchaser. There were sections of different thicknesses, and in the mould one was expanding while the other was contracting, so that they were working one against the other, and the castings were left in a state of strain. There were two remedies in that case. One was the remedy which the foundryman always desired, namely, to tell the engineer to give him uniform sections, and then the trouble would, to some extent at all events, disappear. The other method was to produce an iron which had smaller graphite and less phosphorus eutectic, because those caused the expansions, and by that method the liability to fracture was reduced.

The Case of Brass Grids.

Another instance had come to his notice some years ago in connection with the casting of brass grids. Very often grids were thick outside, and had thinner bars through the middle, and these grids would crack on the corners. He had inquired as to the material used and had looked at the expansion curve, and had found that they were at the point at which there was the maximum expansion for that range of alloys. He had suggested altering the composition in order to get to a point at which there was no expansion as recorded by the extensometer. That suggestion was adopted, and the trouble had ceased immediately.

Importance of Slow Teeming.

Dealing with Mr. Dews' statement in connection with the casting of liquid metals and alloys, that precautions could be taken so as to prevent the formation of shrink holes or contraction cavities, he said he was definitely of the opinion that it was possible to cast any ordinary alloy or any ordinary metal without having these contraction cavities at all if only one could take the time necessary to allow the metal to be poured sufficiently slowly. Of course, he was assuming that one had no thin sections in the middle—for that one must have some suitable arrangement—but for a straightforward casting, assuming that the pouring temperature was correct and that one had cooled the metal slowly before starting to pour, it could be done. The slow cooling was in order to get rid of as much of the gas as possible, because that question of gas was of very great importance. By keeping the metal just above the pouring temperature for some time a good deal of the gas would naturally pass off, and by then pouring it sufficiently slowly one could prevent or largely diminish the formation of cavities.

Chilled Rolls.

Taking as an illustration the casting of a chilled roll or a large cylinder, cast upright, Prof. Turner said that very often there were quite considerable cavities at the top, and endeavours were made to overcome that by altering the composition of the metal. People thought, perhaps, that it was a little too grey or a little too hard; each of those defects, of course, might increase the trouble. A great deal could be done by regulating the speed at which the metal was poured during the last stage of filling the mould. One could pour it in as quickly as one liked while the lower part of the mould was being filled.

Determining the Densities of Liquid Metals.

Dr. S. W. Smith (Vice-Chairman of the London Local Section of the Institute of Metals) showed a number of lantern slides to illustrate methods which had been adopted from time to time in order to determine the densities of metals in the liquid state. These methods bore a close analogy to those which were used for determining the densities of ordinary liquids, and may be briefly classified according to procedure:—(1) Measurement of the volume of a known weight of liquid at some particular temperature; (2) measurement of the loss of weight of a "sinker" when immersed in the liquid, and (3) measurement of the pressure per unit area exerted by a column of liquid of known height.

Fig. A illustrated the application of the first method by Robert Mallet in 1874, who was one of the first to attempt to determine the liquid density of cast iron. A conical vessel of wrought iron about 2 ft. in depth, 1.5 ft. in diameter at the base and tapering to an open neck of 6 in. diameter, was filled to the brim with molten grey cast iron. The vessel and its contents were again weighed when cold. From the known volume of the vessel, corrected for expansion at the higher temperature, it was possible to calculate the liquid density of molten cast iron as compared with distilled water at ordinary temperatures.

Mallet repeated his experiments at Woolwich Arsenal by using a spherical bomb-shell as the containing vessel, the fuse-hole being closed by a screw plug. This was shown in Fig. B. Subsequent workers have followed this method by using glass or silica tubes as "dilatometers."

A more recent application of this method was made by Frary and Edwards in America, who filled a graphite crucible of known volume with liquid metal at a known temperature. Their apparatus was shown in Fig. C.

Roberts-Austen repeated some of Mallet's work in 1875, and later, in 1881 and 1882, in collaboration with Thomas Wrightson, adopted the second method referred to above. A metal sphere, used as a sinker, was suspended from a spring balance and the loss of weight measured. This instrument they called an "oncosimeter."

Fig. D showed a quartz bulb filled with gold which he (Dr. Smith) had used some years ago as a "sinker" in making some determinations of the liquid densities of lead and bismuth. This method was also followed by Pascal and Jouniaux in France in 1914 by using a hollow quartz bulb fixed to the arm of a balance.

Slide E showed a similar sinker containing an iron cylinder which was used by Frary and Edwards to determine the liquid density of aluminium. They abandoned this method, however, in favour of the one already described.

An interesting development of the "displacement" method was made by Bornemaun and Sauerwald in 1922, and another along similar lines by Endo in 1923, to which Mr. Dews had referred.

Fig. F. illustrated the application of the third method by Hogness, in California, to metals of low melting point. The metal was melted in an apparatus of "Pyrex" glass and then forced up a vertical tube by the pressure of some inert gas. The relation of this pressure to the difference of level in the two arms gave the necessary data for calculating the liquid densities.

Professor Turner said that in his determinations he had used the sinker method, but not being provided with gold, he had used tungsten as the weighting material inside the sinker. For high temperature determinations the sinker was made of "Alundum," which was a very refractory material, quite suitable for cast iron.

THE AUTHOR'S REPLY.

Mr. Dews replied to the discussion. After expressing his gratification at the manner in which the Paper had been received, he said he sympathised with Mr. Mundey in his efforts to produce castings exactly to size. He must have some really great difficulties to contend with in producing castings accurate within 0.001 in. of the required size, but he envied him to a certain extent in having low-melting-point alloys to work with, and it must be very fascinating to be able to determine the constants, which he himself had deplored the lack of, for high-melting-point alloys. Continuing, he said he was glad to hear that work had been done at the National Physical Laboratory on liquid alloys, but Dr. Rosenhain had dashed his hopes to the ground by saying that work had not been done on density determinations. Dealing with the question of the eutectic squirting out of the ingots of aluminium alloys, he said that very frequently the same thing was found in gunmetals, of course, when cast too hot, and also in phosphor bronzes one met with the condition in which the alpha-delta eutectoid squirted out on the runner. He agreed that to explain that by expansion of the alloy was not necessarily correct; in fact, it seemed to him that contraction would squeeze the molten eutectoid out of the alloy. Dr. Rosenhain, however, had given, as his idea of the true explanation, the presence of gas. He (Mr. Dews) agreed to a certain extent with all that had been said in the discussion on the question of gas in metals, but, at the same time, he wished to utter a word of warning. In the last two years or so there had been an increasing tendency to attribute every foundry defect to the presence of gas. Gas in alloys was certainly important, but it was certainly not responsible for shrinkage cavities.

Columnar and Equi-axed Crystallisation.

Dr. Rosenhain had apparently misunderstood the reference in the Paper to the columnar and equi-axed crystals, and had rather confused the reference to temperature gradient and rate of cooling. The two, of course, were entirely different, and the point of his remarks in the Paper was that whether a columnar or equi-axed structure would be formed, the solid and liquid would be always in even contact. With a pure metal, whether it was cooled quickly or slowly, the solid-liquid interface was always fairly even; with an alloy it might not necessarily be so. He had not intended to imply that one should seek to obtain big dendrites; the weakness of a dendritic structure was very well known. He was pleased to hear that Prof. Turner had carried out investigations into the determination of densities, and urged him very strongly to publish his work, whether or not he was confident that it would meet with approval, for the necessity for an advance in this direction was very pressing. In his Paper he had not considered the question of the skin effect of castings, although he agreed that it was rather important. He was rather sorry, however, that Prof. Turner had based some of his arguments in relation to skin effect on cast iron. Cast iron was the alloy most universally used, and was the most complicated alloy in engineering practice at the present time; unfortunately, too, it was the alloy we knew least about, so that he considered it rather unwise to base any conclusions on the behaviour of cast iron. In the Paper he had not dealt with the question of volume changes in the solid, because he was rather doubtful as to whether, once the whole casting was solid, any volume changes would affect the contraction cavity; he believed the contraction cavity was formed and finished with immediately the alloy was completely frozen. Discussing the methods adopted for density determinations, described by Dr. Smith, he said that they all suffered from the defect that they were applicable only to low-melting-point alloys, or they measured the contraction from the liquid to the solid; what was wanted was a method of determining the density changes in the liquid only, and not the density changes that took place during the whole of the freezing of the casting.

On the proposition of Mr. A. H. Mundey, seconded by Mr. D. Finlayson, a hearty vote of thanks was accorded Mr. Dews for his Paper.

Newcastle-on-Tyne Branch.

THE MANUFACTURE OF IRON CASTINGS FOR PETROL ENGINES.

By W. J. Molyneux (Member).

This paper will endeavour to explain some of the methods commonly used in the manufacture of petrol-engine castings and will also show some devices new, and perhaps novel, of which the author has made use during some 10 years' close connection with the business. Few foundries in this country have laid out their plant on such a lavish scale as the highly-specialised motor foundries in America, although some of the cylinder foundries in the Midlands are making rapid strides in this direction. When carried on under capable management this is one of the most profitable branches of the foundry business, but where guesswork is in vogue and laxity is allowed to creep in, disaster is inevitable. Jobbing foundry practice is useless in this highly-specialised work. The following are a few of the factors that make for success.

Important Factors.

(1) *Design.*—It is highly desirable for a foundry engineer to be consulted during the design of a new engine, as much useless labour can thus be saved, and many difficulties avoided, most particularly on such castings as the cylinder unit, without any sacrifice of efficiency in the final product. On one occasion the author quoted for a large quantity of cylinders for a well-known American make of car, the price of which worked out at about one half that of a representative English car of the same horse power and of the same class of design. The reason for this considerable difference was that in the case of the American design there was every indication of expert foundry knowledge having been well applied, whilst in the English design there had been little

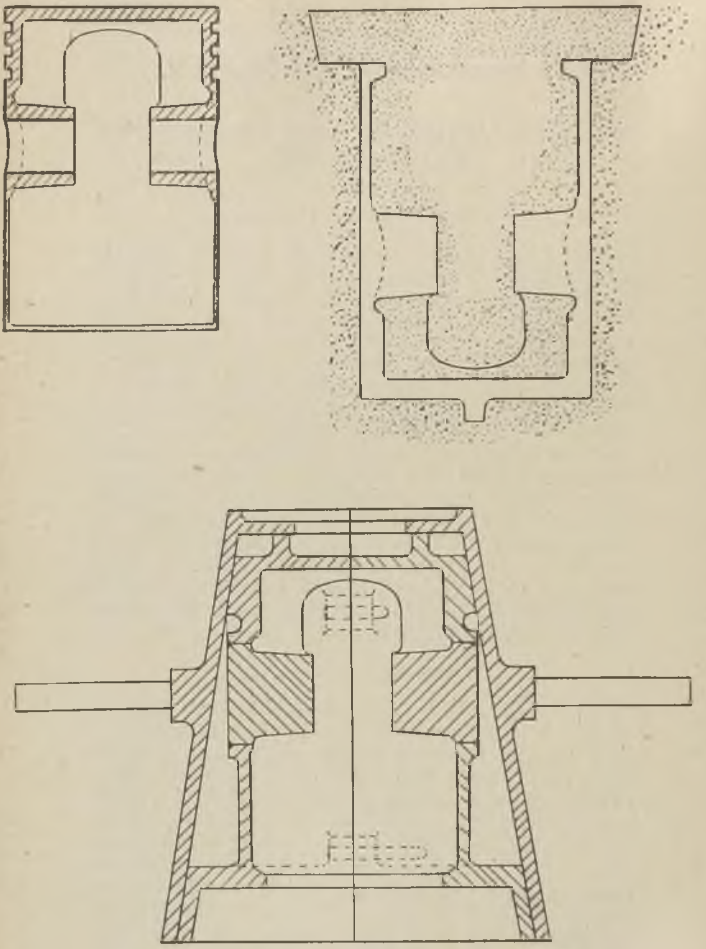


Fig. 1.—Shows Usual Method of Moulding a Piston together, with Suitable Coreboxes for Quick and Accurate Production.

or no effort in this direction, although the two cars were competing in the same market.

(2) The foundry executive must, or should, plan every operation down to the smallest detail before

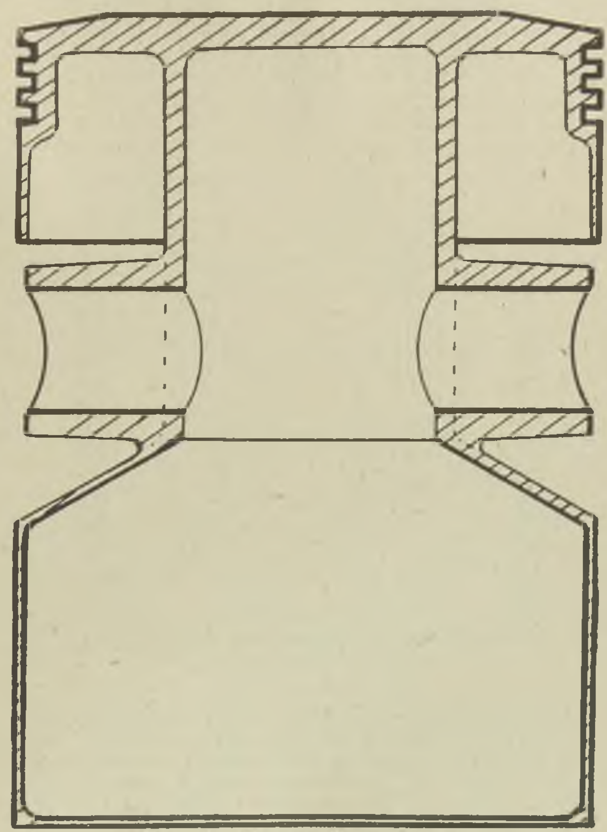


FIG. 2.—ZEPHYR TYPE PISTON.

pattern-making is started. Definite location points for jigging purposes that can be guaranteed by the founder must be mutually arranged between the tool design and the foundry executive.

(3) Pattern-making must be of the very best and no reasonable expense spared in equipment for the pattern shop to enable a high degree of accuracy to be maintained. Patterns should strip cleanly from the sand and leave no hand tooling to be done except in dry-sand work which requires wet blacking, which should be done by spraying. Cores must fit accurately into their prints and be made from core boxes so constructed that finishing is unnecessary. Provision must be made for the venting of cores; this often involves quite elaborate provision in these core boxes or the use of jigs for inserting the vents where required. It is a fallacy to assume that oil-sand cores do not require venting, extensive venting is often necessary. Porosity in a cylinder or cylinder head can often be traced to an unvented or improperly-vented core. This can be readily seen if a mould with all its cores in is cast without the top box on, and the disturbance in the metal observed as certain parts of the core are covered.

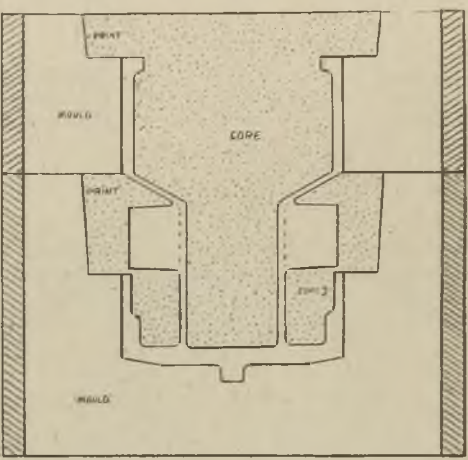


FIG. 3.—USUAL METHOD OF MOULDING A ZEPHYR TYPE PISTON.

(4) To ensure accuracy and cheap production moulding must be done on suitable machines, pre-

ferably power operated. Moulding boxes must be accurately machined and have well-fitting pins.

(5) All operations—especially the cupola practice—should be under accurate control. Raw materials should be checked and analysed systematically and routine analysis of the daily casts taken. It is a good practice to have the date of pouring (or some code mark to indicate the date) cast on to cylinders and other important castings. It is then possible to refer to the charge book at a future date and trace any abnormality or irregularity in a casting even after the engine has been in service for a long time.

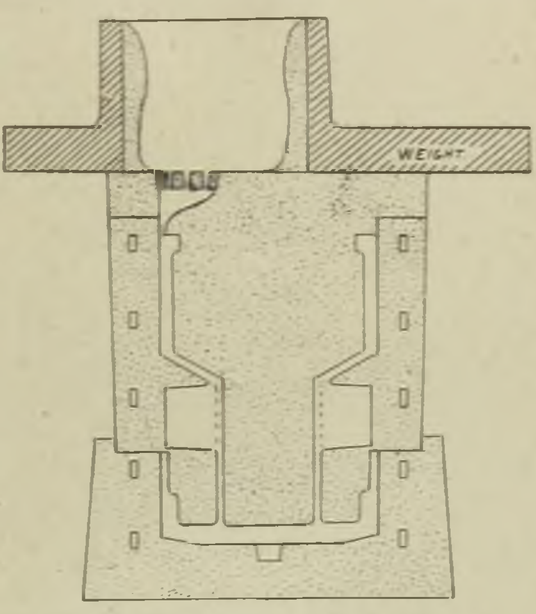
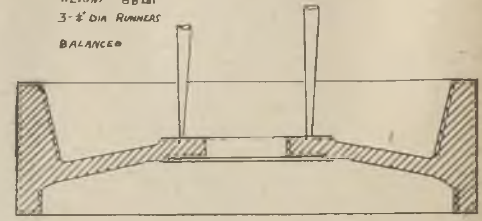


Fig. 4.—New Method of Moulding with Three Oil Sand Cores and Strainer Cores. It is an Accurate Method, as Concentricity can be Checked during Construction.

LORRY ENGINE FLYWHEEL

WEIGHT 88 lbs
3-¾" DIA RUNNERS

BALANCED

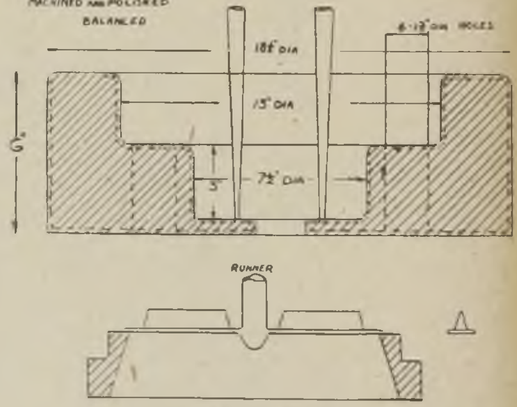


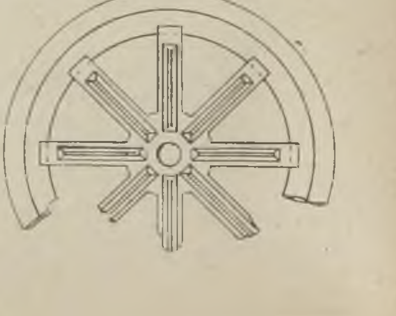
FLYWHEEL.

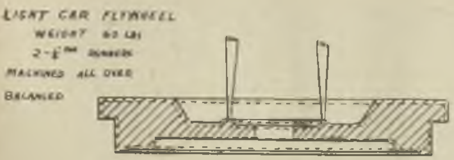
FLYWHEEL FOR PETROL LIGHTING SET

WEIGHT 3½ cwts
3-¾" DIA RUNNERS

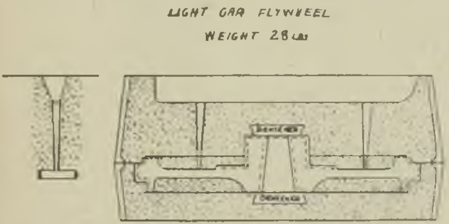
MACHINED AND POLISHED
BALANCED







ITHOUT RISERS OR FEEDERS)



6.—Flywheels Made with Jet Runners and no Feeders. Clutch Ring with Special Spray Runner for Feeding Metal of Even Temperature, and thus Avoiding a "Hot Spot." Feeding is Eliminated.

Making Petrol Engine Pistons.

Although aluminium alloy pistons have supplanted those of cast iron for speed work, and also in many cases are now used for car work generally, many cast-iron pistons are still made. These are best moulded on jar ram machines with pin lift, the cores being of oil sand. The most suitable sand, in the author's experience, is a very fine silica sand, such as Ryarsh, the cores being left unblacked. These castings must machine easily, be quite clean, free from porosity, and due to their rapid movement in the cylinder, they must be as light as possible and of uniform weight. To set up in the lathe a collet is expanded inside the pistons, and as the finished thickness of the skirt is 1/16, or even less, the insides must be quite free from even small irregularities.

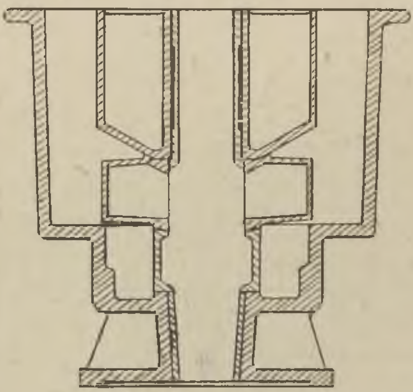


Fig. 5.—Section of Main Core-box for Zephyr Piston.

A piston that was used largely during the war and is still much used for lorry work, is the Zephyr piston, shown in Fig. 2. It is not generally used for cylinders under 100 mm. in dia. Its chief advantages over the orthodox type are its small weight, greater strength, and freedom from piston slap. This is one of the few castings found to be more satisfactorily made by hand than machine moulded. Many founders have found this a difficult casting to make and up to 90 per cent. of a consignment of castings have been known to be rejected, chiefly because the job was treated as an ordinary moulding proposition, and the few castings that were finished cost at least twice as much to machine as those produced by the following rather original methods.

Flywheels and Clutch Rings.

These are most important castings which revolve at a high speed. The material must be strong, quite free from porosity and surface defects, and easily machined. After machining these castings must be accurately balanced, this is usually done by drilling holes in the periphery, and it is surprising to see the amount that has to be drilled out of some wheels (even if they are machined all over) before they are in balance. The best results have been obtained by:

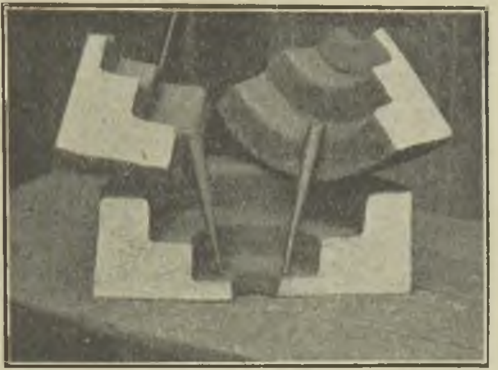


FIG. 7.—AN 18½-IN. DIA. FLYWHEEL AS SHOWN IN FIG. 6. SPLIT TO SHOW FREEDOM FROM POROSITY.

(1) Machine moulding from metal patterns and plates (the heavier wheels being made in dry sand).

(2) Casting with very hot metal through jet runners, and dispensing entirely with feeders, somewhat on the lines indicated by Ronceray.

Fig. 6 shows a lorry flywheel; and a heavy lighting set flywheel which is drilled in several places and must be free from unsoundness; two lighter car flywheels. Additionally it shows a clutch ring, a section which is very prone to porosity through hot spot. The runner shown supplies metal of even temperature.

Fig. 7 shows a large flywheel sectioned.

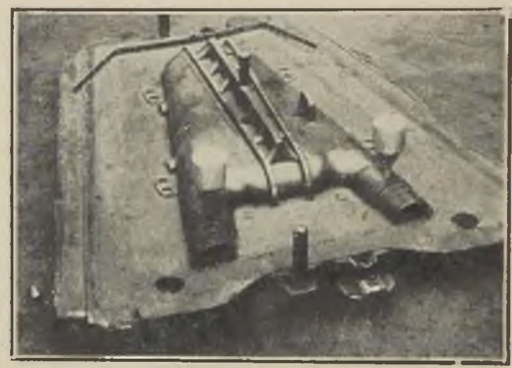


FIG. 8.—PATTERN PLATE FOR TOP WATER PIPE. TOP AND DRAG RUNNERS MADE FROM THE SAME PLATE CORE HAS 3-POINT BEARING. NO CHAPLETS ARE NECESSARY TO SUPPORT CORE. EACH MOULD PRODUCES TWO CASTINGS.

Pipes.

Top water pipes are made in pairs with a 3-point contact for the covers, and both tops and bottoms are moulded off the same pattern.

Induction pipes are generally most quickly made on squeezer machines or (where deep draws are encountered) a jar-ram machine. Oil-sand cores are used for the pipe portion.

Air-Cooled Pipes.

Jar ram machines are best suited for these pipes. An interesting feature is the cooling fins, which are often $\frac{7}{8}$-in. deep. They are moulded in the top-part and can be carried without sprigs. (Fig. 9.) The fin portion of the mould is made of a very strong plain milled red sand and a small amount of fine coal dust.

Fig. 10 shows the pattern and mould on a Britannia machine.

Small Castings.

Valve guides, water-pump and oil-pump details, crank-shaft bearings, valve caps, pump pulleys, gear blanks, etc., are usually made from double-sided, reversible, or single-pattern plates on squeezer or jar ram machines by semi-skilled workers. Big outputs of uniform quality and size are possible. The patterns must strip cleanly and all runners must be formed on the plates. The runners should be so placed that the castings break clean so that it is not necessary to file or grind them.

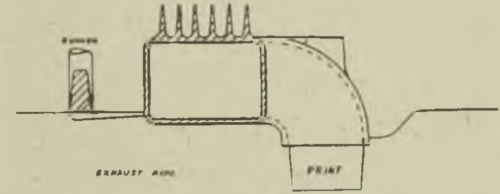


Fig. 9.—Section of an Air-cooled Exhaust Pipe, showing Method of Moulding and Running.

Figs. 11 to 14 give details of the manufacture of some of these.

Cylinders.

Cylinder castings can be roughly divided into two classes—air-cooled and water-cooled. The former are chiefly used for motor cycle engines, and the latter for car, lorry, stationary and aero engines. During the last few years the tendency has been for foundries to specialise in these castings, and in many foundries no other castings whatever are made. Although it must be recognised that much progress has been made there is still scope for vast improvement in the layout, equipment and general conduct of these foundries.

Air-Cooled Cylinders.

These have either loose heads or closed tops. They are generally made from gunmetal patterns on jar- or hand-ram machines, stripping plates being invariably employed for ensuring the stripping of the fins, which are sometimes $1\frac{1}{2}$ in. deep. The moulds are made of dry sand and cast on end.

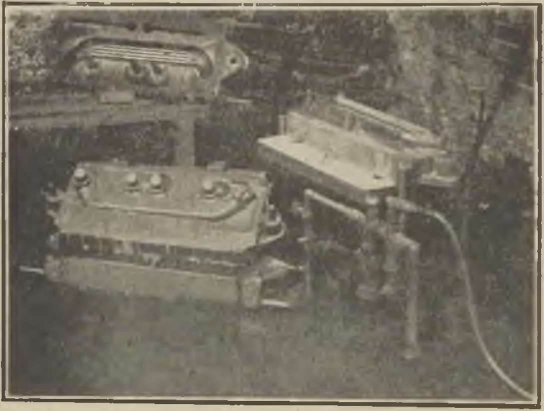


FIG. 10.—AIR-COOLED EXHAUST PIPE AS SHOWN IN FIG. 9, SHOWING PATTERN ON BRITANNIA MACHINE AND PATTERN FOR BOTTOM-HALF MOULD. THE TOP HALF OF THE MOULD IS IN THE BACKGROUND.

Oil-Cooled Cylinders.

This is a moulding problem that serves to show what can be done by sometimes getting off the beaten track in foundry practice. It is a small motor cycle cylinder, and the problem was first brought to the author's notice because of the large number of castings of an outside founder that were rejected by the machine shop for a variety of reasons. The castings were required in three varieties of 1, 2 or 3 cooling fins, and were being moulded in halves with the centre cored out.

These castings were eventually most successfully produced in large quantities as shown in Fig. 16. Four cast-iron patterns were mounted on a machined plate with a stripping plate for the outside and stools to lift the centre cores which were made to strip from the pattern. An oil-sand core was used for the cooling fins and the strainer core. Note the irons to support cores and rods for vents. Fig. 15 explains this.

It was thought to be impossible to make these castings successfully—they are machined all over except for the fins, and must be free from porosity—in green sand and with a green-sand core. Two serious difficulties were encountered before success was attained. Sand presented the first difficulty, as with the ordinary facing sands the ramming had to be so soft to prevent blown castings that they were out of shape. A sand was finally obtained that exceeded all expectations. This sand was made from a strong, fine red sand, dried sea sand and fine coal dust, well milled,

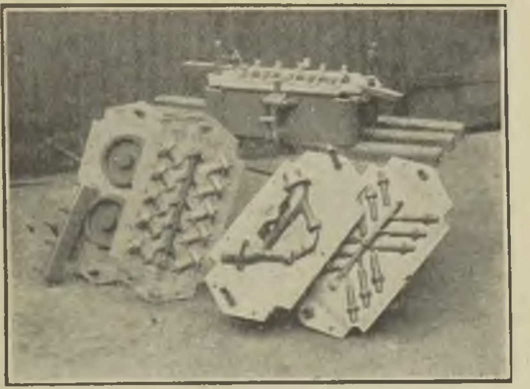


Fig. 11.—Pattern-plate Carrier for Jar Ram Machine and 5 Pattern Plates of Engine Details, such as Gear Blanks, Oil-pump Details, Water Pumps, Valve Guides and Camshaft Bearings.

passed through a disintegrator and used extremely dry. This sand was very porous, and with very little gas being generated could be rammed almost brick hard and still be free venting, thus producing extremely clean, true castings. The obtaining of this sand led to a further difficulty however; it was found that the coal dust, which was very fine, gradually found its way down between the plungers and the patterns, making them stick. This involved taking the whole thing to pieces for cleaning after a few hours' work. The trouble was overcome by cutting $1\frac{1}{4}$ in. off the tops of the plungers and making new tops of hardened steel, which were lapped into the patterns. These pieces were packed with wool that was soaked in oil each night. No difficulty was afterwards experienced. As an example of output it may be noted that 1 man and 2 boys mould and cast 140 per day, with 2 helpers during the casting period.

Fig. 12.—The Wheel Blanks as seen in Fig. 11, showing Freedom from Porosity. Note the Jet Runners.

Water-Cooled Cylinders.

Cylinder Heads.—The tendency in car engine design since the war has been decidedly towards the overhead valve type, and where side by side valves are used loose heads are frequently employed. This has simplified the cylinder castings very much, especially overhead valve cylinders, but the heads are very often difficult castings to make. There are frequently four valves per cylinder, which mean 24 bosses in a six-cylinder head with the same number of inlet and exhaust pipes, besides the necessary bosses for bolting the head to the cylinder. All these bosses must be quite sound when drilled and water-tested. The jacket cores are often very intricate and delicate.

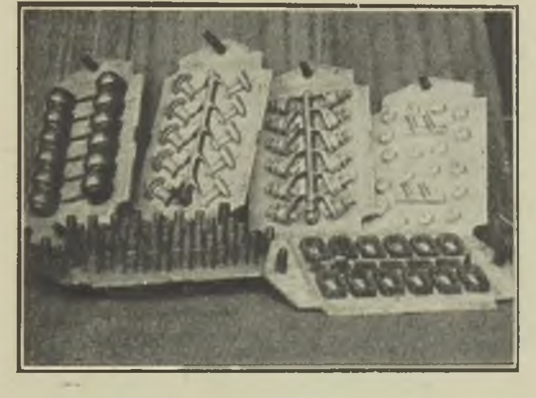


Fig. 13.—Six Good Examples of Machine Pattern Plates for Engine Details. Note the Plate in Left Foreground with 30 Valve Guides in an 18-in. × 12-in. Box.

Cylinders.

These are required with from one to eight cylinders in one casting (Fig. 18). Some cylinders are bolted with the crank-cases, while others are designed with the cylinder and crank-case in one piece. It will be readily understood that some castings are comparatively simple, while others, such as a 4- or 6-cylinder cast in one with their crank-cases and flywheel housings are very intricate, and seriously tax the skill of the patternmaker and moulder, as 40 or more cores are sometimes required. The cost of these patterns, too, is considerable, often running into hundreds of pounds where large numbers of castings are required.

In modern machine shop practice cylinders are not marked off before machining, the castings must be sufficiently accurate to admit of their location in jigs, and come out accurate after complete machining.

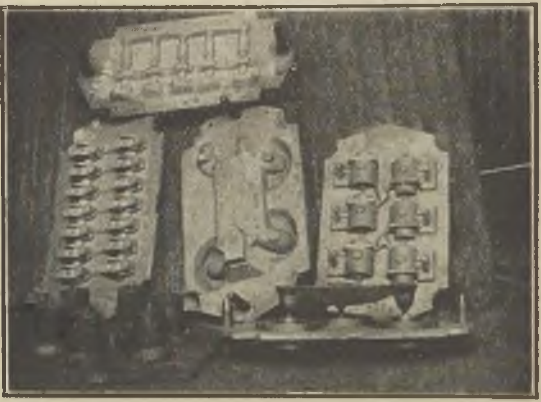


FIG. 14.—DOUBLE-SIDED PATTERN PLATES FOR MACHINE-MOULDING ENGINE DETAILS.

Moulding.

Where large numbers are wanted the moulds are invariably made on machines, generally of the jar ram type by semi-skilled workers. In many cases the moulds are cast in the "green" state. The moulding boxes must be accurately machined, strictly interchangeable, and have very little tolerances in the pins. For large quantities metal patterns and plates are desirable, although excellent results and big numbers can be obtained from hard mahogany patterns on metal plates, as there is much less danger of wood patterns being damaged on power-operated machines. Vents for cores and all runners and risers should be formed on the patterns or plates, and not left for cutting by the operator. The various joints of a cylinder mould must be flat to facilitate the gauging of cores and where undercut parts occur these should be cored out, drawbacks being out of the question.

Coremaking.

This is a branch of the cylinder founders' business that offers almost endless possibilities for time-saving, and although much has been done in the economic production of oil-sand cores, there is still far too much of the foundry practice of 20 years ago in evidence, even in some otherwise well-appointed foundries. One has only to glance round the core rooms to see skilled workers literally wasting their time in finishing cores due

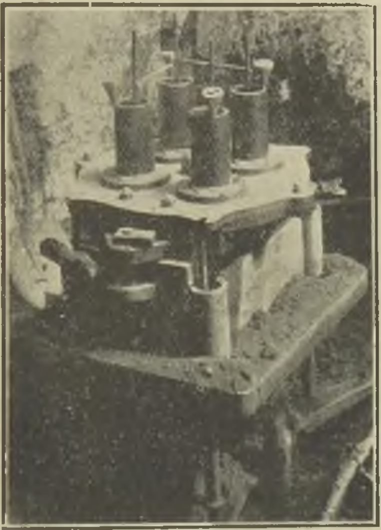
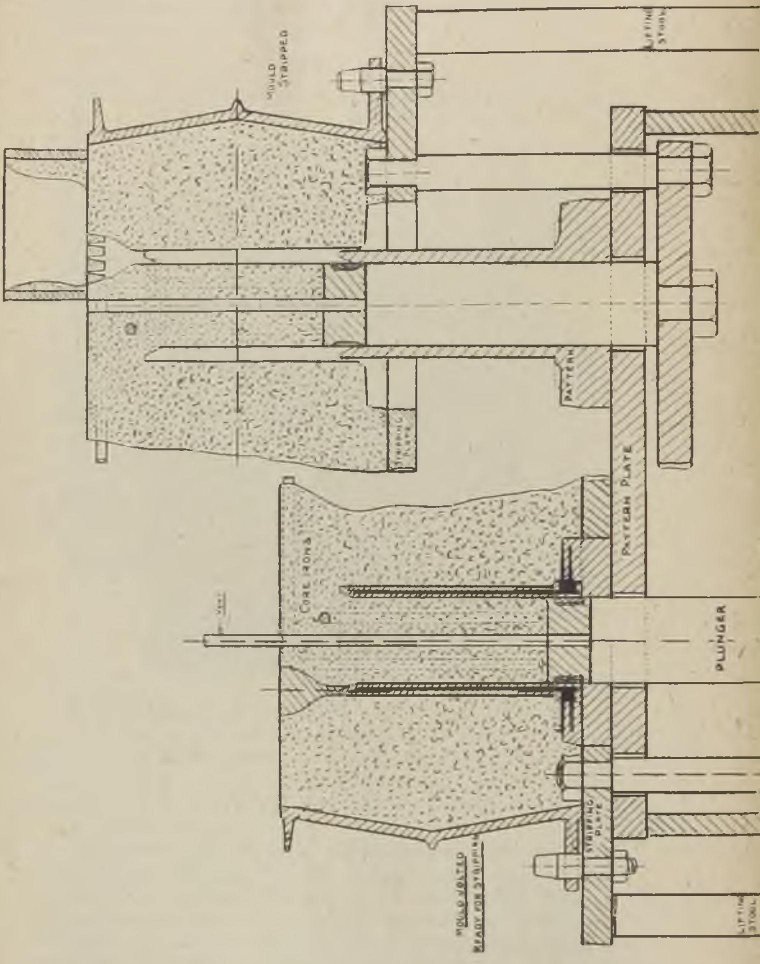


Fig. 15.—Oil-cooled Cylinder. The 4 Patterns on Britannia Machine, with 4 Vent Rods in Position and 2 of the 4 Core Rods also in Position.


MOULD STRIPPED
LIFTING STOOL
PATTERN
STRIPPING PLATE
PATTERN PLATE
CORE IRONS
VENT
PLUNGER
STRIPPING PLATE
MOULD BOLTED READY FOR STRIPPING
LIFTING STOOL

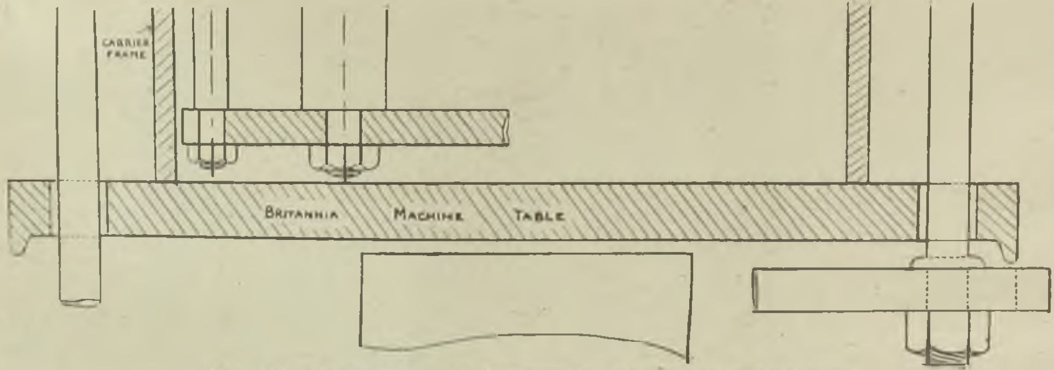


FIG. 16.—MOULDING AN OIL-COOLED MOTOR-CYCLE CYLINDER.

Left Hand part shows mould as jar-rammed (finished cylinder in black section). Right Hand portion shows mould stripped, with strainer cores in position ready to be lifted off the machine. The usual way is to mould in halves and cast on end in dry sand.

to faulty draws, cleaning out loose sand from awkward corners in coreboxes, rubbing of dried cores, blacking with brushes, etc., etc., to realise what can be saved by the expenditure of a little more money at the outset and the employment of a first-class man to plan every operation beforehand and design the equipment to avoid this useless labour. It is possible to-day to produce all the cores for any ordinary cylinder (1) by female labour; (2) without any hand tooling whatever after the corebox is removed; (3) without the necessity for rubbing the dried cores; and (4) at an exceedingly cheap rate, and at the same time enable the coremakers to earn big wages and work under excellent conditions.

Fig. 17.—Two Parts of the Mould with Four Cores in the Drag. Also a Finished Cylinder and a Rough Casting with Strainer Cores.

Where quantities justify the expense, wood coreboxes should not be used, but where this is not the case it will be found that a good hard mahogany will give good service, especially if reinforced with aluminium in the delicate parts. It is also excellent practice to face the corebox joints with aluminium about $\frac{1}{2}$ in. thick, which can be machined over after final assembly on a vertical milling or similar machine.

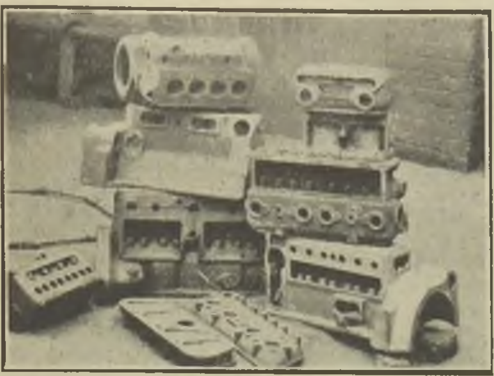


FIG. 18.—GROUP OF CYLINDERS AND HEADS.

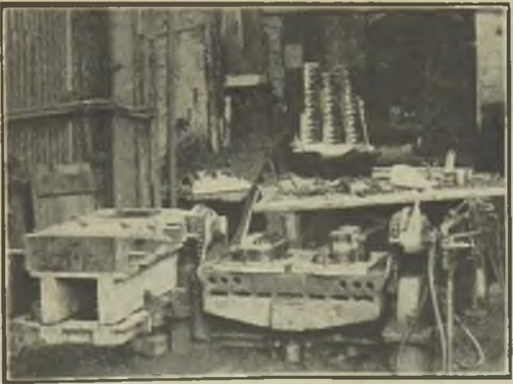


FIG. 19.—TWO-BORE LORRY CYLINDER-PATTERN PLATES MOULDED IN PAIRS ON OSBORN MACHINE.

In Figs. 22 to 33 are shown the making of the cores for a small 4-bore side-by-side valve cylinder that has heads and inlet pipes and ports all cast in, all the cores are produced by female labour. The boxes are so constructed that there is no bedding in of loose pieces with mallets, all wires can be easily put in, and every core can be made without patching up of any kind whatever. The cores strip clean from the coreboxes, are dried, blacked and assembled. Each operation was carefully planned beforehand, and the coreboxes designed and machined by tool makers.

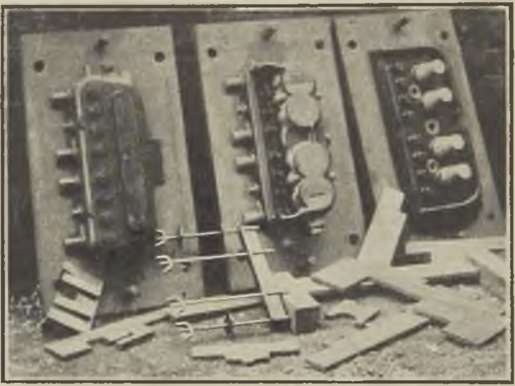


Fig. 20.—A Set of Pattern Plates, Core Gauges, etc., for 4-Bore Cylinder.

Pouring Cylinder Castings.

Some difference of opinion exists regarding the pouring of cylinder castings. Perhaps the most favoured method is to pour directly down the cylinder bores. This is an excellent way for comparatively plain cylinders, but with more complicated castings, such as those with much pipe and valve work in and for those cast in one piece with the crankcase, pouring very fast through numerous small runners extending round three sides of the casting produces the best results. A pouring speed of 8 seconds per 1 cwt. is a satisfactory rate. Where the cylinders are densened it is inadvisable to pour direct down the cylinder bores.

Where the life of the cylinder is of more importance than top speeds in machining, the usual practice is to use an iron as hard as possible consistent with moderate machining speeds in all parts of the casting—of course, taking care to avoid the possibility of white iron in the thin jacket or crankcase parts. The thickness in these cylinders varies from $\frac{3}{16}$ in. in the jackets and pipes, etc., to $\frac{1}{2}$ in. or $\frac{5}{8}$ in. in the cylinder bores, and up to $1\frac{1}{2}$ in. or even more in some of these bosses. It may be said in ordinary practice the degree of hardness varies inversely with the thickness of the section, so that with the cylinder bores being comparatively thick and in the hottest part of the mould when cast, the heat is radiated much more slowly than in some of the remote parts of the casting. This, together with the fact that large bosses are often attached to the cylinder walls, leads to the production of a somewhat softer iron in the very place where maximum hardness is desirable. It has been stated by

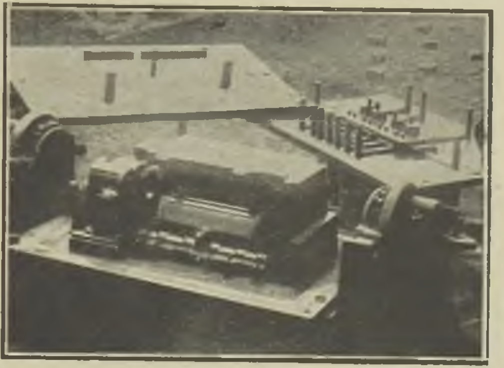


FIG. 21.—GROUP OF 4-BORE CYLINDER AND CRANKCASE PATTERN PLATES ON OSBORN MACHINE. SOME 7,000 CASTINGS HAD BEEN PRODUCED FROM THIS PATTERN WHEN THE PICTURE WAS MADE.

H. B. Swan, of Detroit, that a cylinder bore ½ in. thick is softer, due to cooling conditions, than a 1-in. square bar cast separate from the same ladle of iron.

This was very pronounced in an experience the author had in 1919 and 1920 with a 4-bore cylinder that had a large thin crankcase cast on. These castings were being made in several foundries in this country and on the Continent. In some of these castings the cylinders were much too soft to wear satisfactorily, and in others, where the cylinders were reasonably hard, difficulty was experienced in machining thin parts towards the outsides of the castings, but what was even worse, several of these castings developed cracks in the jacket and crankcases in service. This led to experiments with hardened cylinder bores, a practice eventually made standard. To obtain this hard surface each cylinder bore core is provided with two half-round denseners which extend to within ¼ in. of each end. These denseners are used over and over again, and are made quite cheaply from plate patterns on jar ram machines.

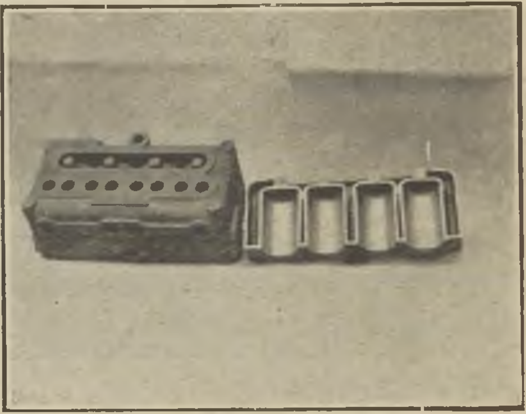


FIG. 22.—A 63-M/M BORE CYLINDER CASTING.

The advantages of this method are: (1) The cylinder bores are of uniform hardness through-

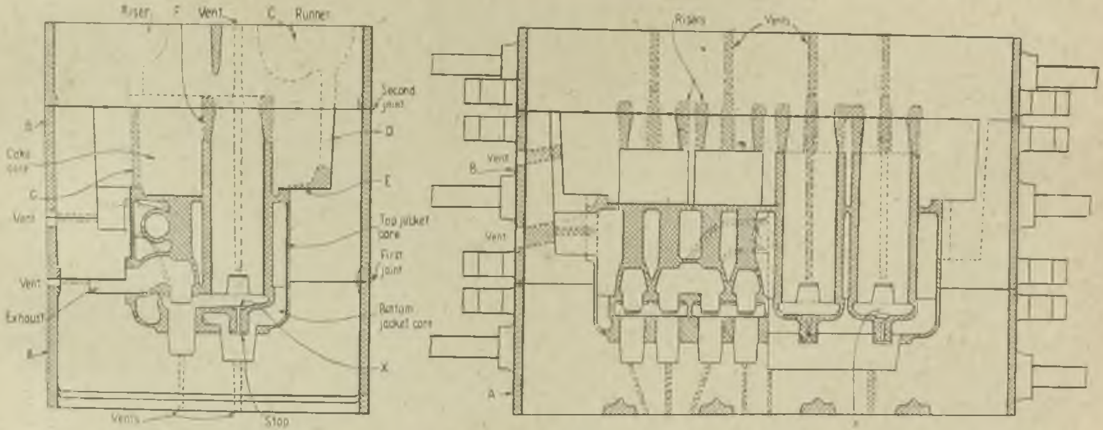


FIG. 23.—LONGITUDINAL AND CROSS SECTION OF THE MOULD FOR CYLINDER SHOWN IN FIG. 22.

out. Many cylinder founders use local denseners where heavy bosses adjoin the cylinder walls. This practice is undesirable, as it is usual to-day to ream-finish a cylinder bore instead of grinding, and this is rendered difficult due to the various degrees of hardness, also in use the wear on the walls and pistons is uneven; (2) the cylinder bores are the hardest part of the casting; a Brinell number of over 200 is easily maintained; (3) porous cylinders are almost unknown; (4) the machine-shop rejects are much less; a most successful run was experienced in 1924 using this method; an overall scrap of 3 per cent. was maintained for the year; and (5) although boring is somewhat slower, other parts of the castings can be machined at a much higher speed.

Fig. 24.—Two Pattern Plates on 403 Osborn Machine. One of 2 Plates for Making Green-sand Tops, which are seen in Foreground.

Most foundries have pet ideas regarding their cylinder mixtures, and there is some conflict of opinion regarding the most suitable composition. In this country in particular some of the elements—notably phosphorus—vary considerably. Some founders turning out first-class work believe

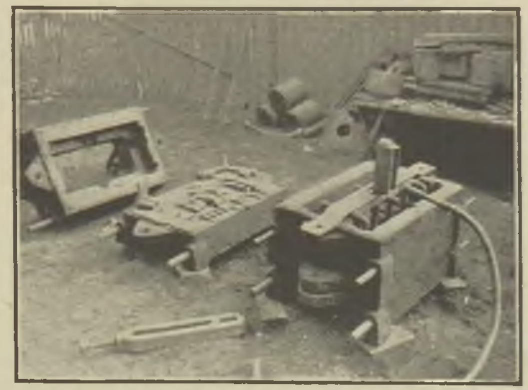


Fig. 25.—The Cylinder shown in Fig. 22 in Process of Coring. Note the Gas Drier for reaching all parts of the Mould.

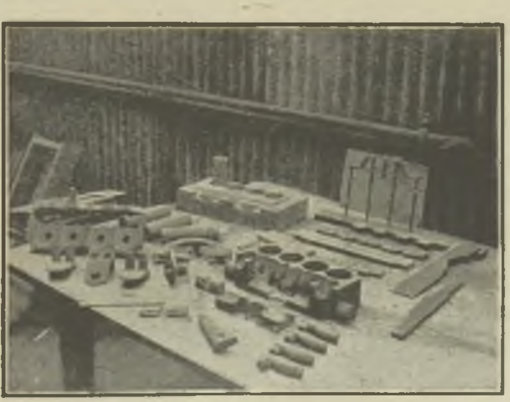
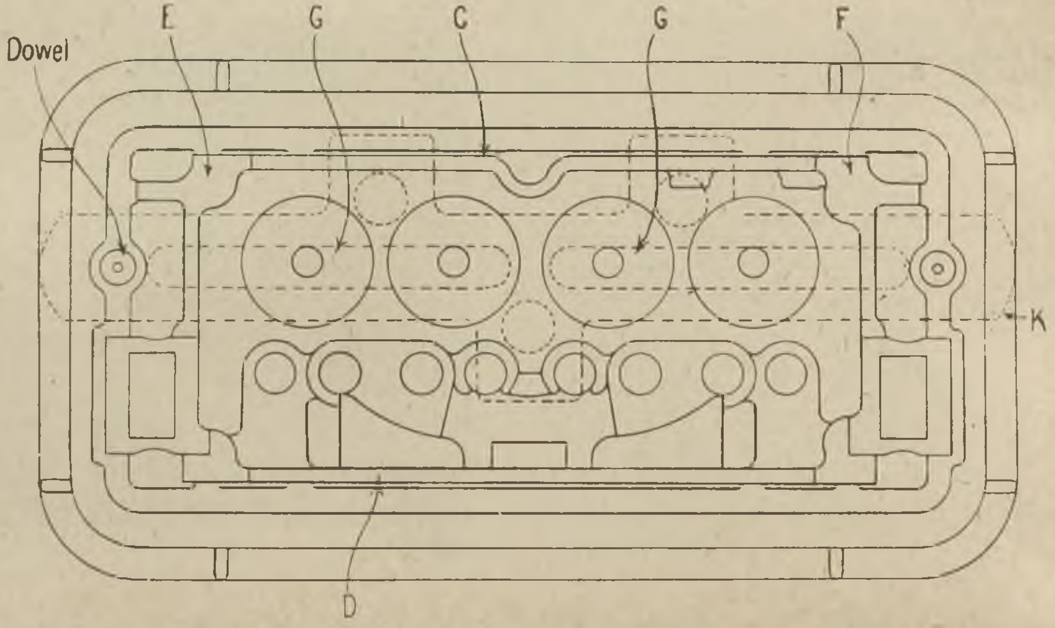


Fig. 26.—Group of Cores and Gauges for the Cylinder shown in Fig. 22.


Dowel
E
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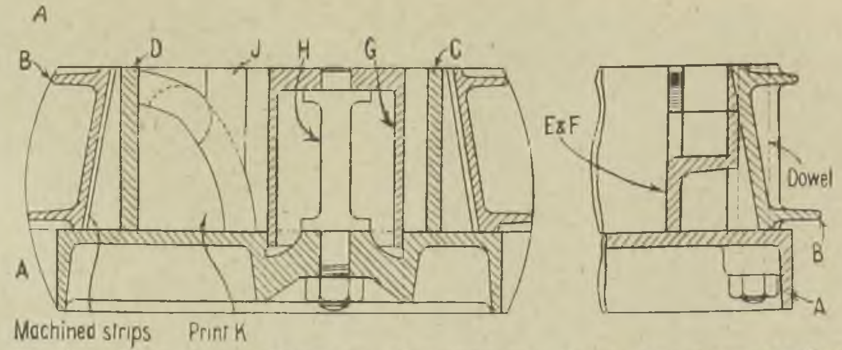


FIG. 29.—THE MAIN JACKET CORE-BOX. DESIGNED FOR QUICK AND ACCURATE PRODUCTION. NOTE THE NOVEL METHOD OF SECURING BARREL PIECES IN POSITION.

in a phosphorus-content of up to 1.2 per cent., while others regard 0.5 per cent. as the maximum. The author has had satisfactory results with irons of the following composition: TC, about 3.2; Si, 1.4 to 2.0 for hardened bores; S, 0.1 maximum; Mn, 0.5; and P, 0.4 to 0.5 per cent.

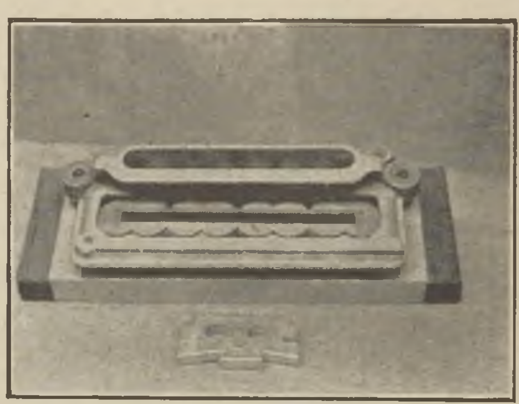


FIG. 27.—VIEW OF BOTTOM JACKET CORE-BOX IT IS ARRANGED TO AVOID THE BEDDING OF ALL LOOSE PIECES.

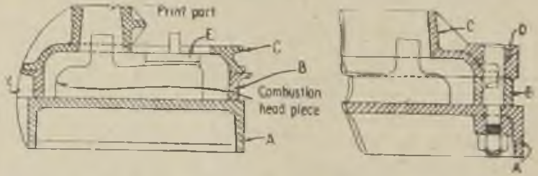


FIG. 28.—CROSS SECTION OF BOTTOM JACKET BOX SEEN IN FIG. 27.—NOTE CURVED RIBS MARKED × TO ENABLE THE OPERATION OF "ROLL" THE CORE-BOX INSTEAD OF LIFTING.

It is of paramount importance that the cupola practice be of the best. Cupolas up to 3 ft. dia. are most suitable, and this metal must have sufficient superheat to allow of its being in good condition after tapping into Bull ladles, and probably carried in shanks for considerable distances.

In conclusion, the author's thanks are due to Messrs. Iliffe & Sons for their permission to use certain illustrations, also the directors of Messrs. Dormans, of Stafford for their permission to use certain of the photographs.

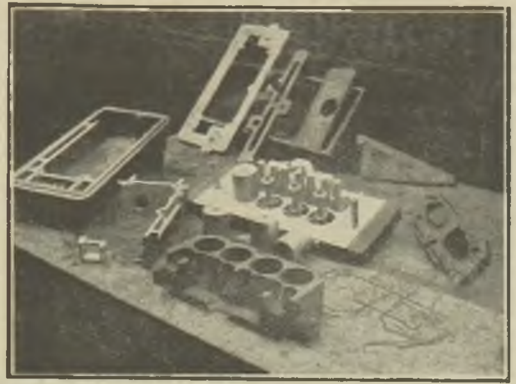


FIG. 30.—GROUP OF THE COMPONENT PARTS OF THE MAIN JACKET CORE-BOX, WITH CORE IN FOREGROUND AND BENDING BLOCKS FOR SOME OF THE CORE IRONS USED.

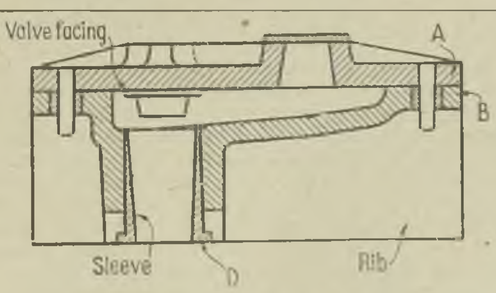
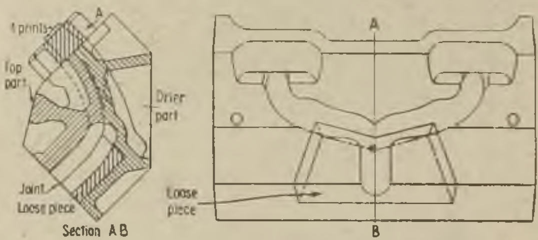


FIG. 31.—CROSS SECTION OF CORE-BOX FOR CYLINDER HEADS.

DISCUSSION.

In opening the discussion, Mr. V. Stobie remarked that he was very interested in what Mr. Molyneux had said concerning the material. Although he had said that the iron should be as hard as possible, bearing in mind, of course, the machining speed, the analysis which he had given did not strike one as being that of a hard iron. He had noticed in Fig. 12 a casting which had been made with some small jet runners. The top seemed to be a very large block of iron, if he had read the drawing correctly, which appeared to be out of proportion to the jets, which one would think would be chilled long before the top iron was fed.



Section AB

Drier part of core box and loose piece

Fig. 32.—Core-box for Induction Pipe.

Mr. W. J. Paulin said that he had also been very interested in Fig. 12, which had shown a casting with a very heavy head and fine runners, which would involve a certain space of time to run. In the first place, there was the running period in which there was no question of rushing the metal, which must be run regularly and without displacing the design. After the metal had been run the casting itself began to consolidate and liquid metal to draw together.

Regarding the sand for the oil-cooled cylinder, was the object in milling the red sand and sea sand to get the particles all the same diameter? If a container was filled with any particular size of sand, the relationship between the solid size and air spaces was exactly the same; but if different sizes of grain were put in the same container the relationship was at once disturbed. At the same time, it apparently made a much firmer core, and yet, if the theory were right, it ought to have been the opposite. In Fig. 7 was shown a heavy flywheel with jet runners, and it was surprising how solid it looked. Was the same mixture of iron used for it? Mr. Molyneux had also referred to denseners made from cast iron. Did he make that iron of any special mixture to reduce gas? Had he ever experimented with wrought iron?

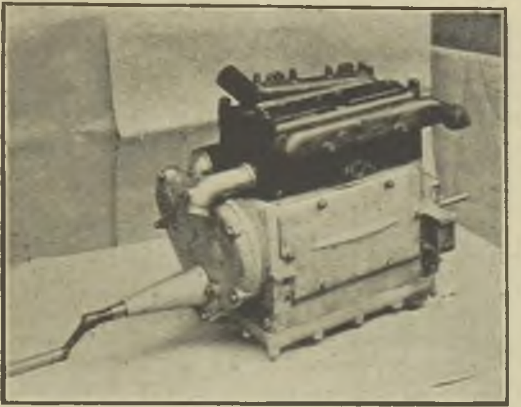


FIG. 33.—A FINISHED ENGINE.

MR. H. J. YOUNG, F.I.C., observed that Mr. Molyneux had mentioned that he considered a pouring speed of 8 secs. per cwt. was a satisfactory one for small castings. He (Mr. Young) had seen ingot moulds in cast iron cast at the same speed take 5 to 10 minutes to pour. On the other hand, in marine foundries castings were actually poured at ½ sec. per cwt. He would like Mr. Molyneux to tell him, if he could, why these things were done. Mr. Young also asked if Mr. Molyneux really thought strainer cores strained the metal, and what he strained out of it. He was interested in what Mr. Molyneux had said about flywheels frequently being thrown out of balance after machining, and wished to know what was the reason for that.

Mr. J. W. Frier said that he would like to know the thickness of the cylinders, and allowance Mr. Molyneux gave for contraction, and the depth of chill and the effect of the chills, as he had been very interested in the method of chilling the bore of the cylinder. He had noticed that in the photograph of the pistons that they were run from the top, the runners being dropped into part of the dry sand core, and he wondered if there were any ill-effect.

Mr. J. M. Smith said that he would like to inform the meeting of a strange case, which might explain that question, in connection with a flywheel for a motor engine. The casting was rejected because it was half an ounce too light. The drawn side could scarcely be seen, and yet that was the cause of the trouble. The work which they were discussing was so accurate that even a fraction of an ounce would reject the casting.

Mr. H. C. Jay remarked that in making flywheels for fire engines, care had to be taken to get the flywheels perfect in form. Similar results had been obtained with a lower phosphorus mixture than that mentioned by Mr. Molyneux. For motor cylinders, phosphorus in the neighbourhood of 0.4-0.5 per cent. had been very satisfactory, although on the Continent it was generally as high as 1.2 per cent.

Mr. W. J. Paulin remarked that this was unusually high. He also asked Mr. Molyneux if any trouble was experienced with the pistons which had extremely thin sections and yet two large bosses.

In reply to the discussion, **Mr. Molyneux** said that the apparently large piece of metal at the top of the jet runners on the half-time wheel in Fig. 12 was simply the runner basin, and was made narrow and deep in section simply to facilitate moulding on the jar ram machine. No attempt was made to " feed " the casting through the jet runners. The loose runner pattern was clearly seen with the pattern plate on the left-hand side in Fig. 11. One reason for using jet runners (and, in fact, strainer cores too) is to get clean castings. When these are used on castings made in large quantities (it was impossible to supervise the pouring at all times) a man must keep his runner filled and cast very hot or the mould will not fill, and he is not paid for the casting. It was almost impossible to get slag into a casting using jet or strainer runners. With jet runners, too, one most important feature is the particularly sound casting resulting, as he thought was well illustrated in the case of the flywheels and wheel blank.

The sand used for moulding the little oil-cooled cylinder was very uniform in size and shape of grains, and by being rammed on the jar machine and used very dry, little gas was generated. The mould could, therefore, be rammed extremely hard. A very suitable silica sand which was finer than seashore sand was " Ryarsh " sand, and was suitable for cores such as piston cores, which must be very clean inside, no blacking being required with this sand. Referring to wrought iron, Mr. Molyneux said that he had never tried it, but that he had tried steel with very good results. For pistons, a mixture containing less than 0.4 or over 0.9 per cent. phosphorus gave sound castings, but in between these amounts there was a great tendency for porosity.

Replying to Mr. Young, Mr. Molyneux said the pouring rate of 8 secs. per cwt. had been taken from actual practice. It was simply a case of necessity, as the mould had to be filled quickly, although in different cylinder foundries there were differences of opinion as regards the speed of pouring; but he found that a good working speed, and after the first trial casting runners were altered to give this speed.

Mr. Molyneux stated that he could not say what was strained out of the metal by pouring through a strainer core, although he was conversant with the experiments of Brunellie, Ronceray and others; but his reason for using them was as stated in reply to Mr. Paulin, and by placing a piece of paper over the strainer core the metal on entering the bush was momentarily arrested until the bush was full, and after that if the man failed to keep the bush full slag would get into the strainer and cause a misrun. Great difficulty was often experienced in getting a flywheel in balance, as sometimes as many as six holes had to be drilled in the periphery to bring the flywheel into balance owing to porosity or unequal density. By using jet runners, however, very little balancing was required.

Replying to Mr. Frier, the thickness of cylinder chills could only be discovered by experience. The cylinders are chilled with two half-round chills. Mr. Chapman raised the question of the thickness of the sand under the bosses in Fig. 4. The boss was round and the thin sand occurred just in one place, and no difficulty whatever was experienced; Mr. Jay, more or less, confirmed what he himself had said concerning flywheels. In cylinder composition standard practice in the U.S.A. was to have the phosphorus about 0.2 per cent.

In proposing a vote of thanks to Mr. Molyneux, MR. E. WOOD (President) said that he would like to mention that the subject of the grain size of sand was dealt with in a Paper which had been given by Mr. Herbst.

The vote of thanks was passed with acclamation.

Replying to the vote of thanks, MR. MOLYNEUX said that his only regret was that he had been able to cover so little of his subject in the short time at his disposal.

Newcastle-on-Tyne Branch.

THE SAND PROBLEM.

By A. Logan (Member).

Although a fair amount of research has been carried out on the subject of moulding sands, and a certain amount of fundamental knowledge obtained, yet there seems to be very little application of this knowledge in the average foundry. The object of this Paper is to focus attention on the sand question, and although the latter part of the Paper deals with the subject in a general sense, it is the sand question as it applies particularly to the Tyneside district with which it is proposed to deal primarily.

Sands Used Locally.

At the present time there is very little steel founding carried out on Tyneside, and in any case steel founding requires rather special sand, so that the Paper deals only with sands for iron- and brass-moulding. Sand being a comparatively worthless material in itself, and transport costs being high, it follows that the ideal as regards economy would be for large founding districts to be situated on, or immediately adjacent to, suitable sand strata and coal measures. Such conditions exist in the Midlands, and account for the area known as the "Black Country." It will be readily seen that the growth and prosperity of the Birmingham district is due largely to a natural use and application of the combination of resources available. Unfortunately, whilst Tyneside has the coal measures, suitable deposits of sand are not available locally. The evolution of Tyneside as a founding centre, therefore, is mainly due to the growth and demands of local shipbuilding and engineering. The cost of transport being practically the determining factor, it is easy to see why the greatest bulk of sand used in this district comes from the Erith deposits on the Thames. Being shipped direct, and water-borne, it is practically the cheapest available source of supply. Prof. Boswell, one of the foremost authorities on sands, in a Paper to the Institute of Metals (Vol. XXII, No. 2, 1919), gives a map showing the principal foundry districts and the available deposits of suitable moulding sands. This is with special regard to non-ferrous work, but is generally applicable for both iron and non-ferrous work, as the same sands are often used in both cases.

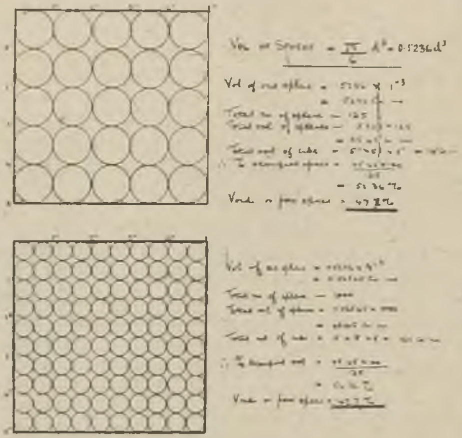


FIG. 1.

Suitable supplies of sand are indicated in the Counties of Durham and Yorkshire. The Durham sand is within easy reach of Tyneside, whilst the Cleveland sand is quite close to the Middlesbrough district. Up to the present, the Durham sands have not been found very suitable, and they do not seem to be in general use. Certainly a sample which has been examined is quite unsuitable for moulding purposes. Other sands which are used to some extent are from the Selby, Doncaster and Mansfield area, and are all of the same type (Bunter) and deposit. Small quantities of other sands are possibly used in some foundries for special purposes.

Properties Desirable in a Moulding Sand.

There are certain well-defined properties which are essential in a moulding sand, whether for brass or iron, and certain others which are not so well defined, but which are also thought to be of great importance. A good moulding sand must possess good bond, strength in the green state, maximum porosity and permeability, suitable grain size, and freedom from fusing, with long working life. The bond, of course, depends mainly upon the clay content, and in some sands where the ferric oxide content is high, this hydrated iron oxide also forms a considerable bond in itself. There is a difference in the behaviour of a clay bond and a hydrated iron-oxide bond in service, and the long-life qualities are closely connected with the type of bond present. Both clay and hydrated iron oxide are colloidal bodies, that is, they exist in particles which are so small that they are ultra-microscopic, and the ratio of surface to mass is definitely

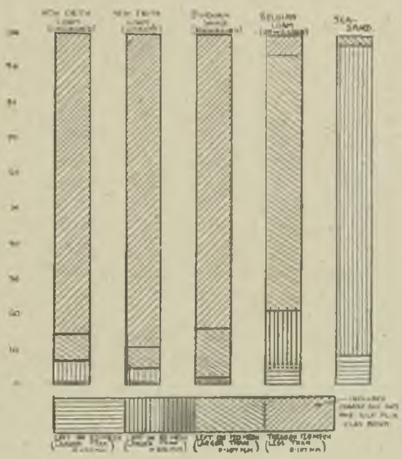


FIG. 2.—COMPARISON OF SIEVE TESTS ON VARIOUS SANDS.

high. Chemically, clay consists of a heterogeneous mixture of various hydrated aluminium silicates. No satisfactory explanation of what actually causes the plasticity of clays has yet been advanced, but we know that "ageing" or "weathering" in the moist condition, or "working" the clay, increases this property. On heating, the hygroscopic water is driven off at 100 deg. C. and the clay loses its plasticity and dries to a hard mass, but moistening and working will restore the plasticity. On further heating to approximately 500 deg. C., however, the chemically combined water is driven off, and the clay permanently loses its plasticity. No amount of moistening and working will then restore it, and it is said to be "burnt." This action is continually happening when a moulding sand is in use. The layer of sand forming the wall of the mould is strongly heated by the hot metal adjacent to it. All the sand heated in this way to approximately 500 deg. C. and over will be burnt and lose its bonding properties completely. The bond due to hydrated iron oxide is not so easily affected by the degree of heating which destroys the clay bond.

Porosity and Permeability.

It is a very prevalent idea among foundrymen that porosity and permeability mean the same thing, but in reality they are two quite distinct properties. Porosity refers to the actual pore spaces or voids which exist in a mass of sand, whereas permeability relates to the ease or otherwise with which gas can permeate or pass through those voids. Generally, the greater the porosity the greater the permeability; but it does not follow. Two sands of equal porosity may be of widely different permeability. One may be composed of large grains, and the other of small grains, or may have the bond differently distributed, and lower permeability will be caused by the increased friction of the smaller pore spaces. This fact can be visualised by simple practical experiment.

Suppose there are two 5-in. cubes and into one is put 125 spheres of 1-in. diameter, and into the other we put 1,000 spheres of ½-in. diameter. At the first glance it might be thought that the larger spheres would have a larger void space, but actually both are equal—the ratio of occupied volume being always 52.36 per cent. where the particles are perfectly spherical. Thus we can add a further 47.6 per cent.; the volume of water in each case will occupy the air space or voids between the spheres without increasing the total volume. It will be seen, however, that although the total porosity or pore space remains the same, yet in the case of the larger spheres the spaces are also larger, and there are fewer of them compared with the small spheres which have smaller spaces and more of them. The permeability or ease with which gas can find its way through will, therefore, be greater in the first case where the voids are fewer and bigger. Where mixtures of particles exist of various sizes, these conditions do not hold good, as the smaller

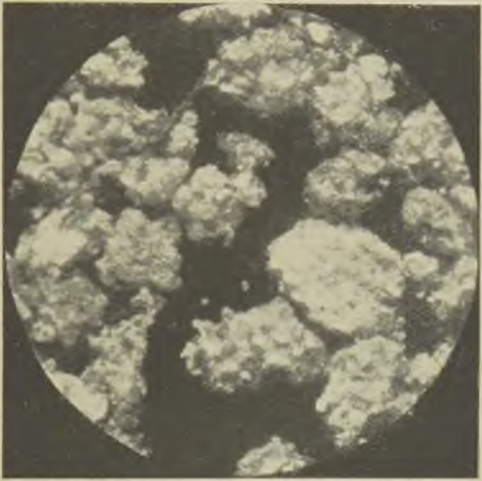


FIG. 3.— × 25. UNWASHED ERITH LOAM. SAND GRAINS REMAINING ON THE 50-MESH I.M.M. SIEVE=6.35 PER CENT.

particles tend to pack into the void spaces between the larger grains, and thus reduce the permeability considerably. From this point of view it is unwise to mix different varieties of sand in the hope of improving the quality, unless full information is available concerning the respective grain sizes. If the sands are of different grain size, a mixture of the two will give a sand with poorer properties than either of the original.

Although sand grains as they exist in moulding sands are not clean, perfectly spherical grains, yet these principles apply, and it will be seen how the physical constitution (that is, the sizes, shapes, and amounts of the different sizes, and their bond coating) affect the permeability. If a moulding sand is examined under the microscope, it will be found to consist of irregular grains of different sizes. New sand has the clay bond very unevenly distributed on the sand grains, generally forming wart- or knob-like masses. After working or milling, this clay is distributed more uniformly, forming a more or less complete envelope or jacket round the sand grains.

Methods of Testing.

The foundryman has his own rough-and-ready method of testing a new sand. He rubs it between his thumb and finger in order to get an idea of its texture or grain size, then he squeezes a handful in order to test the bond or strength. Not very scientific, perhaps, but still very useful when accompanied by experience.

The separation of the sand into definite grades is only carrying the foundryman's rough test to its logical conclusion, and is accomplished by means of sieves of varying mesh. The standard Institute of Mining and Metallurgy sieves are used, and for ordinary purposes three have been chosen which divide up the sand into coarse, medium and fine. The material passing through the last sieve is a mixture of coarse silt, fine silt and clay. The sieve numbers chosen are 20, 50, and 120 respectively. The No. 20 sieve retains all material larger than 0.635 mm. (0.025 in.); the No. 50 sieve retains all larger than 0.254 mm. (0.01 in.); the No. 120 sieve retains all larger than 0.107 mm. (0.0042 in.). If the material passing through the last sieve is only a small percentage of the total, it is not necessary to examine it further, but with very fine-grained sands, where a considerable proportion of the whole passes through, it is necessary to further grade the material. This is accomplished by elutriation.

It has been objected that square hole sieves are not so satisfactory as round hole sieves, and inasmuch that grains with one axes greater than another may get through the diagonal axes of the square hole, this is quite true, but for practical comparative work this does not matter. It is obvious that a moulding sand with its coating of clay bond on the grains will give an apparently larger grain size on sieving. Sands should therefore be sieved in both the washed and unwashed conditions for comparison.

FIG. 4.—× 25. ERITH LOAM. SAND GRAINS REMAINING ON THE 50-MESH I.M.M. SIEVE = 4.48 PER CENT.

The results of sieve tests on different sands are shown graphically in Fig. 2, for comparison purposes.

Actually, in fully investigating different sands, it is necessary to go further than the sieve tests, and divide up the material which passes through the 120 sieve into its respective grades of coarse silt, fine silt, and actual clay bond. For instance, comparing the Durham sand with Erith loam, it would appear that they are very similar, and might be used or mixed and give the same results. Actually, however, this is not so, as the Durham sand is almost useless for moulding purposes, containing in addition to a poor clay of inferior bonding properties a large proportion of fine silt, which chokes up the pores and reduces the permeability. Smalley has quoted the relative permeabilities of Erith and Durham sands under the same conditions as practically 7 hours and 87 seconds respec-

FIG. 5.—× 25. UNWASHED ERITH LOAM. SAND GRAINS REMAINING ON THE 120-MESH I.M.M. SIEVE=7.58 PER CENT.

tively. (Time to pass 600 ccs. of air through tested sand in his own permeability apparatus.) This low permeability is easily understood by comparing the photo-micrographs.

Figs. 3, 4, 5, 6, 7 and 8 show photo-micrographs of the various size sand grains of Erith sand, in both the unwashed and washed conditions. Fig. 9 shows the fine silt in a Durham sand, and Fig. 10 grains of sea-sand.

The testing of permeability is not a simple operation, but the general principle consists in measuring the time taken to pass a certain volume of air through a definite amount of the sand to be tested. There are many different variables which influence the test, and owing to lack of standard apparatus comparative tests are all that can be obtained. The degree of moistness originally present in the sand, the degree of ramming, the area and thickness of the tested sand, the head or pressure behind the air, all have their influence. In green sand

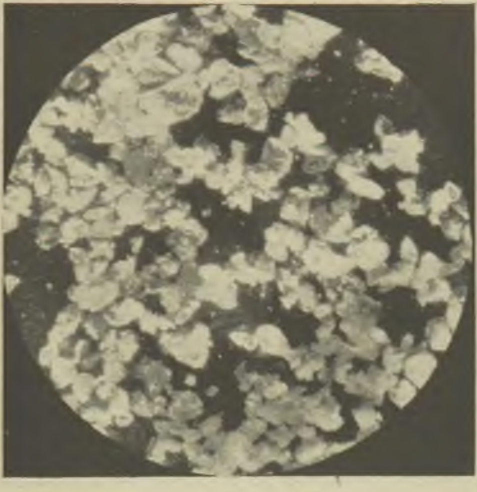


FIG. 6.—×25. WASHED ERITH LOAM. SAND GRAINS REMAINING ON THE 120-MESH I.M.M. SIEVE=5.69 PER CENT.

work the moisture content is important, and this is easily obtained by taking a weighed quantity of sand and drying at slightly over 100 deg. C. until a constant weight is obtained.

For some years the American Foundrymen's Association have had a special committee, known as the Moulding Sand Research Committee, going thoroughly into the question of methods of sand testing, and they have done admirable work, which will be referred to later.

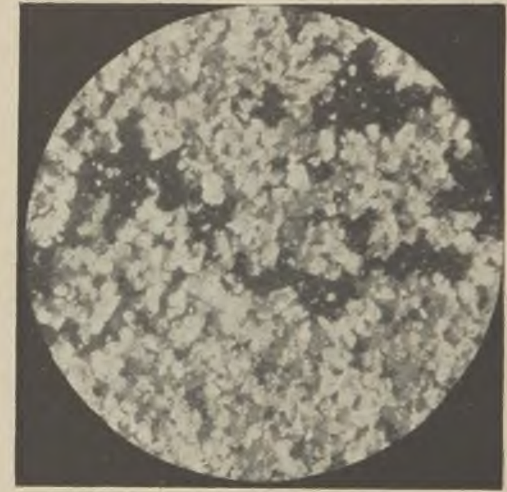


FIG. 7.—× 15. UNWASHED ERITH LOAM. SAND GRAINS PASSING THROUGH THE 120-MESH I.M.M. SIEVE=85.14 PER CENT.

Deterioration of Sand in Use.

The greatest source of loss is due to the layer of sand forming the wall of the mould being "burnt" during casting. As pointed out previously, all sand which is heated to 500 deg. C. or over has its clay bond destroyed, and becomes useless. It depends upon the initial casting temperature, and the section and mass of the casting as to how far the zone of temperature exceeding

500 deg. C. penetrates back into the sand. When the casting is removed from the mould it is impossible to entirely separate the burnt sand from the unburnt, so that a certain proportion of "dead" sand becomes mixed with the good. The handling of sand also tends to break down the sand grains, so that the tendency of the floor sand is always to deteriorate into finer and less strong material, with a decreased permeability.

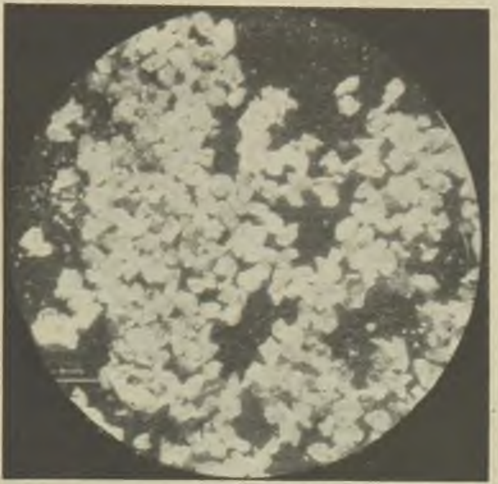


FIG. 8.—×25. WASHED ERITH LOAM. SAND GRAINS PASSING THROUGH THE 120-MESH I.M.M. SIEVE=89.35 PER CENT.

There is also the continual accumulation of small particles of metal, iron being the worst offender in this respect, as a drop of iron spilt whilst pouring flies in all directions, and is split up into very small "shot" which are too small to be sieved out with an ordinary foundry riddle. In time these "shot" rust, and where the facing sand is a mixture of riddled floor sand and new sand, etc., some of these rusty "shot," perhaps only a matter of an $\frac{1}{8}$ in. dia. or less, may happen to find their way to the actual mould face, and it is quite possible that they may cause excessive local evolution of gas when the job is cast.

Normally the floor sand is kept in condition by circulation, the addition of new sand to the facing mixture balancing the discarded burnt sand, and keeping the whole in good condition.

Foundry Aspect of the Sand Question.

The most vital quality in a moulding sand from the foundry point of view is that of strength, and this is bound up with the question of the bond. This is directly influenced by the moisture content, and every particular sand has its own optimum water content which gives the maximum strength. Generally the moulder will find this out for himself, and he is able to work within fairly close limits from day to day.

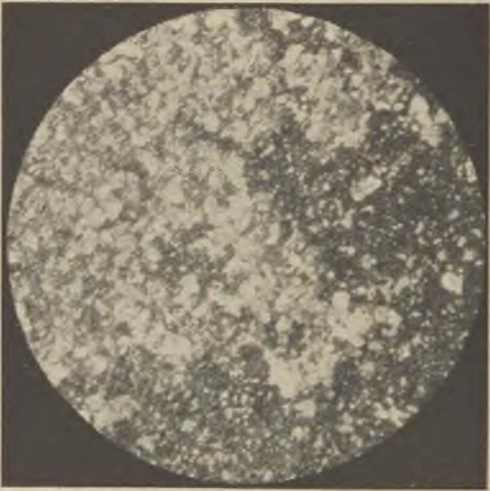


Fig. 9.—Unwashed Durham Sand. The Grains which have passed through the I.M.M. Sieve=82.35 per cent. Note the Large Proportion of Silt Present and Compare with Fig. 7.

It seems to the writer that even at the present time there is very little practical application in the foundries of this country of the results of researches which have been carried out both here and in America and on the Continent. How many foundries attempt in any way to control the properties or regulate the sand in any definite manner? Or do they not simply take the cheapest available source of supply and make the best of it? On Tyneside, for instance, the majority of the sand used is Erith, not because it is necessarily the best sand, but because it is relatively cheap. This fact emphasises another point upon which it is desired to draw discussion. Looking at the grading of new Erith loam, it will be noticed that over 85 per cent. passes through a 120-mesh sieve—that is, allowing, say, about 8 per cent. of this as being clay bond, then over 75 per cent. of this sand is of the fineness which is classed as silt, and the permeability is low com-

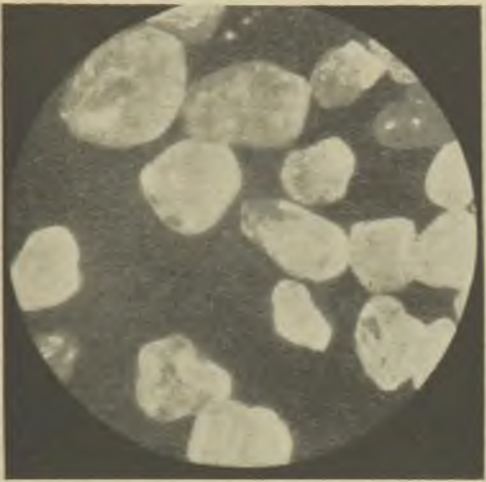


Fig. 10.— × 25. Sea-Sand Grains remaining on the 50-Mesh I.M.M. Sieve = 89.51 per cent. Note the Approach to Spherical Shape.

pared with sands used in other districts, such as Mansfield or Belgium loam, which are much coarser or more "open" sands, and which have higher initial permeabilities. What, then, is the value we are to set on permeability from the foundry point of view?

Although some go so far as to say that permeability is not a necessary quality at all, it is believed that permeability does matter to some extent even in a dry-sand mould, and becomes very important, of course, in cores or in places nearly surrounded by molten metal. When it is recollected that simple castings were made in early times in stone moulds, and later in clay moulds, and that semi-permanent moulds are being used to-day where there can be very little, or no, permeability, the whole question becomes very difficult. In the dry-sand mould certainly, the sand has little more to do than to accommodate the increased volume of the air occupying the pore spaces, and which is expanded due to the heat of casting, and possibly a little extra gas caused by slight decomposition of the plumbago facing on the mould surface. If the casting temperature is sufficiently high, and the layer of sand forming the face is burnt, then there will be a further amount of water vapour liberated from the hydrated bonding material. However, the time element comes in, and it is only the first few seconds or so when the molten metal makes contact with the wall of the mould that is the critical time from the casting's point of view, for a skin is formed very quickly. Any gas then generated by the decomposition of the face would not be able to penetrate into the metal, and would be forced to find its way back into the sand. Trying to picture the sequence of events as they take place, we can imagine a mould being filled from the bottom and the liquid metal rising up the walls. Immediately a fresh part of the mould surface is covered, a certain amount of decomposition of the facing takes place, and the majority of the gas liberated frees itself into the mould cavity and thus escapes into the open. The heating of the sand next the metal occurs, and this expands the air held in the pore spaces, which has to escape back into the cooler sand.

Sand is a very poor conductor of heat, and although the layer of sand next the casting is very strongly heated, this is not conducted very rapidly by the adjacent sand. The abstraction of heat by the sand rapidly forms a skin on the outside of the metal where it is in contact with the mould surface; and although it is possible that by now the layer of sand may be heated to over 500 deg. C. and consequently becoming "burnt" by the decomposition of the clay bond with consequent liberation of further quantities of gas, yet this is unable to escape by way of the metal owing to the impervious skin, and it is forced to gradually find its way out through the sand.

In any case, the volume of gas generated in a properly dried, dry-sand mould must be very small, and it finds its way out imperceptibly. The case of the green-sand mould is rather different. To commence with, there is both free moisture and coal dust present, so that the volume of gas generated is very much greater—much greater than the ordinary permeability of the sand can accommodate, so that free channels or vents have to be artificially provided.

Permeability.

From a strictly practical point of view, the only time that the actual permeability of the sand is of any importance is the critical moment or so when the molten metal first lies on the wall of the mould. If the permeability is such that the volume of gas being generated can find its way through the sand sufficiently fast to prevent the accumulation of a pressure greater than the pressure of the head of the liquid metal, then no gas can escape by way of the metal. If the pressure builds up greater than the liquid pressure in the metal, then some gas will pass into the metal. This can only happen momentarily, for in a very short time a skin will have formed and prevent either ingress or egress of gas. It does not follow that a bubble of gas which enters will be found at the same spot on machining, for on entering the metal, it may be carried along some distance if the mould is still being filled. This explains why gas holes are sometimes found at places where there is no apparent explanation for their presence.

Another reason is that sometimes an intense local evolution of gas may take place at some particular spot on the mould face, due to the lodging of some foreign body in the sand at that spot. The risks of this sort of trouble are very much greater in green-sand work. Patching is a frequent cause of both gas holes and scabbing. Generally a place is patched with sand which contains more moisture than the sand already forming the mould. The excess moisture in the patching sand is absorbed into the mould by capillary attraction and it carries with it a certain amount of the clay bond. This accumulates in a layer behind the patch, so that there is not only a weak place due to insufficient bond which may scab; but even if the patch resists the wash of the molten metal, the lowered permeability due to the layer of clay behind the patch may cause gas trouble.

Another cause of scabbing may be due to too hard ramming on one local spot, or ramming too near the pattern. Up to a certain point, uniform increase of density of the sand, only reduces the permeability a little. This corresponds with the point where all the sand grains with their jacket of bond are touching each other. Further ramming then causes the breakdown of the bond coating round each grain and causes packing of the grains and choking of the pore space. The decrease of permeability is then very marked, and any local spots of this kind will probably " scab " or " blow." As will be readily understood, these are troubles which are due to the use or mis-use of the sand, and not to the sand itself, and are only avoided by the moulders' individual skill and care in working. Gas troubles in castings, especially green-sand work, are nearly always due to some irregularity in moulding, and very seldom to the metal or sand. The biggest causes are as outlined above—wet patches, unevenly rammed places, ramming too near the pattern, patches, etc., and also the possibility of mechanically mixed impurities lying near the mould face. It must not be forgotten also that the speed of pouring, or the shape of the pouring basin may cause air to be drawn in and mixed with the stream of molten metal entering the casting.

Various investigators have shown from time to time the importance of correct water content, both from the strength point of view and particularly as to its effect on the permeability. As a matter of fact, the permeability of a dry sand mould is much less affected by over-ramming than by an excessive amount of water in the first place. The type of sand—that is, the general grain size—and the amount and nature of the bond influence the amount of water required. An open sand of the Mansfield type therefore requires only a matter of from 6 to 7 per cent., whereas a very fine sand, such as Erith, requires from 10 to 11 per cent., although both perhaps would appear by observation to be of the same comparative degree of moistness. Fortunately, observation and experience on the part of the moulder enable him to gauge fairly accurately the necessary amount of water, and, with care, he is able to work very closely to the correct amount. Actual tests on a moulder's sand heap, over a period, have shown that the greatest variation was only a matter of about 2 per cent., from approximately 10 to 12 per cent. Nevertheless, the water content being so important, attention to this point is desirable, especially where machine moulding and mass production are in operation. In many American foundries the water content is checked on every batch of sand mixed.

The difficulties in the way of obtaining definite permeability tests have been touched upon, and, although a standard apparatus in a robust form suitable for practical foundry work has been prepared by the Sub-Committee on Tests of the Moulding Sand Research Committee of the American Foundrymen's Association, yet apparently everybody in this country uses a different kind of apparatus. The same thing occurs with the strength tests. Everybody seems to have a different size test bar and different conditions of doing the test.

Necessity for Practical Tests.

In general, there are two directions in which sand testing can be effectively applied. One is in deciding, in the first place, whether a sand is suitable for any particular moulding purpose. It is useless, for instance, trying to blend two different sands with a view to improving the properties, unless the respective properties of each—grain size, bond, etc.—are known. Again, the properties of a satisfactory sand in use being investigated, it may be possible to match these properties in a cheaper local sand.

Secondly, a suitable sand being fixed upon, it is desirable to regulate the properties of the sand in use, by simple, daily, routine tests. It is thought that from the strictly practical point of view, all that would be necessary would be a moisture test, a permeability test, and a strength test, something after the style of the practical foundry test recommended by the American Foundrymen's Association Committee mentioned. Proof that this practical test is of value in everyday working is given by S. H. Russell in his "Impressions of American Foundries," given before the East Midlands Branch of this Institute.* To quote from this account, of one foundry visited he states: "These people have adopted the Standard A.F.A. tests for their sands. The test can be quickly taken and gives valuable comparative results. A weighed quantity of sand is taken from the heap, and is rammed into a brass cylinder by three blows from a weight falling down a spindle through a fixed distance. The height of the column of sand is measured by a lever resting on the top of the spindle, and a pointer at the end of the lever indicates the height on a graduated scale. Wet sand rams closer than dry, and an indication is given as to the comparative moisture and permeability. The brass cylinder containing the core of sand is then taken and transferred to another apparatus, and a simple water gauge indicates the pressure necessary to drive air through the core and indicates permeability. The core of sand is then removed from the cylinder and is compressed in a machine like a small, old-fashioned letterpress. The core stands on the table of a spring balance, and the reading in pounds when the core collapses is taken. These three tests are made in less time than it takes to describe them,

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* FOUNDRY TRADE JOURNAL, January 6, 1927.

and this firm appear to regulate their sands entirely by the result of these tests. . . ."

Although it is fully recognised that, with the natural moulding sands available in this country, our sand problem is not so pressing as it is in America, and granted these suitable supplies of moulding sand—that the troubles due to the mould which do arise in everyday working are more probably the result of unskilful or careless moulding than of actual variation or unsuitability of the actual sand itself. Yet it is still thought that the problem is sufficiently important to warrant a thorough examination of the whole question of moulding sands, and particularly methods of testing, on a much bigger scale, and with a broader outlook than has been possible on the part of individual workers—admirable as their pioneer research has been.

The whole question of sand testing at the present time in this country is chaotic. To give only one instance—that of the simplest test of all—the grading or sieve test. This is conducted by different workers (both in this country and abroad) with different sieves, some with round holes, some with square, all with different diameter openings. There are different methods of conducting the sieving; some sieve only for a fixed time, others sieve till no more passes through, and so on. The very first essential is that we should have definitely standardised tests, preferably internationally standardised, or at least to be comparable with work done in other countries. The tests should, roughly, fall into two categories—more or less fundamental research tests, suitable for laboratory research and investigation of new sands, etc., and practical, everyday routine tests, which would give practical guidance as to the condition of the sand in use.

There does appear to be a real need at the present time for some such body as the Institute of British Foundrymen to set up a committee on the lines of the existing Test-Bar Committee, which has done such useful work, and to go thoroughly into this question of sands and sand testing.

Wales and Monmouth Branch.

SEMI-STEEL.

By J. E. Hurst (Member).

It is just over ten years since the author addressed the Lancashire Branch of the Institute on the subject of semi-steel. Since that time the use of steel mixtures in the foundry cupola has extended considerably, and they are more thoroughly understood by the general ironfounder. In fact, during the last ten years semi-steel has occupied the position of the ultra-fashionable cupola mixture. It appears that the popularity of semi-steel in the fashionable world of the ironfoundry is on the wane, and is being usurped steadily by a new fashion, under the guise of pearlitic cast iron and low total-carbon content cast iron. This, however, does not detract from the importance of semi-steel, and the knowledge gained in the practice of semi-steel and, in fact, the continued use of steel mixtures either directly or indirectly will still be essential to maintain the high standards of quality set in the more modern fashions.

In some notes on semi-steel or steel mixture irons which the author has included in a chapter of his book on "The Metallurgy of Cast Iron," he has described semi-steel as a delightfully cheap and easy way of producing a low silicon, low phosphorus iron—a good iron. There is no alteration to make to this statement, except to add a proviso that steel scrap remains cheap and easily obtainable. This and the whole of these notes have been criticised in an American review of the book on the following lines. The reviewer complains that the most important detail of melting steel additions in the cupola are omitted as though they were a matter of common knowledge. "Perhaps they are in some quarters," the reviewer goes on to say, "but few foundrymen can meet a heat containing 25 to 30 per cent. steel without running into difficulties unless they have been instructed by an expert in this practice. Those foundrymen that do employ large quantities of steel scrap seem loath to describe exactly how it is done."

This criticism reveals an attitude towards semi-steel which is unfortunately typical of the attitude of many foundrymen and ironfoundry metallurgists (including many who ought to know better) towards new suggestions and innovations in cast iron cupola mixtures. The attitude is one which endeavours to attribute some extra special knowledge and skill as being necessary to accomplish the successful operation of the innovation. The ironfoundry section of metallurgy as a whole appears to be peculiarly susceptible to this kind of thing, and it is thought that certain sections of the industry prefer to maintain the atmosphere of mystery and complexity surrounding its processes rather than they should be laid bare and simplified.

There are, of course, many reasons for this attitude, but one of the principal reasons which it is necessary to mention here is that the introduction of these innovations in cast iron mixture practice is generally heralded by the most extravagant claims, and as experience modifies them the attitude above mentioned arises as an attempt to sustain the initial unfounded claims.

Ten to twenty years ago semi-steel was inferentially and directly made the subject of such extravagant claims, and one meets people to-day who still have the impression that the physical and mechanical properties of semi-steel are between those of steel and cast iron. This is, of course, not true, and should any foundryman desire to obtain such results, then it will be necessary for him to have recourse to the services of such an expert as is not to be found in this country at any rate. Otherwise, if he desires to obtain a 25 or 30 per cent. semi-steel, as the case might be, the final result and the services of the expert will remain unnecessary.

Composition of Semi-Steel.

The whole point in producing semi-steel is the decision as to the most suitable chemical composition for the particular castings it is desired to make, neglecting for the moment any consideration of the total carbon contents and confining attention solely to the remainder of the composition, *i.e.*, silicon, manganese, sulphur and phosphorus contents.

The decision as to the most suitable composition will determine the amount of steel to be used in the mixture and the composition of the remaining portion of the charge. This decision is governed by the same rules and regulations as in the case of ordinary castings, and the decisive feature is generally the silicon content. In so far as the items of the chemical composition enumerated above are concerned, the addition of steel simply acts as a diluent and reduces their proportions by an amount depending upon the amount of steel added, taking into consideration obviously the normal losses and gains experienced due to remelting. The normal loss in silicon and manganese takes place, as does also the normal gain in sulphur.

It is obvious that if the composition decided upon is unsuitable for any particular casting the steel mixture can hardly be held responsible. This may quite easily happen as in the following hypothetical case. Assuming a foundry operating on light castings not more than $\frac{1}{8}$ in. thick and using an iron of approximately 2.0 to 2.5 per cent. silicon, the addition of 25 per cent. steel to this iron would reduce this to a silicon content in the neighbourhood of 1.5 per cent., which would be at once accompanied by disastrous results in the shape of hard castings due to the low-silicon content. One may further imagine that this same mixture has a low manganese content and comparatively high sulphur content, *e.g.*, 0.30 per cent. Mn and 0.15 per cent. S. The addition of 25 per cent. steel to this mixture with the reduction of the silicon content to 1.5 per cent. may be accompanied by a tendency to hard castings. If, however, in addition the manganese is raised at the same time, either by the addition of ferro manganese or pig-iron or steel of high manganese content, the tendency towards hard castings would disappear. In this case satisfactory castings would be obtained with silicon content of 0.5 per cent. lower than the original of 2.0 per cent., and this would be accompanied by superior properties in the same castings. These superior properties are not wholly due to the added steel, however, but to the elimination of the influence of the sulphur by the addition of manganese, and the only effect of the steel is to improve what was originally a defective mixture.

This brief consideration serves to show that in the manufacture of semi-steel it is important correctly to decide the desired composition, and in obtaining this the composition of the cast iron portion of the cupola charge is of the greatest importance.

Total Carbon Contents.

There is no doubt that the early claims for semi-steel were based upon the expectation that the final mixture would have a low total-carbon content proportional to the amount of steel added. That these expectations have not been justified has been amply demonstrated over and over again in practice, and the general experience is that in ordinary cupola practice the total carbon content suffers very little and more frequently no change due to the added steel. In this respect the added steel has proved itself not to act as a diluent. Of the many examples that can be quoted, the results of Wheeler (Manchester Association of Engineers, 1921) will serve to illustrate this point. Of the two mixtures, the one containing 50 per cent. steel has actually a higher total-carbon content than the 25 per cent. steel mixture.

This question of the behaviour of the total carbon contents when remelting mixtures of steel and cast iron in the cupola is of the utmost importance in connection with the modern trend of ideas in improving the quality of cast iron.

When mild steel is charged by itself into the cupola without the admixture of cast iron (*i.e.*, 100 per cent. steel) the steel melts and liquid metal is withdrawn from the tap hole of the cupola. The mild steel may have a carbon content of approximately 0.20 per cent. and the liquid metal will be found to have a total carbon content very much in excess of this original amount. There are quite a number of published results available of this experiment. Dr. Stead obtained a total carbon content of 3 per cent., and other results are available showing an increase in the total carbon contents varying from 1.5 to 3.0 per cent.

This absorption of carbon, of course, takes place as a result of the intimate contact of the steel with the carbonaceous fuel and gases in the cupola, and the results obtained by various investigators indicate the comparatively wide limits of variation in the extent of this absorption. The conditions which influence the extent of this absorption can be summarised under the following headings:—(1) The temperature attained in the cupola; (2) the rapidity of melting and the length of time of contact of the steel and carbonaceous fuel and gases; (3) the length of time the molten metal lies in contact with the coke; (4) the surface area per unit weight of steel exposed to the carburising and melting influences; (5) the character of the coke and amount charged, and (6) the blast pressure and quantity.

The influence of any one of the above conditions is not necessarily separate and distinct, and they are for the most part mutually interdependent. For example, the character of the coke (5) and the size of the material used (4), in addition to any direct influence they might have on the extent of the absorption of carbon, exert an influence on the rapidity of melting (2) and the temperature attained in the cupola (1). In this manner they exert an additional influence on the extent of the carbon absorption. It will be evident that consistent results can only be obtained in any individual case by the careful standardisation of all these conditions

As a matter of interest some results obtained by the writer on various occasions are summarised in Table I.

From these results and similar results published by other workers it may be assumed that the general extent of the absorption of carbon by steel scrap when melted in the cupola is generally from 2.5 to 3.0 per cent. The low results are generally obtained when melting light scrap such as borings, and particularly when these are rapidly melted.

The next question of importance is whether the extent of the carbon absorption is the same or is greater or less when the steel scrap is melted in conjunction with pig-iron and scrap as a portion

TABLE I.

Melt No.	Tot. C.	Si.	Mn.	S.	P.	Coke Ratio.	Blast Press, in ins.	Melting Rate per hour.	Total Melt.	Percentage Loss.	Character of Scrap.
1	2.75	0.16	0.30	0.19	0.032	6.1	18–24	3 tons.	6 tons.	8.33	Crop ends, Sheet Steel Borings and plate punchings.
2	3.33	0.79*	0.24	0.13	0.023	7.1	20	25 cwt.	6 tons.	1.23	Spring Steel Crop ends.
3	2.25	—	—	—	—	7.1	14–18	—	16 tons.	8	Heavy and light Scrap.
4	1.61	—	—	—	—	7.1	,,	—	18 tons.	3	Plate cuttings and punchings.
5	2.25	—	—	—	—	7.1	,,	—	40 tons.	3.5	Steel turnings.

* Ferro Silicon added.

of the semi-steel mixture. There is, of course, no *a priori* reason why it should be any different, and very probably it is not. The same conditions as enumerated above will exert a similar influence, and will require to be standardised in any particular instance with the object of obtaining uniform results.

The following is an example of a comparatively recent experiment in melting a semi-steel mixture. This experiment was performed with considerable care in a standard Whiting cupola equipped with the standard depth of bed. The molten material was collected in the bed and tapped out in quantities of approximately 15 to 20 cwts. at one time. The details of the mixture and the analytical results are given below:—

A total of 4 tons was melted, the first ton of which was not used in the experiment. The charge consisted of 10 cwts. of boiler plate punchings and 12 cwts. of pig-iron of the following composition:—C.C., 0.30; Gr., 2.84; Si, 3.14; Mn, 0.80; S, 0.104, and P, 1.02 per cent.

The charges containing just over 45 per cent. steel were melted and the molten metal collected in the bed of the cupola. The analysis of three separate taps of approximately a ton each time are given in Table II:—

TABLE II.

Sample No.	2	3	4
C.C. ..	0.77	0.80	0.82
Gr. ..	2.31	2.19	2.13
T.C. ..	3.08	2.99	2.95
Si ..	1.52	1.46	1.48
Mn ..	0.57	0.54	0.54
S ..	0.172	0.184	0.14
P ..	0.72	0.64	0.68

The most effective reduction in the total carbon is in sample No. 4, in which the metal was continually running from the open tap hole and not allowed to lie in the bed of the cupola.

The amount of carbon picked up by the steel is calculated as follows:—No. 2, 3.03; No. 3, 2.81, and No. 4, 2.72 per cent.

These experiments were carefully carried out with normal cupola practice, and it is of special importance to notice that the calculated silicon content allowing a normal loss of 10 per cent. should be approximately 1.75 per cent. The actual mean silicon content obtained is 1.50 per cent., bringing the actual loss up to 20 per cent.

With even 45 per cent. steel in this mixture under ordinary conditions of melting the reduction in total carbon content is not very great, and the amount of carbon absorbed by the steel under these conditions of melting along with the pig-iron and scrap is approximately the same as when melted above. A more effective reduction in total carbon content is obtained when the molten charges are prevented from remaining in prolonged contact with the bed coke.

As a result of various investigations the view is now held that the absorption of the carbon by the steel occurs during its passage through the melting zone and during the period in which the molten drops are passing over the incandescent coke and are collected in intimate contact with this coke in the bed of the cupola. This view is undoubtedly well-founded, and is confirmed by analysis of samples of molten metal collected through the tuyeres. For this reason it is desirable to reduce the depth of the bed coke and to allow the metal to run direct into a receiver or forehearth. In this manner the molten metal is removed from prolonged contact with the incandescent bed coke and low total-carbon content material can be obtained with a greater degree of certainty.

Industrial Semi-Steel.

From personal experience of the industrial product semi-steel produced from various foundries in different parts of the country, it is found that they can be divided broadly into two classes, according to whether the total-carbon content has been reduced or not. The latter type in which the carbon content practically remains unaffected is by far the most common, and until the last year or two the low total-carbon variety of semi-steel was rarely if ever encountered amongst the industrial examples of the product.

The question of interest to engineers and foundrymen is the extent of the influence of the added steel on the properties of the resulting mixture. If attention is confined to the variety of semi-steel in which the total-carbon content is practically unaffected by the steel added, the reduction in silicon and phosphorus contents would be expected to be accompanied by an increase in the strength properties. The most satisfactory figures published during recent years are the investigations of Wheeler. As a result of his investigations, Wheeler came to the conclusion that the quantitative effect of steel added in quantities of from 10 to 30 per cent. to a soft cast iron was an increase of 1 ton per sq. in. tensile strength for each 5 per cent. of steel added.

Whilst this improvement results from the addition of steel, it must not be lost sight of that the improvement is essentially due to the cumulative effect of the reduction in silicon and phosphorus contents. Any other method of bringing about a similar reduction in composition will be accompanied by a similar result. For example, the use of low-silicon hematite white iron in place of steel and in proportionate quantities is accompanied by similar results which confirms the fact that the improvements are not the intrinsic result of the added steel.

The question of distinguishing between the intrinsic influence of steel and the influence due to the modification in the composition induced by the added steel is one which constantly arises in these considerations. It arises again in connection with the size and distribution of the graphite. It is the general experience that the graphite structure in semi-steel mixtures is of a fine nature, and it is often stated that the addition of steel results in a finer graphite structure, but *finer than what?* This question is never answered. Is the graphite structure of a semi-steel finer than that of the identical composition produced by some method other than the addition of steel and cast under identical conditions of casting temperature and rate of cooling? The demonstration of this has never been carried out, and is, of course, a demonstration of exceptional difficulty.

For many reasons, however, the author is of the opinion that there would be no practical difference found in the graphite-size arrangement and distribution, if such a comparison could be effected. The fine graphite arrangement referred to in connection with semi-steels is undoubtedly a comparison with material of a different composition, and is due to the influence of the steel in the reduction of the silicon and phosphorus contents, not to any intrinsic influence of the added steel. Finally, it should always be remembered that the size and arrangement of the graphite structure is greatly influenced by the casting temperature and rate of cooling to which the metal is subjected. Even in semi-steels, poor graphite structures can be obtained under bad conditions of casting temperature and rate of cooling.

Low Total-Carbon Semi-Steels.

The first of the two divisions of industrial semi-steels is not nearly so often encountered in practice. When they are obtained it is generally agreed that they are accompanied by improved mechanical properties. Tensile strength of upwards of 20 tons per sq. in., even 26 tons per sq. in., have been recorded on low total-carbon content irons.

The conditions under which really low total-carbon content semi-steels can be produced with systematic regularity are by no means clearly understood yet. It is wrong that individual foundrymen should deceive themselves that this is the case. That such low total-carbon content irons can be produced from the cupola has been demonstrated on many occasions, but one constantly encounters many examples in which the very low carbon contents fail to materialise in spite of many precautions, some of which have already been enumerated.

In examining the possible causes of the variations in carbon content experienced, the author's attention has been directed to the possible influence of different varieties of coke on the results. The variations in the character of coke are now tending to be more clearly understood, and this aspect of the subject still awaits careful investigation in connection with the production of low total-carbon content irons.

The "Emmel" process consists essentially of the production of semi-steel. From his British Patent

No. 244,405, one gathers that Emmel uses large quantities of steel from 50 per cent. of the charge upwards. It is stated that the low total-carbon contents are to be secured principally by regulating the amount of the blast or blast pressure. Blast pressures of 16 in. of water are quoted in the examples, and it must be confessed that these do not strike one as being very greatly different from those used in ordinary practice. Details of the quantity of air used are not given, and the coke charges given are 12 per cent. of the iron charged.

In view of other experiments, it is very doubtful whether these details constitute the whole story of the reduction in carbon contents obtained, and it might possibly be that the variety and character of the coke play an important part.

Semi-Steel Practice.

The American criticism referred to in the earlier part of these notes casts doubt on the ability of all but few foundrymen to make 25 to 30 per cent. semi-steel unless they have been instructed by an expert. It is of some interest to discuss the possible difficulties.

The difficulties which confront those who are desirous of producing semi-steel of very low total-carbon content have already been fully considered, and these difficulties are admittedly of such a nature as not to have been yet completely solved by experts.

What other difficulties are likely to be encountered? The answer is that there are few that are not fairly well understood by the majority of foundrymen. The general conversation of foundrymen when discussing this aspect of semi-steel manufacture generally centres round (*a*) the character of the steel additions; (*b*) the uniformity of composition of the final melt, and (*c*) the soundness and regularity of the final castings.

The Character of the Steel Additions.

Quite a wide variety of opinions have been expressed on the character of the steel scrap additions. Amongst these varieties of steel which have been strictly forbidden by various writers are:—(1) Borings, turnings and sheet cuttings; (2) punchings, and (3) high-carbon steels.

Speaking personally, the author sees no substantial reason why these varieties of steel scrap should be forbidden, with the exception of finely divided borings as distinct from turnings. Turnings are, of course, awkward in handling owing to the large bulk for a given weight, and are certainly to be preferred in a bundled or baled condition. He has used turnings consistently, and some of the results quoted above are obtained with their use.

Uniformity of Composition.

There is no doubt that in melting two materials so dissimilar in chemical composition it is difficult to ensure regularity and consistency in the chemical composition. This difficulty was met in the earlier days by remelting the steel and iron mixture. This practice is not nearly so common, and undoubtedly the best way of ensuring regularity is either the use of a forehearth or mixer or to make arrangements for each individual charge to be tapped into one ladle.

Soundness and Regularity of the Final Castings.

The reduction in silicon contents resulting from the addition of steel results in an increase in the shrinkage value and the reduction in phosphorous contents is accompanied by a loss in fluidity which both have the tendency to increase the risk due to unsoundness. Provision requires to be made for this in the size and disposition of the heads, gates and runners, and also in the provision of sufficiently hot metal.

The presence of irregularities in the castings in the shape of hard spots has often been commented upon, and this is still regarded by many foundrymen as being due to the presence of particles of unmelted steel which have been carried along into the casting. This view, however, can be definitely ruled out as fallacious. One has only to consider for a moment how rapidly a steel stirring rod or skimmer melts and absorbs carbon when immersed in liquid cast iron to realise how unlikely it is that small particles of steel can survive as such in liquid iron, after flowing down the cupola spout, agitation in the ladle, agitation during pouring and flowing down the various " gates " into the casting. If such particles had any reasonable size they would hardly pass the cupola tap hole and through many of the gates used on various castings. The author has certainly never seen a hard spot in semi-steel castings which could be ascribed to this cause. Ordinary castings, particularly low silicon irons, are equally as much liable to the presence of hard spots as are semi-steel.

These points have been dealt with very briefly, as they have been ably covered by various writers recently, particularly by Mr. H. Field. None of these points presents any more serious difficulties than are normally met with in everyday cupola practice, and it is not thought that the average foundryman utilising his normal cupola experience needs the guidance of experts in making 25 to 30 per cent. semi-steel.

In concluding these notes it is thought essential to emphasise the fact that semi-steel is a cast iron possessing all the distinguishing properties of cast iron. Whatever better properties than common foundry irons it possesses are due to the effect of the steel in modifying the final composition of the melt. As in the case of general cast iron practice, semi-steel can be made of varying silicon, manganese and phosphorous contents, and the resulting properties will vary in accordance with the composition in an exactly similar manner to general castings. It is still necessary to add, for the benefit of many engineers who use castings, that none of the essential properties of steel, viz., malleability and ductility, is possessed by semi-steel intrinsically as a result of the steel additions. For the benefit of the average foundryman it may be permitted to repeat that semi-steel offers a delightfully simple and cheap method of obtaining a low-silicon, low-phosphorous iron—a good iron.

DISCUSSION.

Mr. Hird thought many engineers believed that semi-steel was something quite unique, and agreed with the lecturer that hard spots did not come from the steel additions. A few months ago he cast some test bars, which, when broken, showed a peculiar fracture. Running through the test-bar was a hard patch of white iron surrounded by grey. This was submitted to Mr. Pearce, of the

B.C.I.R.A., who reported the patches were entirely due to sulphur. The test-bar was 2 in. × 1 in., 3 ft. long and cast on the flat, and when remelted there were no hard spots. The casting was made of pig-iron and scrap mixture.

Mr. McClelland, after ascertaining that the coke charge shown in Table I was exclusive of bed charge, asked what was the additional cost of the 100 per cent. mixtures, because much depended upon results, and one could not expect to get a better material at a reduced cost.

Mr. Hurst pointed out these mixtures were not suitable for ironfounders. The tables had been utilised to show the amount of carbon absorption. White iron had been used in all except No. 2, when silicon had been added.

Mr. Williams asked how the lecturer would account for the big percentage of waste in lots one and three.

Mr. Hurst said that he could not now say the character of the scrap used for these experiments, which were made in 1912. Very often 75 per cent. turnings and 25 per cent. something else were used. When dealing with turnings, as in the 40-ton melt, they were all quite clean, but he rather suspected the character of the turnings used in the other experiments.

Mr. McClelland said that it seemed strange in using steel turnings, which are lighter and more bulky than rolled steel sections, that the loss should be so much less, 3.5 as against 8 per cent.

Mr. Hurst pointed out there were turnings in both, and it was possible that the turnings in one portion were bad, dirty and rusty. Replying to Mr. Colin Rees, he repeated that if one used pig-iron and got a certain analysis and then incorporated steel and produced the same analysis, and providing same are cast under identical conditions, then one would get the same properties. There is the question of dry and green sand moulding, etc., and a hundred and one details to be controlled to ensure the same results. This is an impossibility in practice.

Mr. Hird said that meant to say that cooling down and thickening of the casting played almost as big a part as the chemical analysis.

Mr. Hurst said that a metal poured hot would have a tensile strength of 14 tons, whilst one poured cold would only have a tensile strength of 9 tons. A 20 per cent. steel mixture would have 4 tons extra tensile strength. If the casting temperature is increased without any addition of steel, better results are obtained.

Mr. Hird suggested that if one wanted to get the best results and could obtain really good iron and had the facilities to obtain the best brands of pig, it would be preferable to adding steel, if the same results were obtained.

Mr. Hurst replied that he objected to paying the price for cold blast irons. Mr. Hird had suggested that cold blast iron had properties which were not to be found in other irons, but he (the lecturer) did not agree. The cold blast irons maintained their reputation in the roll industry, but it had yet to be demonstrated that cold blast irons had better properties. Emmel in his specification gives a 100 per cent. steel and claims 26 tons tensile strength per sq. in. Again, Keller, when making shells for the French Government by melting steel scrap and re-carburising in the furnace, obtained a tensile strength of over 30 tons per sq. in. France used to be large buyers of cold-blast irons, but since the coal strike synthetic irons can be bought at a price and roll makers are educated up to the fact that it is not essential to use cold-blast irons. It is practically a matter of roll makers having a chance of demonstrating some alternative.

Mr. Hird insisted that if one cast two test-bars from exactly the same iron, one would stand more than the other.

Mr. Hurst replied that this was not due to sulphur, but to the cooling conditions. An explanation of this would be found in THE FOUNDRY TRADE JOURNAL some time ago. White iron has no graphite, grey iron has graphite. Graphite forms at a certain temperature. Assuming the metal is solid at 1,150 deg. C., graphite forms at 1,145 deg. C. Graphite can be prevented from forming by virtue of the correct cooling. If metal is cooled sufficiently quickly, graphite does not form. The rate of cooling above 1,145 deg. C. can be anything, but it does not form graphite.

Mr. McClelland proposed and **Mr. Williams** seconded a hearty vote of thanks to the lecturer.

Sheffield Branch.

THE INFLUENCE OF SULPHUR IN CAST IRON.

By J. E. Hurst (Member).

The influence of the various constituents present in cast iron is always a matter of considerable interest to both foundrymen and engineers. As the makers and users of castings respectively, the interest of both foundrymen and engineers is very often distinctly opposed, and for this reason alone it is very necessary that periodical attempts should be made to review the state of existing knowledge of the influence of these constituents.

At a time like the present, as a result of the coal strike the foundries are constrained to use low-grade, high-sulphur coke, and the last vestiges of pig-iron stocks which have been laid aside owing to their high sulphur-contents. Under these conditions, with the danger of high-sulphur contents in the final castings, the influence of the constituent sulphur assumes a *rôle* of additional importance.

Some years ago the influence of sulphur was regarded as fatal to the production of good castings, and was almost the universal explanation for the defects which are prone to appear in castings. In a text-book on ironfounding published in 1912 the influence of sulphur is summarised as follows: "With an insufficiency of manganese to satisfy the whole of the sulphur, the excess of the latter combines with the iron, so that both manganese and iron sulphides may be present. Of the sulphides, iron sulphide is the more objectionable, as it is readily fusible, and decomposes at high temperatures, gaseous sulphur compounds being given off which, as they escape, give rise to blowholes, and therefore cause spongy, unsound, and weak metal. Further, being readily fusible, it is probably the last constituent to solidify, and as a result it tends to be unevenly distributed and segregates in the middle and upper parts of the casting. Manganese sulphide is not so readily fusible, and the temperature of decomposition is higher." This statement, as a whole, represents the belief of many foundrymen and engineers at the present date, and lest there should be any mistake, we may state at once, without any equivocation, that as a whole it is grossly wrong.

In 1908 Rhead, whilst calling attention to the fact that sulphur is only too often made responsible by the foundryman for all the faults of the metal and the defects of castings, stated that the general effects observed are that the iron is made harder, more rigid, and perhaps brittle, is liable to cast more unsoundly, is more sluggish, contracts more, and is liable to produce drawn and distorted castings (especially in green-sand moulds). To this general statement, in its broad sense, very little exception can be taken, and the fact that Rhead deliberately caused the element sulphur to serve a useful purpose by using it to harden and stiffen otherwise soft metal, is an aspect of the influence of sulphur which will be more readily appreciated to-day. Incidentally, Rhead considered 0.2 per cent. sulphur to be the extreme limit of sulphur which should be present in foundry iron, whilst for good results the amount should not exceed 0.10 per cent.

Very broadly speaking, the more modern views consider that in the presence of sufficient manganese the harmful effects of sulphur are completely neutralised. Modern views, however, do not go so far as to express an opinion as to the maximum limit, if any, of the sulphur-content which can be neutralised in this manner. It is important to refer to the publicity which has been given to various methods of desulphurising cast iron, mostly of Continental origin; to the so-called duplex processes, in which cupola-melted cast iron is refined in subsidiary furnaces. The recent publicity given to such processes would tend to indicate that there exists a school of opinion which, at any rate, is uncertain as to whether the harmful effects of sulphur can be completely neutralised. Putting this on one side for the moment, the theoretical reasoning on which the modern view is based are certain facts regarding the manner in which sulphur exists in conjunction with certain other constituents in cast iron.

It is generally considered that the sulphur may exist in cast iron in the form of two separate constituents, which are the chemical compounds sulphides of iron and manganese respectively. The existence of these two compounds having the respective formulæ FeS and MnS is apparently well founded, although the study of these compounds and their respective solubilities in iron has been very much restricted and rendered uncertain owing to the fact that these systems are very much influenced by the presence of oxides and silicates which are difficult to eliminate in preparing the alloys. Other possible compounds of sulphur with silicon and carbon: sulpho-silicide and sulpho-carbide of iron have been suggested on evidence of a very flimsy nature. The possibility of the existence of such compounds is considered to be very remote.

Manganese Sulphide.

Of the two sulphides above mentioned, if one is of more importance than the other in their connection with cast iron, it is probably the sulphide of manganese. This sulphide has an extremely high melting point of 1,620 deg. C., which is 115 deg. C. above the melting point of pure iron, and approximately 470 deg. C. above the melting point of cast iron of eutectic composition. It has a very low specific gravity of 3.99, which is about half that of ordinary cast iron, and is generally assumed to be insoluble in liquid cast iron within the temperature ranges usually met with in everyday practice.

The assumption of the insolubility of manganese sulphide is supported largely by the manner in which this compound segregates in masses of solidifying metal. The example given by the author in a recent contribution* is illustrative of this tendency. This is a sulphur print taken from the cross-section of a 4½-in. diameter cast iron bar approximately 17 in. long. This bar was cast in a hot metal mould, and the

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* FOUNDRY TRADE JOURNAL, vol. 34, page 325, fig. 3.

marked segregation of the sulphide constituent to the top of the ingot gives some evidence of both the insolubility and the lower specific gravity of this constituent.

Some doubt has been cast on the insolubility of this sulphide constituent, and the fact that it is pure manganese sulphide (MnS). Dr. Stead,* from his examination of blowhole segregates in steel, considers that at high temperatures the sulphur is combined with the iron as FeS, and that at lower temperatures MnS is formed in accordance with the equation

$$FeS + Mn = Fe + MnS.$$

The observation which prompted these considerations is the fact that whilst the segregation of the sulphur was quite marked, that of manganese was negligible. At a later date, in his discussion on Arnold and Bolsover's paper,† Stead suggests that the MnS does not solidify pure but as the double compound $Mn_2Fe_3S_5$ (3FeS.2MnS), and that as the mass slowly cools this becomes unstable, and the manganese in the surrounding steel replaces the iron in combination with the sulphur. This double compound is identical with that discovered by Rohl, and which is more properly to be regarded as the saturated solid solution of FeS and MnS.

Further support to this view is forthcoming from the Report on the "Heterogeneity of Steel Ingots," presented to the Iron and Steel Institute this year. In their examinations of various steel ingots the committee who presented this report encountered the same observation that the segregation of the sulphur was not invariably accompanied by the manganese. The committee realised the importance of this, but refrained from advancing any explanation or reason to account for these observations. They definitely stated that the question of the formation and solubility of MnS is one of the matters which must be cleared up by direct experiment.

It is not within the province of this Paper to discuss this question further in relation to steel. Some experiments in connection with cast iron are

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* Cleveland Institute of Engineers, 1912, page 33.

† Journal, Iron and Steel Institute, No. 1, 1914, page 396.

of interest. When large masses of liquid cast iron are rapidly rotated or "centrifuged," as is done in the commercial centrifugal casting processes, a marked segregation of the sulphur constituent takes place; the constituent invariably moving towards the axis of rotation. The movement of the sulphide constituent in this manner under the influence of the centrifugal action is clear evidence, on a practical scale, of the insolubility and lower specific gravity of the constituent under the temperature conditions of the liquid iron in these experiments.

The segregation of the sulphide constituent is more effective in the case of large masses of molten metal which are so disposed as to maintain themselves liquid for a longer period during the centrifugal operation, thus presenting a more favourable opportunity for the sulphur to segregate.

The analyses taken from the segregated portion and the main body of a centrifugal casting are as follows:—

	Segregated Centre Portion. Per cent.	Main Body of Casting. Per cent.
Mn ...	0.60	0.33
S ...	0.23	0.06

There is here distinct evidence of the movement of manganese along with the sulphur. The manganese remaining in the body of the casting is considerably in excess of the requirements of 0.06 per cent. S to form the compound MnS. If we deduct from this percentage 0.33 per cent. the quota of manganese corresponding to the 0.06 per cent. sulphur present, the amount remaining, viz., 0.2262 per cent., can be regarded as the amount of manganese not in combination with the sulphur. If it is assumed that this portion of the manganese has not been influenced by segregation effects and is evenly distributed throughout the whole casting, one would expect the amount of manganese remaining, after deducting this amount from the total present in the segregated portion, would correspond to the quota required with the sulphur present in this portion to form the compound MnS. The results are set out in Table I.

TABLE I.—*Distribution of Sulphur in Cast Iron.*

Item.		S. per cent.
1	Sulphur in body of casting	0.06
2	Quota of Mn corresponding to MnS with (Item 1)	0.1038
3	Manganese in body of casting	0.33
4	Manganese in casting not combined with sulphur (Item 3 minus Item 2)	0.2262
5	Manganese in segregated portion ..	0.60
6	Manganese in segregated portion combined with sulphur (Item 5 minus Item 4)	0.3738
7	Sulphur in segregated portion	0.23
8	Theoretical quota of Mn required to form MnS with (Item 6)	0.3979

The value (Item 6) 0.3738 per cent. is sufficiently near the theoretical requirements of the compound MnS, viz., 0.3979 per cent., as could be expected under the conditions of this experiment. In the light of this evidence it may be concluded that in cast iron of the composition used in the experiments, and in the presence of sufficient manganese the sulphur exists largely as the simple manganese sulphide (MnS), and that this compound is insoluble in liquid cast iron at the temperatures met with under ordinary foundry conditions. In addition this evidence is strong confirmation of the lower specific gravity of this constituent.

It is of interest to suggest that the application of this centrifugal method might be applied to the investigation of the condition of sulphur in steel. The American Bureau of Standards have published an investigation on a sample of centrifugally cast steel, and reported a slight segregation of the sulphur towards the inner surface. In an investigation of this nature specially undertaken with the object of determining the condition of the sulphur much larger masses of metal would be used than those dealt with in this investigation.

The modern view that in the presence of sufficient manganese the harmful effects of sulphur are neutralised is based on the above facts. It is considered that by virtue of the insolubility of the manganese sulphide compound, the sulphur in this form is removed from participation in the graphite forming actions which have so much influence on the properties of cast iron.

In all the samples previously illustrated no hard white spots accompanied the segregation of the sulphide. No marked difference was commented upon in the hardness or machinability of the various specimens at the points where the segregations were prominent. This fact indicates at least that MnS has no serious influence in preventing the formation of graphite.

An interesting case of segregation came before the writer's notice some time ago. The analysis of certain segregated lumps which were found on the inside surface of a centrifugal casting was as follows: CC, 0.31; Gr, 4.72; T.C., 5.03; Si, 4.46; Mn, 1.22; S, 0.69; and P, 1.20 per cent.

The important feature illustrated by this specimen is that, in spite of the abnormally high sulphur-content, the combined carbon has not been maintained at any excessive value. There is sufficient manganese present to convert the whole of the sulphur to MnS. (Admittedly the silicon has attained a high value, but this should be taken in conjunction with the fact that the samples were not more than $\frac{1}{4}$ in. thick and were cast in metal moulds.)

The experiments of the late Dr. Stead may be used to illustrate the neutralising effect of the deliberate conversion of sulphur present in cast iron to MnS. The addition of 1 per cent. manganese to a white iron containing practically 3.0 per cent. combined carbon and 0.28 per cent. sulphur converted this into a grey iron containing 0.6 per cent. combined carbon. These further examples serve to confirm the modern view that the insoluble MnS is without influence on the condition of the carbon in cast iron, which in its turn supports the view that its influence on the ultimate quality of the metal is not likely to be harmful.

Amount of Manganese Necessary to Neutralise Sulphur.

A question which is often asked and which is of considerable practical importance is—What amount of manganese is necessary to neutralise the sulphur? Theoretically, 1.73 parts of manganese are required to form the manganese sulphide with 1 part of sulphur. It is often also asked if this theoretical ratio is sufficient to ensure the whole of the sulphur in commercial cast iron being completely converted to MnS. It is the general opinion that considerably more than this theoretical amount of manganese is necessary. In connection with steel, eight times the amount of sulphur present has been suggested. Levy has stated that the excess of manganese required is likely to be greater in low-carbon alloys than in high-carbon alloys (cast iron).

The necessity for such an excess of manganese has been explained on the grounds that a portion of the manganese is invariably occupied by some other constituent, and that a portion only of the manganese goes to satisfy the sulphur. This explanation is due to Dr. McCance, and appears to the author to be the most rational from the point of view of our present knowledge. The partition of the manganese between the sulphur and whatever other constituent (possibly the carbon) with which it is connected is a subject on which we have no quantitative information. It is reasonable to assume that this partition will be profoundly influenced by the amount of carbon and silicon present, in addition to the actual amounts of manganese and sulphur themselves.

Some extremely valuable information on this point has been recently disclosed by Mr. John Shaw in his recent Paper before the Detroit Convention of the A.F.A. Mr. Shaw has disclosed what might be termed a critical ratio of manganese and sulphur above or below which the condition of the carbon is profoundly influenced. This critical ratio in Mr. Shaw's examples is about 3 of manganese to 1 of sulphur. All the examples are taken from roll metal having total carbon contents of approximately 3.0 per cent. and silicon round about 0.75 per cent. I think Mr. Shaw's findings may be summarised briefly as follows: (1) When the ratio of manganese to sulphur is less than 3:1 the combined carbon is maintained at a higher value than when the ratio is greater; and (2) in a like manner the depth of chill in large masses cooling under similar conditions is maintained to a greater extent than when this ratio is greater than 3:1.

It is necessary to point out that these ratios may not be exactly maintained in irons of different compositions from Mr. Shaw's examples, and these results might conceivably be interpreted as evidence of the necessity for an excess of manganese over and above the theoretical amount to ensure the sulphur being converted to manganese sulphide. There is, of course, an alternative interpretation which has already been put forward by Mr. Shaw, and it is obvious that further experiment is necessary to determine the exact mechanism of the phenomenon.

Whatever the exact mechanism may be, this is distinct evidence that an excess of manganese is required to neutralise the effect of sulphur, and in low-silicon, low total carbon irons this excess is in the ratio of 3:1 as compared with the theoretical ratio of 1.73:1. On *a priori* grounds it is probable that this excess would be less in irons of higher silicon and total carbon contents.

Iron Sulphide.

In the absence of manganese it is generally accepted that the sulphur exists in the iron as the sulphide of iron, FeS. It is in this form that the sulphur is alleged to exert its influence in retaining the carbon in the combined form and thus preventing graphitisation.

The compound FeS has a melting point of 1,180 deg. C. and a specific gravity of 5.02. It has a limited solubility in pure iron, and forms a eutectic with this solid solution, having a melting point of approximately 980 deg. C. The effect of the presence of carbon and silicon on the solubility of iron sulphide has not been thoroughly investigated. The existence of a ternary eutectic has been confirmed, but whether this exists in the presence of silicon is uncertain.

In the light of all our existing knowledge we are justified in making the hypothesis that FeS is soluble in liquid cast iron, and to a limited extent in the solid cast iron. How the dissolved sulphide is distributed, whether in the austenite or cementite, we are unable definitely to say.

The influence of sulphur in the condition FeS in preventing the formation of graphite has been well established by various workers, including Stead, Levy, Hatfield and others. The demonstration of this influence in low-silicon alloys for malleable castings has formed the basis of the most conclusive proofs of this influence of sulphur. The recent additional evidence furnished by Kikuta will be interesting to quote here in demonstration. It will be noted that when the sulphur is in excess of that required to form MnS the graphitisation becomes increasingly difficult, and the so-called second-stage graphitisation was incomplete under the conditions of the experiment.

The influence of iron sulphide on the graphitisation of grey irons has been extensively investigated by Piwowarsky. All his samples contained 0.26 per cent. manganese, which requires 0.15 per cent. sulphur fully to convert this to MnS. It may be assumed for the purposes of comparison that the sulphur contents up to this percentage are all in the condition MnS, and above this value increments of sulphur represent increments of FeS. The A curves represent conditions of slow cooling and the B curves represent conditions of quick cooling, and the curves are plotted for various silicon and total carbon contents.

The most astounding result to many foundrymen disclosed by these curves is that, with quite normal silicon and total carbon contents with slow rates of cooling, the sulphur can exist—as iron sulphide—up to a sulphur percentage of 0.6 to 0.75 without any serious diminution in the extent of the graphitisation. The influence of speeding up the rate of cooling, variation in the total carbon and silicon contents, are also demonstrated. The marked effect of the influence of quicker rates of cooling demonstrates the influence of sulphur in the iron-sulphide constituent in increasing the liability to chill.

One of the most important demonstrations of these curves is the fallacy of attempting to describe the influence of sulphur without reference to the remainder of the chemical composition and the cooling conditions. This is a fault common to many descriptions of the influence of constituents on cast iron, particularly those "potted varieties" served up to engineers. In no case is this fallacy more clearly demonstrated than in this one under review. Almost universally sulphur has been condemned as having a detrimental influence, yet when considered in reference to other features it may have a useful and beneficial influence, and, in fact, does enable results to be obtained which would be impracticable in any other way.

Interpretation of Modern Theory.

In the absence of manganese there is a general tendency for the presence of increasing quantities of sulphur to prevent graphitisation, and, as a result, to increase the hardness, liability to chill, and total shrinkage of the castings. This general tendency is resisted by the silicon content and also by the rate of cooling. Where the silicon content is high or the rate of cooling slow, quite large percentages of sulphur may be present without any serious effect on the extent of the graphitisation. As the silicon content is lowered or the rate of cooling quickened, the tendency of the sulphur, in the absence of manganese, to increase the hardness becomes more and more predominant. In all commercial cast iron some manganese is present, and, in accordance with the amount present, some of the sulphur must be rendered innocuous as a result of the formation of manganese sulphide. This fact further reduces the risk of any serious trouble arising out of the sulphur content.

The Influence of Sulphur on the Mechanical Properties.

From a practical point of view, probably the best method of demonstrating the influence of sulphur lies in the examination of its influence on the mechanical properties of cast iron. Obviously it is not of much use answering the engineer's or foundryman's query, as to what is the influence of sulphur, by telling him that under certain conditions sulphur prevents graphitisation, and under other conditions it has exactly the opposite effect.

Many investigations have been made on the influence of sulphur on the mechanical properties, but, unfortunately, these investigations have not been made with the object of demonstrating the influence of this constituent on the lines of the modern conception already outlined. The results of Schmauser (Fig. I) were obtained on a cast iron of the following composition:—Tot. C, 3.0; Si, 2.2; Mn, 0.5; and P, 0.7 per cent. A rapid fall in the strength properties accompanied by an increase in hardness is disclosed by these investigations. To contrast with these investigations, there are the results of Hamasumi,

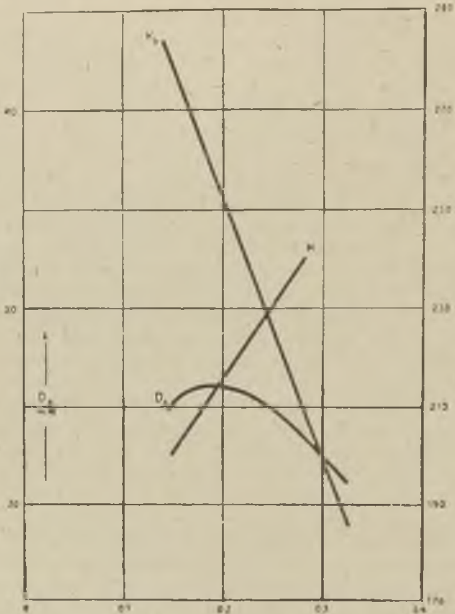

Fig. 1.—Schmauser's Results.

where the influence of sulphur shows a general tendency to increase the hardness and also the strength properties. These are typical examples of the contradictory nature of the various investigations which have been published. Any consideration of such results is at once rendered futile by the lack of the necessary information as to size of test pieces and cooling conditions, and, most important of all, the condition in which the sulphur exists.

A series of results have been obtained on white-heart malleablised cast iron, from which it is accompanied by a decrease in strength properties and difficulty of machining if its effect is exerted on an initially close-grained cast iron. In other words, the influence of sulphur in the condition of FeS is dependent upon the rest of the composition, particularly the silicon content and the rate of cooling. It is possible to imagine that under conditions of silicon content and rate of cooling such as those outlined in the high-silicon members Group A of Piwowarsky's experiments, that the influence of sulphur up to percentages much larger than commonly met with would be negligible, even in the FeS condition.

The general uncertainty of the actual test results published would appear to confirm this general view, and to quote Piwowarsky's own words: "any exaggerated demands calling for the removal of the last traces of sulphur in high-manganese cast iron are not sufficiently borne out by the practical and scientific investigations hitherto carried out."

In actual present-day practice, the manganese content of cast iron is usually sufficiently high to take care of all the sulphur normally present. A percentage of manganese of 1.0 per cent. in a common iron containing 2.5 per cent. silicon will probably take care of sulphur up to 0.5 per cent.—a value which is rarely met with except under very abnormal conditions.

Limit of Safety in Content.

From the point of view of general foundry practice it is, of course, difficult to place a really definite maximum limit to the sulphur-content above which the results are likely to be disastrous. Such a limit cannot be defined strictly without reference to the other conditions of composition and cooling conditions. From the considerations above, it appears to be certain that in an iron containing 2.75 per cent. Si and 1 per cent. manganese, a composition which is commonly used in these days even the maximum limit of sulphur of 0.30 per cent. mentioned by Moldenke can be exceeded. There must be many foundrymen who have knowledge of this figure having been exceeded during the recent coal strike without being accompanied by disastrous results.

It will also be evident that by careful adjustment of the manganese and silicon to allow of the sulphur existing partially in the iron-sulphide condition, the sulphur may be utilised in the manner suggested by Rhead to maintain the hardness of the metal. We may quote a practical example mentioned by Mr. H. J. Young, in which he states that liners of very hard iron have been at sea for eight or nine years containing nearly 0.25 per cent. sulphur, a value considerably in excess of the limits imposed by many of the text-books.

From an examination of these and other published test results in the light of modern conception of the influence of sulphur, the necessity for the reinvestigation of the influence of this constituent in this respect becomes apparent. The author has no data whatever from which to determine the intrinsic influence of the sulphur in the condition of Mn, S, and FeS respectively. For this reason one's conception must of necessity be based on inference.

From an application of the inferential method we are justified in concluding that, providing the sulphur exists in the form of MnS, in which form it is without influence on the condition of the carbon, it is likewise without influence on the mechanical properties. When the sulphur exists as FeS, with its tendency to maintain the carbon in the combined condition, its influence on the mechanical properties will be exerted in the direction of increasing the hardness. This increase in hardness will be accompanied by an increase in strength properties if its effect is exerted on an initially soft and otherwise open-grained cast iron. The same influence will be obvious from the composition that the sulphur exists as the iron sulphide. The outstanding feature is that, apart from the elongation, no serious influence of the sulphur is felt until a percentage of between 0.4 to 0.5 per cent. is reached. Similar results are demonstrated by the Izod impact tests.

It is, of course, undesirable to utilise high-sulphur irons purely for the sake of using them, as in any event it is superfluous to increase the amount of the impurities in cast iron without any substantial reason. At the same time, it will be appreciated that many varieties of iron, both scrap iron and pig-iron, which in normal times are rejected as containing too much sulphur, might with care be used with no harmful results.

Conclusions.

To enable a conception of a concise nature to be obtained of the influence of sulphur might be briefly summarised as follows:—

(1) In the presence of sufficient manganese, at least in the ratio of 3:1 in lower-silicon iron, the sulphur is converted to MnS, in which form it is harmless up to quite appreciable amounts. (In higher-silicon irons the excess of manganese over the theoretical amount is probably much less than the above ratio.)

(2) Even in the absence of sufficient manganese, the presence of FeS in appreciable quantities will not have any serious effect in the presence of the higher silicon and total carbon contents, and particularly when the rate of cooling is comparatively slow.

(3) It is highly probable that in the presence of manganese the comparatively high safe limit of sulphur specified by Dr. Moldenke, viz., 0.30 per cent., can be exceeded with safety.

(4) Quoting Piwowarsky's own words as the final conclusion that "the exaggerated demands for the removal of the last traces of S in high Mn cast irons are not justified in the light of modern knowledge."

Finally, one of the main reasons for the choice of this subject is with an eye to the future. Modern tendency in the development of the metallurgical side of foundry practice is towards the use of low total carbon-content irons, and this tendency will be considerably hastened if low total carbon-content irons become available at a price comparable with ordinary foundry pig-iron.

As far as the author can see, the various methods available for the production of such low total carbon-content irons, either direct from the blast furnace or by other semi-synthetic methods, the pig-iron is likely to be accompanied by a sulphur-content higher than normal. This has often been raised as a serious objection, and for this additional reason it becomes necessary to point out that the findings of investigation, so far as it has progressed up to the present, is that the influence of sulphur is not likely to be accompanied by anything like the disastrous results which many text-books indicate.

Lancashire Branch.

THE HEAT TREATMENT AND GROWTH OF CAST IRON.

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

Numerous investigations have been carried out during the last twenty years on the influence of heat-treatment on the properties of grey cast iron. The subject is one of considerable industrial importance, as many engineering parts have to sustain conditions of considerable temperature for more or less prolonged periods of time. An admirable review of the work that has been done is given by Hurst in his book on the "Metallurgy of Cast Iron," so that it is not necessary to do more than refer to one or two of the more important conclusions arrived at.

Decomposition of carbide in grey cast iron takes place at temperatures below the pearlitic change point. The extent of the decomposition depends on the silicon content, being more pronounced the greater the quantity. It also depends on the temperature and the duration of the heat-treatment. Additional elements, such as manganese, tungsten, and chromium, retard very considerably the decomposition of the carbide. Microscopic examination of low-temperature heat-treated cast iron confirms the results obtained analytically with reference to decomposition of the carbide.

The tensile strength of grey cast iron at first falls off as the temperature increases, then increases to a maximum usually in the vicinity of 400 deg. C., after which it decreases rapidly as the temperature increases. Irons which have been subjected to a preliminary heat-treatment before testing show consistently lower values when tested at elevated temperatures than those obtained in the normal irons tested under similar conditions. The depression which is noted in the normal irons is absent in the heat-treated irons. The influence of varying proportions of manganese, tungsten, and chromium not only increase the initial tensile strength but also yield a higher strength value at temperatures up to 500 deg. C.

Volume changes or growth in grey cast irons take place after repeated heatings and coolings at temperatures below the pearlite point. The extent of these changes, which are no doubt largely due to carbide decomposition, are modified by the composition of the iron and the addition of special elements. Chromium in quantity produces actual shrinkage after repeated heatings and coolings.

These conclusions have been arrived at, as previously mentioned, as the result of various investigations to which the author has contributed. In the discussion on his Paper on "Low-Temperature Heat-Treatment of Special Cast Irons," read at the Glasgow Conference of the Institute in 1925, it was suggested that a series of heat-treatment tests should be carried out on cast iron cast by the Perlit process. It was also suggested in a Paper by J. E. Hurst that the experiments on carbide decomposition had been carried out at 450 deg. C. and 550 deg. C., and that the minimum temperature at which this decomposition takes place had not been determined. As those two points are of considerable industrial importance, it was decided to carry out further experiments along these lines.

TABLE I.—*Analysis and Strengths.*

Mark.	O.	P.	Pt. 1.	Pt. 2.
	Per cent.	Per cent.	Per cent.	Per cent.
Graphitic carbon ..	2.75	2.48	2.33	2.44
Combined carbon ..	0.45	0.68	0.87	0.91
Total carbon	3.20	3.16	3.20	3.35
Silicon	2.19	1.48	1.05	0.65
Sulphur	0.064	0.054	0.123	0.117
Phosphorus	1.01	0.704	0.34	0.17
Manganese	0.79	0.97	0.57	0.85
Tensile strength Tons per sq. in.	11.2	16.6	15.0	18.3
Transverse strength Lbs. per sq. in.	2,912	3,472	3,394	3,017

Materials Used.

The composition of the irons selected for these experiments, together with their tensile strengths, are given in Table I. "O" is an ordinary iron used for general engineering work. The tests were carried out on test bars which were cast on a casting. "P" is a cylinder iron of a composition which has given good results in service and was cast in dry-sand moulds in the form of test bars 14 in. by 1⅛ in. diameter. "Pt. 1" is an iron cast by the Perlit process in the form of test bars cast on a casting, while "Pt. 2" is also cast by the Perlit process, but the test bars in this case were cast separately in bars 14 in. by 1⅛ in. diameter.

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

Cast iron.	Duration of heating in hours.	Total carbon.	Combined carbon.	Tensile strength tons.	Brinell hardness.
P	0	3.16	0.68	16.6	223
	40	3.17	0.64	16.2	212
	80	3.17	0.48	15.7	197
	120	3.19	0.43	15.3	183
	160	3.13	0.38	15.4	183
	200	3.15	0.38	15.5	179
Pt. 2	0	3.35	0.91	18.3	217
	40	3.33	0.88	18.0	212
	80	3.33	0.84	17.7	207
	120	3.32	0.80	17.3	201
	160	3.32	0.80	17.3	197
	200	3.32	0.80	17.5	201

Heat Treatment Tests.

Heat-treatment tests were subdivided into two groups, one dealing with carbide decomposition, strength and hardness, and the other with carbide decomposition alone, and the minimum temperature required to produce it.

The first group of tests was carried out in two series. In the first series five bars of "P" and "Pt 2" were heated in separate electric resistance furnaces to a temperature of 450 deg. C. for 8 hours, cooled overnight, then reheated again to the same temperature the following day. After each 40 hours' heating a bar was removed from each furnace and its combined carbon content, tensile strength, and Brinell hardness determined. A similar procedure was adopted in the second series of tests, only the bars were heated to 550 deg. C. The results obtained are given in Tables II and III.

In the second group of tests, bars from each of the four irons were heat-treated in a similar manner at six temperatures, varying from 200 deg. C. to 550 deg. C. After each 40 hours' heating, a piece from each of the bars was removed and its composition as regards combined carbon determined. The results obtained are given in Table IV.

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

Cast iron.	Duration of heating in hours.	Total carbon.	Combined carbon.	Tensile strength tons.	Brinell hardness.
P	0	3.16	0.68	16.6	223
	40	3.13	0.12	15.8	138
	80	3.16	0.11	15.1	129
	120	3.15	0.09	14.8	129
	160	3.15	0.12	14.6	125
	200	3.14	0.12	14.8	129
Pt. 2	0	3.35	0.91	18.3	217
	40	3.33	0.77	18.0	201
	80	3.32	0.72	17.5	197
	120	3.31	0.70	17.0	192
	160	3.34	0.72	17.2	192
	200	3.34	0.72	17.0	192

Consideration of these tables shows that carbide decomposition takes place in all the irons but varies considerably, according to the temperature of treatment and iron tested. At 200 deg. C. the amount of decomposition after a period of 200 hours' treatment is in each case so slight as to be almost negligible. As the temperature, however, increases decomposition is more pronounced and varies for each iron. The amount of decomposition for the various temperatures is represented graphically for each iron in Figs. 1 and 2.

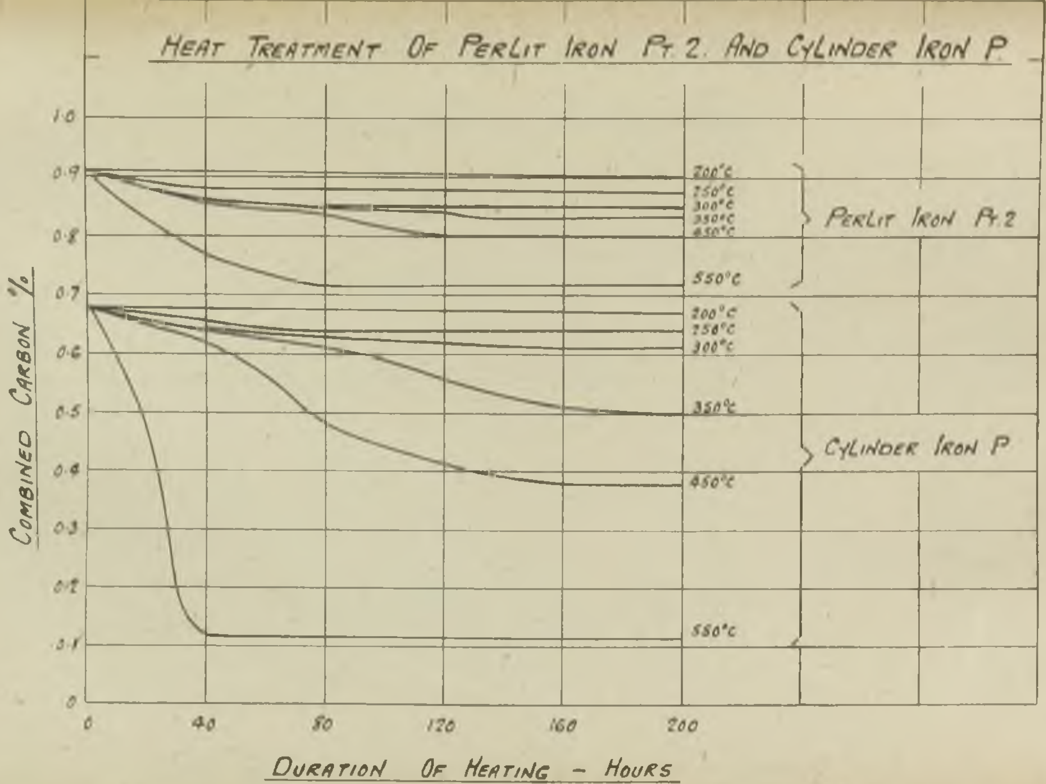

FIG. 1.—HEAT TREATMENT OF PERLIT IRON PT. 2 AND CYLINDER IRON P.

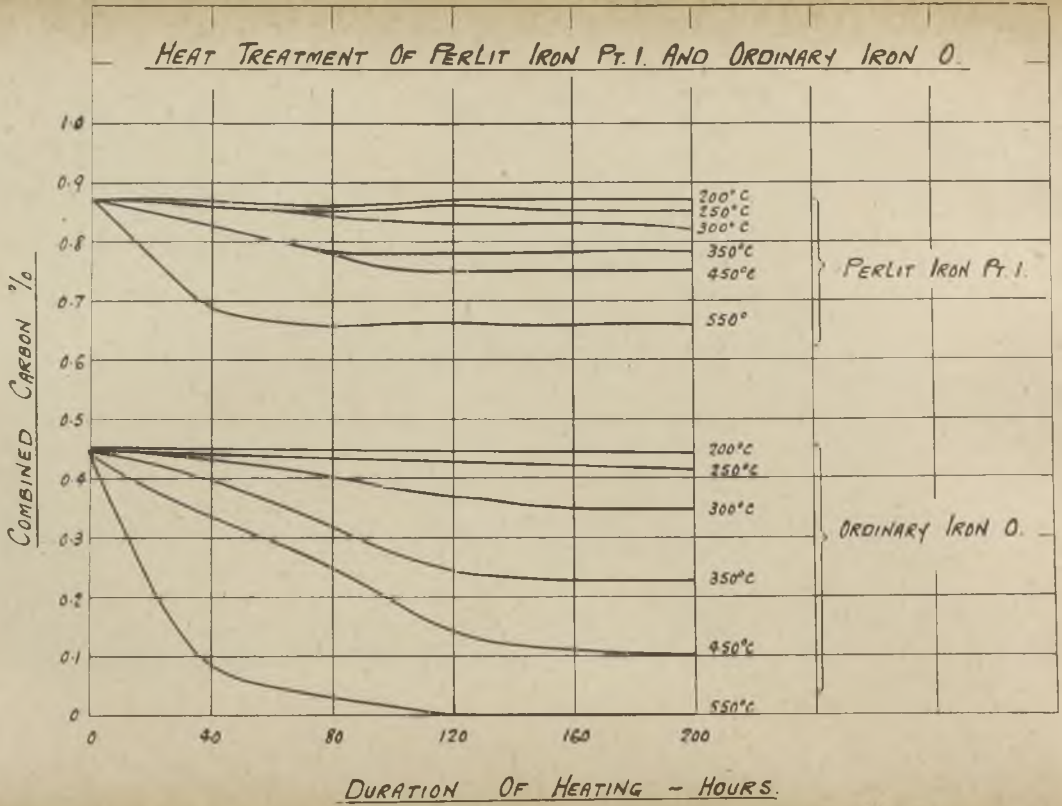

FIG. 2.—HEAT TREATMENT OF PERLIT IRON PT. 1 AND ORDINARY IRON O.

With the ordinary iron there is a steady increase in the rate of decomposition as the temperature rises, being pronounced at 350 deg. C and almost total at 550 deg. C. The cylinder iron shows marked decomposition at 450 deg. C., and at 550 deg. C. 82 per cent. of the carbide is decomposed. In the two Perlit irons decomposition is less marked, the "Pt 2," which has the lower silicon content, showing only 20 per cent. carbide decomposition at 550 deg., as against 25 per cent. in the "Pt 1."

TABLE IV.—*Heat Treatments at Various Temperatures.*

Cast iron.	Duration of heating in hours.	Temperature of Heating °C.					
		200	250	300	350	450	550
O	0	0.45	0.45	0.45	0.45	0.45	0.45
	40	0.44	0.44	0.43	0.40	0.33	0.08
	80	0.44	0.42	0.40	0.32	0.27	0.04
	120	0.45	0.43	0.37	0.24	0.14	Trace
	160	0.44	0.41	0.35	0.22	0.11	Trace
	200	0.44	0.41	0.35	0.23	0.10	Trace
P	0	0.68	0.68	0.68	0.68	0.68	0.68
	40	0.68	0.66	0.65	0.65	0.64	0.12
	80	0.67	0.64	0.64	0.61	0.48	0.11
	120	0.68	0.65	0.63	0.56	0.43	0.09
	160	0.68	0.64	0.61	0.51	0.38	0.12
	200	0.67	0.64	0.61	0.50	0.38	0.12
Pt. 1	0	0.87	0.87	0.87	0.87	0.87	0.87
	40	0.87	0.86	0.86	0.83	0.83	0.68
	80	0.86	0.85	0.84	0.78	0.78	0.65
	120	0.87	0.86	0.83	0.78	0.74	0.66
	160	0.87	0.85	0.83	0.79	0.75	0.65
	200	0.87	0.85	0.82	0.78	0.75	0.66
Pt. 2	0	0.91	0.91	0.91	0.91	0.91	0.91
	40	0.89	0.87	0.86	0.85	0.88	0.77
	80	0.90	0.87	0.85	0.86	0.84	0.72
	120	0.90	0.88	0.85	0.84	0.80	0.70
	160	0.89	0.88	0.85	0.83	0.80	0.72
	200	0.90	0.87	0.85	0.84	0.80	0.72

In all the irons decomposition takes place steadily for the first 120 hours' heating at all temperatures except at 550 deg. C., and then remains more or less steady. At 550 deg. C. decomposition practically all takes place during the first 40 hours' heating.

A summary of the results obtained for the four irons as regards carbide decomposition, loss in strength, and hardness at 450 deg. C. and 550 deg. C. respectively, is given in Table V,

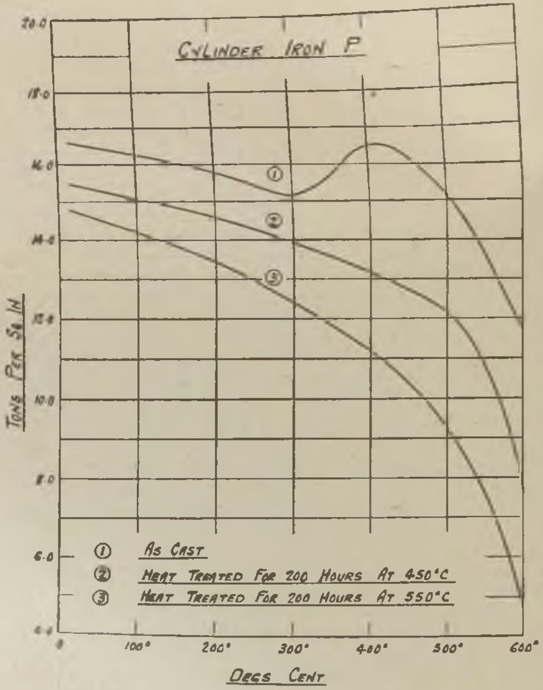

FIG. 3.—CYLINDER IRON P.

together with results for three irons of composition similar to the cylinder iron but containing 0.392 per cent. of chromium, 0.475 per cent. of tungsten, and 0.495 per cent. of chromium and 0.245 per cent. of nickel respectively.

As mentioned previously, the best results as regards carbide decomposition are obtained at

Table V.—*Percentage Changes Produced by Heat Treatment.*

Cast iron.	450°C.				550°C.			
	Duration of heating in hours.	Combined carbon decrease.	Tensile strength decrease.	Brinell hardness decrease.	Duration of heating in hours.	Combined carbon decrease.	Tensile strength decrease.	Brinell hardness decrease.
		Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
O	160	77.7	—	—	120	100.0	—	—
P	160	34.0	7.0	18.0	40	82.0	11.0	42.0
Pt. 1	120	16.0	—	—	80	25.0	—	—
Pt. 2	120	12.0	4.4	7.4	80	19.8	7.1	11.5
C	120	25.0	5.5	16.0	120	46.0	11.0	31.0
W	120	23.0	5.7	15.5	160	65.0	14.7	33.0
C.N.	120	25.0	6.3	14.0	160	51.0	13.0	31.0

both 450 deg. C. and 550 deg. C. with the two Perlit irons, followed by the cylinder irons containing special element additions. This carbide change is reflected in the corresponding decreases in strength and hardness.

It would appear from these tests that the stability of the carbide in grey cast iron under low-temperature heat-treatment conditions is influenced by the silicon content. This effect is most pronounced when the silicon is 1.0 per cent. or less. An iron containing 1.05 per cent. of silicon shows only 25 per cent. carbide decomposition

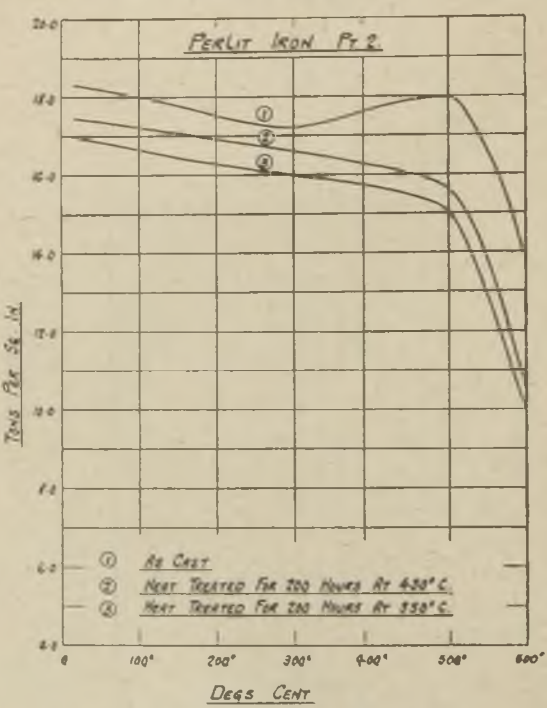

FIG. 4.—PERLIT IRON PT. 2.

at 550 deg. C., as against 82 per cent. for an iron containing 1.48 per cent. of silicon. Even the addition of 0.4 per cent. of chromium to the higher silicon iron does not produce the same degree of stability. Lowering the silicon to 0.65 per cent. only increases the stability to a slight extent, the most marked change taking place between 1.0 and 1.5 per cent. of silicon. This might suggest some critical composition of silicon which affects stability if those lower silicon irons, due to their process of manufacture, did not have a higher initial combined carbon and an all-pearlitic structure. It appears probable that the marked increase in stability is a result of the lower silicon content combined with the higher initial combined carbon. This appeared to be confirmed by a test carried out on an iron having 0.89 per cent. combined carbon, 1.78 per cent. silicon, and a pearlitic structure. After 200 hours' heat treatment at 550 deg. C. the carbide had decomposed to the extent of 48 per cent.

TABLE VI.—*Elevated Temperature Tests.*

Cast iron.	Breaking temperature °C.	As cast.	Heat treated for 200 hours at 450°C.	Heat treated for 200 hours at 550°C.
	Degs.	Tons.	Tons.	Tons.
P	15	16.6	15.5	14.8
	100	16.1	14.9	13.8
	200	15.8	14.5	13.6
	250	15.2	—	—
	300	14.9	13.8	12.4
	350	15.7	—	—
	400	16.5	13.0	11.0
	500	15.1	12.2	10.4
	600	11.7	7.6	4.8
Pt. 2	15	18.3	17.5	17.0
	100	18.0	17.3	16.5
	200	17.5	16.7	16.2
	300	17.2	16.5	16.0
	400	17.7	16.3	15.7
	500	18.0	15.7	15.2
	600	13.7	10.5	10.0

Elevated Temperature Tests.

A series of bars from the cylinder iron "P" and the Perlit iron "Pt 2" were broken at temperatures ranging from 15 deg. C. to 600 deg. C. A second series from each iron were heat treated at 450 deg for 200 hours (and a third series were heat treated at 550 deg. C. for a similar period), in order to produce more or less stable conditions as regards carbide decomposition. After heat treatment, bars from each series were broken over a range of temperatures similar to which the irons in their cast condition were broken. The results obtained from these tests are given in Table VI and represented graphically in Figs. 3 and 4.

Table VII.—*Growth Tests at 450 deg. C.*

Cast-iron.	No. of heatings	Length.	Diam'ter	Volume.	Change.
		In.	In.	Cub. in.	Per cent.
O	—	6.0000	1.0000	4.710	—
	5	6.0004	1.0002	4.712	0.04
	10	6.0004	1.0005	4.715	0.11
	15	6.0010	1.0007	4.718	0.17
	20	6.0035	1.0010	4.722	0.25
	25	6.0052	1.0014	4.727	0.36
P	—	6.0000	1.0000	4.710	—
	5	6.0003	1.0003	4.713	0.06
	10	6.0005	1.0004	4.714	0.09
	15	6.0006	1.0005	4.715	0.11
	20	6.0006	1.0005	4.715	0.11
	25	6.0006	1.0005	4.715	0.11
Pt. 2	—	6.0000	1.0000	4.710	—
	5	6.0004	1.0001	4.711	0.02
	10	6.0005	1.0001	4.712	0.04
	15	6.0004	1.0002	4.712	0.04
	20	6.0005	1.0002	4.712	0.04
	25	6.0005	1.0002	4.712	0.04

The Perlit iron tested in its cast condition shows, as in the case of the cylinder iron, the characteristic drop which takes place in the temperature strength curve at 300 deg. C. This depression in the curve is removed in both irons after they have been heat treated. The Perlit iron in its cast condition, and also after heat treatment, retains its strength up to 500 deg. C. before falling off. In this respect it behaves somewhat similar to the cylinder iron containing 0.392 per cent. of chromium, dealt with in a previous Paper. Similar to the chromium iron, it also retains its strength after heat treatment. As compared with the Perlit iron, the cylinder iron in its cast condition tested at 500 deg. C. shows a drop of 16 per cent. After heat treatment for 200 hours at 450 deg. C. and 550 deg. C. the drop in strength when tested at 500 deg. C. is 19 per cent. and 28 per cent. respectively. These results are consistent with the results obtained in the carbide decomposition tests, the Perlit iron being the more stable under the higher temperature conditions.

TABLE VIII.—*Growth Tests at 550 deg. C.*

Cast-iron.	No. of heatings	Length.	Diam'ter	Volume.	Change.
		In.	In.	Cub. in.	Per cent.
O	—	6.0000	1.0000	4.710	—
	5	6.0006	1.0002	4.713	0.06
	10	6.0020	1.0006	4.717	0.15
	15	6.0030	1.0010	4.721	0.23
	20	6.0046	1.0016	4.727	0.36
	25	6.0063	1.0020	4.732	0.47
P	—	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
Pt. 2	—	6.0000	1.0000	4.710	—
	5	6.0005	1.0001	4.712	0.04
	10	6.0008	1.0002	4.713	0.06
	15	6.0008	1.0002	4.713	0.06
	20	6.0007	1.0002	4.713	0.06
	25	6.0008	1.0002	4.713	0.06

Growth and Volume Changes.

Two bars from each of the three irons, ordinary "O," cylinder "P," and Perlit "Pt 2," were subjected to repeated heatings and coolings for a period of 200 hours at 450 deg. C., each heating being of eight hours' duration. Similar tests were cast out at 550 deg. C. The bars which were accurately machined to 6 in. in length and 1 in. diameter were heated in an electric resistance furnace and were accurately measured by means of a Whitworth measuring machine at the end of every five heatings or 40-hour periods. The results which were obtained are given in Tables VII and VIII and in Fig. 5.

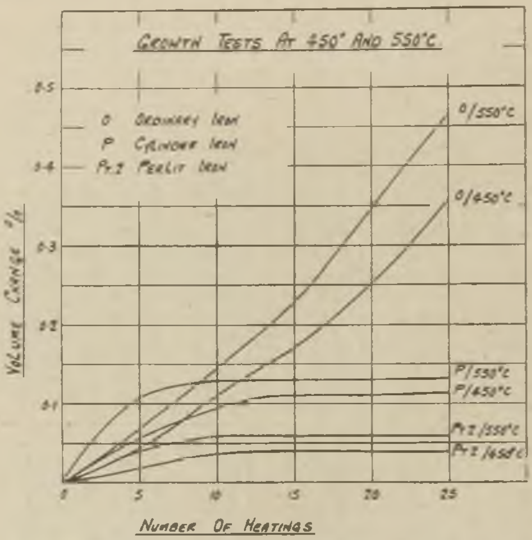

FIG. 5.—GROWTH TESTS AT 450 DEG. AND 550 DEG. C.

The amount of growth which takes place both in the cylinder iron and the Perlit iron at 450 deg. C. and 550 deg. C. is small when compared with the growth in the ordinary iron. Growth in the former irons also appears to attain a maximum after 10 heatings, while in the latter the material is still continuing to grow at both temperatures after 25 heatings, or 200 hours.

That these changes are in some way related to carbide decomposition it is not difficult to surmise, but carbide decomposition alone does not explain everything. A cylinder iron containing 0.4 per cent. of chromium shrinks, yet the carbide decomposition is greater than in the case of the Perlit iron, which shows a slight increase in volume. Microscopic examination does not show any internal oxidation such as is associated with growth at temperatures above the critical range, so that the definite cause of these volume change phenomena requires further investigation.

Microscopic Examination.

An extensive microscopic examination was made on sections taken from the four irons at various stages during their heat treatment, and these, in general, confirmed the results obtained by analytical methods. To illustrate what takes place a few photographs were taken; Figs. 6, 8, 10 and 12 represent the four irons in their cast condition, and Figs. 7, 9, 11 and 13 the irons after being subjected to 200 hours' heat treatment at 550 deg. C.

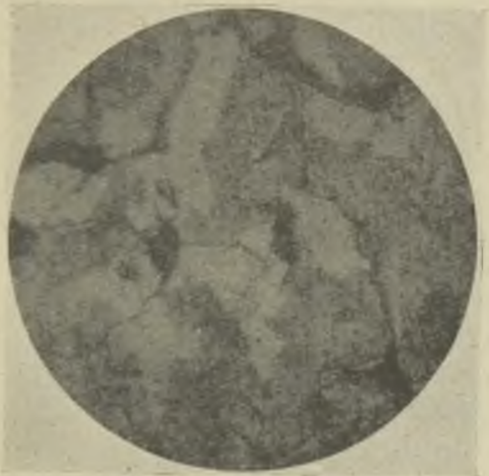

FIG. 6.—× 540.

The microstructure of the irons in their cast condition is what one would expect from their composition and process of manufacture. The ordinary iron shows graphite, pearlite, ferrite and phosphide eutectic, as also does the cylinder iron, except that the ferrite is diminished and the pearlite increased. The two Perlit irons show pearlite and graphite.

In all the irons after heat treatment the graphite plates show an increase in size, and there are evidences of graphite being deposited alongside the existing plates. This deposition of graphite is accompanied by decomposition of the pearlite which takes place generally and not in the vicinity of the deposited graphite. This decomposition of pearlite is most pronounced in the ordinary iron, Fig. 7, where after treatment the amount of pearlite visible is practically nil. The heat-treated cylinder iron, Fig. 9, also shows marked carbide decomposition. Traces of pearlite are still visible, but on a whole it is disintegrated.

Fig. 7.—× 540.

The two Perlit irons after heat treatment retain their pearlitic structure, although there is a distinct change in the nature of the pearlite, Figs. 11 and 13. It is of a less compact nature and has a distinctly weaker appearance. The carbide appears to be in a state of disintegration, especially in the case of the higher silicon iron, where there are distinct ferrite areas formed.

These microphotographs represent the extreme conditions of temperature to which the various irons were subjected. Micro-examination of the pieces heat treated at 200 deg. C. for 200 hours shows no change in the structure. Examination of those pieces of all the irons treated at intermediate temperatures shows changes which are in accordance with the analytical results. The changes in microstructure due to carbide decomposition and graphite deposition are no doubt the cause of the falling off in strength properties of those irons mechanically tested after heat treatment. There are no signs of internal oxidation taking place in any of the heat-treated irons.

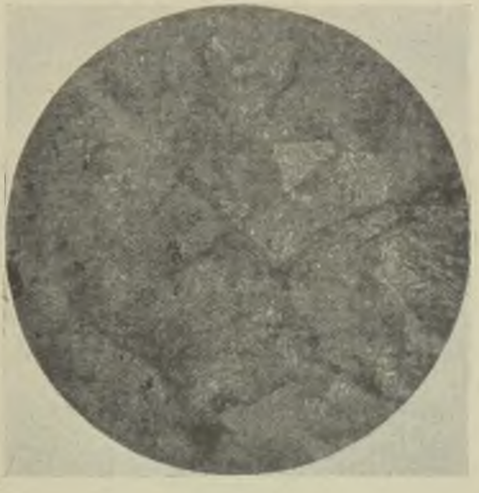

FIG. 8.— × 540.

Conclusions.

In summarising the results obtained from the various tests the following conclusions may be made, although further work requires to be done before all of them can definitely be established:—

1. Carbide decomposition accompanied by graphite deposition takes place in grey cast iron when subjected to low-temperature heat-treatment.

2. Stability of the carbide is influenced by the silicon content, and also by the initial combined carbon content. A combined carbon content of 0.9 per cent., together with an all-pearlitic structure and 1.0 per cent. or less of silicon, gives the greatest stability.

FIG. 9.— × 540.

3. Stability is also influenced by the temperature and the duration of heat treatment. At 200 deg. C. the change is not noticeable except over a long period of time. Over 200 deg. C. the rate of change varies with the temperature and nature of the iron.

4. Carbide decomposition also affects the mechanical properties of grey cast iron according to the condition and duration of heat treatment.

5. Growth and volume changes are in some ways related to carbide decomposition, but not wholly explained by it.

The author's thanks are due to Mr. James Brown, O.B.E., and the other directors of Scotts' Shipbuilding and Engineering Company, Limited, Greenock, for permission to publish the results of those experiments, and to the North-Eastern Marine Engineering Company, Limited, Wallsend, for the Perlit test bars.

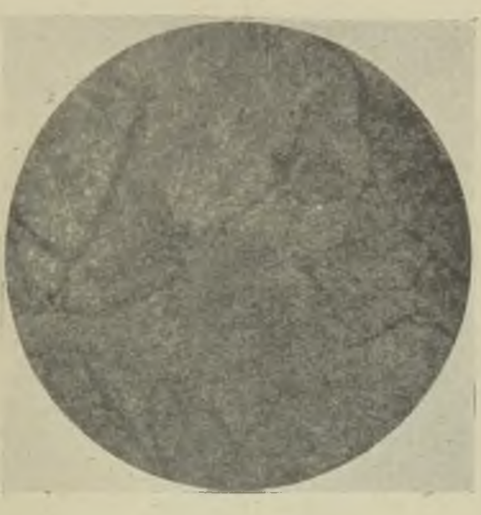

Fig. 10.—× 540.

DISCUSSION.

Perlit Iron.

Mr. C. Gresty (Newcastle) said he was a close follower of the work of Mr. Donaldson, and his interest in the Paper was increased by the fact that he was partly responsible for the production of some of the particular Perlit samples on which the experiments had been made. Ever since Perlit had been introduced into this country he had been engaged on its manufacture. The results obtained by Mr. Donaldson were, in his opinion, exceedingly valuable. In the series of Papers they had had from him in recent years they got clear and concise statements of facts without any theorising; nothing was put down unless there was proof given of it.

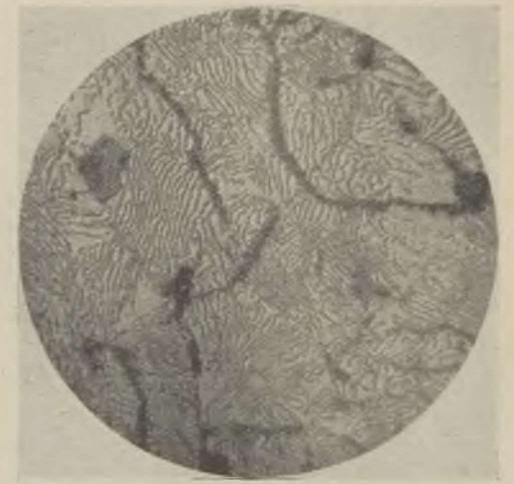

Fig. 11.— × 540.

The most notable fact disclosed by the present Paper was the series of good and consistent results given by Perlit iron in all the tests, not only compared with the irons mentioned in the Paper that afternoon, but also with those referred to in previous contributions. Throughout the experiments good and consistent results had been obtained from Perlit, and whilst the results in the case of other irons were good in certain respects, if they were examined closely it would be found that although they did well on some tests they went down on others rather badly. For example, the iron containing tungsten, which Mr. Donaldson dealt with more fully in the Glasgow Paper, showed high resistance to growth, and iron containing chromium maintained its strength well at high temperatures, but both irons showed greater softening and carbide decomposition than the samples of Perlit. Table V., which gave the percentage alterations under different treatments, was very illuminating, and corroborated what he had just said in a striking manner. For instance, after treatment at 550 deg. C. the hardness of Perlit was only decreased by 11.5 per cent., whereas the next best iron, either in that table or in those previously published, came out at over 30 per cent. decrease. As the author pointed out, it was evident that this great stability of the carbide came from the low silicon content of the metal, because the Perlit iron had no alloy additions. He did not know whether it had come to the knowledge of Mr. Donaldson, but it would per-

FIG. 12.—× 540.

haps be of some interest to state that for a good many months his firm had been manufacturing Perlit iron with silicon between 0.4 and 0.5 per cent. Judging from Mr. Donaldson's results, this very low-silicon iron with 0.4 to 0.5 per cent. silicon would be even more stable than the samples with which he had dealt.

High Temperature Results.

In all his work the author had confined himself to comparatively low-temperature treatment, *i.e.*, up to 550 deg. C., and he would like to ask whether any of the irons containing additions of chromium, tungsten, nickel, and so on had ever been tested for growth above the critical point. He did not think he would be giving away secrets if he stated that Mr. C. E. Pearson, who is working at Armstrong College, Newcastle, under the Carnegie Scholarship Scheme, had been doing research work on heat treatment above the critical point, namely, at 900 deg. C. His work was in the press at present, but he had permission

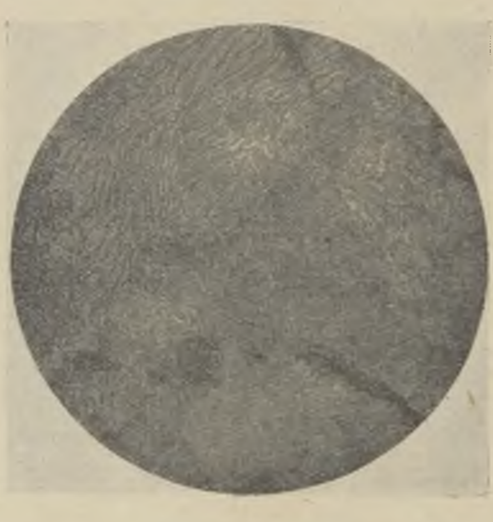

Fig. 13.— × 540.

to mention it at that meeting. At those higher temperatures the percentages of growth were very much greater. Thus, where Mr. Donaldson might show 0.3 or 0.4 per cent. growth at 550 deg. C., at the high temperature of 900 deg. C., they would probably get 30 or 40 per cent. with the same irons. One sample of Perlit iron containing 0.68 per cent. of silicon, roughly the same as Mr. Donaldson had been working on, gave 5.5 per cent. maximum growth. Another sample containing just under 0.5 per cent. silicon had given 2.83 per cent. growth, and of all the ordinary irons Mr. Pearson had dealt with, the lowest figure given was 16.8 per cent. growth. Thus at these high temperatures also Perlit showed a very great resistance to heat.

Growth and Wearing Properties.

About a couple of years ago Professor Mellanby, who is an authority on iron for Diesel work, stated in a Paper that he had found from experience that the wearing properties and growth of cast iron went hand in hand so to speak. If an iron was very resistant to growth, it was also very resistant to wear. His (Mr. Gresty's) own experience of Perlit entirely bore out that statement, and he was wondering whether Mr. Donaldson had ever done any wear tests on any of his other materials.

Dealing with the micro-structures, the author stated that Perlit iron showed a pearlitic structure after 200 hours at 550 deg. C., which in his (Mr. Gresty's) opinion was rather remarkable in view of the statement that the pearlite was in a state of disintegration. It certainly had a slightly weaker appearance, but the physical tests did not show any great drop in strength. In Table V the percentage drop in tensile strength was really very low, being only 7 per cent. after treatment at 550 deg. C.

The author further stated that the actual carbide decomposition at 550 deg. C. was completed at the end of 40 hours as a general rule, so it was quite evident that that particular pearlitic structure must be very stable to enable it to persist even after another 160 hours at the same temperature.

Low Silicon Superseding Chromium.

Mr. Donaldson remarked that in the Glasgow Paper he was dealing with cylinder iron with 1.5 per cent. of silicon. Adding 0.4 per cent. of chromium to it produced a smaller carbide change when tested under similar conditions. One of the speakers, in the course of the discussion, remarked that if the silicon was reduced from 1.5 per cent. to 0.6 per cent. a similar result would be obtained. He had obtained an iron containing 0.65 per cent. of silicon, and they saw what happened on reducing the silicon. Reducing the silicon had a greater effect than adding 0.4 per cent. of chromium.

He was not aware that irons were being made with silicon between 0.4 and 0.5 per cent.; he thought 0.65 per cent. was the lowest. As to high-temperature treatment, he had not carried out any tests above the critical point, his work having been confined to the lower temperatures. Some people, in fact, thought 550 deg. C. was far too high for research work in connection with Diesel engines.

He had not had an opportunity of carrying out tests on wear, and he could not therefore say how Perlit behaved under such tests. Mr. Gresty's remarks with reference to the microscopic evidence were interesting, and he agreed with them.

Producing Low Silicon Irons.

Mr. Shaw (Sheffield) endorsed all that had been said regarding the value of Mr. Donaldson's work. It would appear that with a normal total carbon of approximately 3.2 per cent. it was necessary to get a very low silicon to obtain the best results both as regards strength at high temperatures and lack of growth. It would seem, at first sight, that the hot mould process was needed under these conditions (Si 0.6 per cent.) to obtain a machinable casting. Unfortunately this process was not possible in such cases as large turbines, which took several days to core up. The silicon would have to be raised to compensate for the cold mould if the casting would machine easily. This, according to Mr. Donaldson's findings, was fatal. In the competition that was taking place between the

Diesel engine and the H.P. turbine, the latter was handicapped by lack of suitable material to give satisfaction at much higher pressures and temperatures. It was up to foundrymen to try and find a suitable iron, otherwise the engineer would find something better. He would like to suggest that it might be possible to use lower total carbon irons, with, say, chrome additions; although the silicon would need to be higher, its effect on the low total carbon (say 2.5 per cent.) would be much less and the graphite would be in a definitely finer state. It would also be possible to cast the simpler liners and piston heads in a perfectly white iron free from graphite with these low total carbons. It was possible to turn this white iron (Brinell hardness about 300) in an engineer's lathe without much trouble. These low-carbon irons could be obtained in the cupola, using about 90 per cent. steel and a 10 per cent. more of a 25 per cent. silicon pig. This consistently gave less than 2.5 per cent. total carbon. For certain purposes he used a metal containing T.C. 2.2; Si, 0.7; Mn, 0.35; S, 0.1; Cr, 1.0; and Ni, 0.5 per cent. That gave a white metal which after annealing at 900 deg. C. for 15 hours, showed no signs of graphitisation, but an altered structure that could be drilled and machined at slow speed. Whether this metal would create any difficulty in plain liners, etc., he did not know.

Importance of Sulphur Content.

He would have liked to have seen the complete analyses of the various irons given in the tables, because from a large amount of work done he had no doubt that the ratio of manganese to sulphur played a great part on the quantity and shape of the graphite, quite apart from the silicon content. That was confirmed in most shops that had to work to chill. Notwithstanding the investigations of various people who made laboratory tests on small samples and stated that any manganese above the atomic ratio to sulphur acted as a hardener, he had no hesitation in saying that they were wrong. Of course, there would be a point where excess manganese would harden a casting, but much would depend on the thickness of the casting.

Carbide Decomposition.

Mr. Donaldson, in reply, pointed out in connection with the varying of the total carbon that the irons he had worked with were more or less of the same carbon content. It was the silicon that varied. He had mentioned that he had carried out a test with an iron which had a pearlitic structure and contained 1.78 per cent. of silicon, and that after 200 hours' treatment at 550 deg. C. the carbide decomposed to the extent of 48 per cent. That iron contained 2.75 total carbon.

Mr. Shaw: And what manganese?

Mr. Donaldson: I could not say.

The President: Was chromium added to that?

Mr. Donaldson: No chromium.

Carbide decomposition, continued Mr. Donaldson, was rather a complicated matter, because three factors were involved—total carbon, combined carbon, and silicon—and if chromium was brought in it meant a fourth. The subject required further investigation in a more systematic manner.

Mr. Shaw observed that it was the manganese he was concerned with.

Mr. Donaldson replied that he had not taken that into consideration; it was varying silicon he had dealt with.

Mr. Shaw: The manganese is vital.

Mr. Donaldson remarked that might be so, but, as had been previously pointed out, the only true way of carrying out research work was to vary one variable at a time, but with commercial iron it was difficult to do so because all the other constants varied at the same time. Personally he thought research carried out on commercial irons was of more practical use than that carried out on specially prepared material. Reference had been made to tests at 950 deg. C.; he had no experience of those high temperatures.

High Temperature Requirements.

He (the lecturer) considered there was a future for iron made by the Perlit process in Diesel engine work, on account of the low-silicon content which was obtained. Personally he had never seen the Perlit process in operation, and was only speaking of the samples of material prepared by it which he had received. He had had other pearlite irons prepared by different processes, but, unfortunately, he had never received sufficient bars to enable him to carry out a series of tests. Mr. Shaw had mentioned the question of temperatures in connection with Diesel engine work, and that was a factor which would have to be faced. As he had pointed out, up to 200 deg. C. it did not matter what cast iron was used so far as carbide decomposition was concerned; 200 deg. C., however, was only saturated steam temperature. Superheated steam temperatures reaching 400 C. deg. had recently been attained. He also knew of one case where an oil engine piston had been red hot, and where analysis subsequently made had shown that the temperature must have been somewhere in the vicinity of 600 deg., because there was not a trace of combined carbon left. Abnormal temperatures were met with and had to be considered. Mr. Shaw had suggested that if cast iron would not meet those conditions the engineer would turn to something else. As yet he had not done so, because there was nothing cheaper.

Low Carbon Improves Perlit Iron.

Mr. Gresty agreed with Mr. Shaw that there were processes other than the Perlit by which iron low in total carbon in the cupola could be produced. The point was if Mr. Shaw wished to make a better iron with, say, 2.5 per cent. carbon he could do so, but he could go either lower in carbon or in silicon if he adopted the Perlit process. It was not sufficiently realised that by the Perlit process they were not tied to 3.3 per cent. of carbon; they could go to 2.7 per cent. and obtain a better product than if a higher silicon iron were used.

The President said he was in agreement with Mr. Shaw that a pearlitic structure could be obtained without the Perlit process. He had done so for years, and could do so again. At the same time, if it were possible to get a more consistent material by a certain process which would lessen the responsibility of those who had to make the castings, so much the better for all concerned. The claims set up for Perlit initially were so great that they acted rather as a deterrent than an encouragement, because most people knew the claims could not be substantiated, but if it had reduced the troubles in the foundry a little it had done something.

Mr. Donaldson remarked that he was willing to carry out tests on other pearlite irons if he could get the material, but up to the present he had had only single bars of those other irons, and that was not sufficient to carry out systematic tests.

Influence of Mn on Carbide.

Mr. M. L. Becker, of the British Cast Iron Research Association, said they were privileged in hearing such a valuable Paper, embodying a great deal of recent research which had not previously been published. The problem of growth at low temperatures was receiving attention by the Cast Iron Research Association, and although it was not one with which he was intimately concerned at the moment, he knew that the value of Mr. Donaldson's work was fully appreciated.

The author was quite definite about the effect of manganese in stabilising carbide. He believed a number of people considered that at the higher temperatures manganese had very little effect upon the stabilising of the carbon. He personally had found that on annealing a white iron it graphitised proportionately rapidly according to the amount of silicon present, and that the presence of manganese up to 3 per cent. had very little effect. On the other hand, a white iron free from silicon would graphitise if annealed for a very long time, whereas an iron containing much manganese would not graphitise even in such periods as a thousand hours at 1,000 deg. C. With regard to Figs. 1 and 2, it seemed to him surprising that the effect there shown should occur, because he should have thought that as annealing progressed the combined carbon would have continued to be reduced until it fell to a value of, say, 0.1 per cent. In all irons, however, that did not seem to be the case. Decomposition took place within the first 20 hours, but the final value, which had all the appearance of an equilibrium value, was not the same in all cases even where the compositions, apart from carbon, were similar. He would like to know whether Mr. Donaldson thought this value was an equilibrium value depending upon the composition, or whether, if annealed for considerably longer periods, the combined carbon would be found to be further decomposed.

Decomposition of High Initial Combined Carbon.

The conclusion the author arrived at, that the high initial combined carbon prevented decomposition, seemed to be quite antagonistic to the general view that the higher the combined carbon of a cast iron the more it would be inclined to graphitise. In fact, the Perlit process depended on that. He was speaking of high temperatures, but one would expect the same rule to hold in cases below the critical range. In the micro-sections shown on the screen the laminations became more distinct, and apparently further apart on annealing at 550 deg. C. Was that the case?

Mr. Donaldson said he thought it was that the section or the particular area had been badly chosen. Generally speaking, the photographs showed that, but it was not so.

Factors for Carbide Decomposition.

Mr. Becker continued that the precipitated graphite apparently migrated to the pre-existing flakes, and was, therefore, not visible in the ferrite areas of the fully annealed iron. That was a surprising fact, and was evidence of the hypothesis that the ferrite would take carbon into solution at temperatures below the critical point. The Perlit irons showed up extremely well in resisting growth and carbide decomposition, and it would be interesting to know whether Mr. Donaldson had compared a partially graphitised white iron such as might be obtained in the production of black heart malleable iron if the rate of cooling from the annealing temperature were rapid instead of slow. By treating such a material along with the Perlit and grey irons at a temperature of 550 deg. C. it might be possible to determine whether the form and distribution of the pre-existing graphite were factors influencing the rate of carbide decomposition as distinct from the silicon content. He personally was inclined to the belief that they were.

With regard to the analysis of the iron which had been subjected to heat-treatment, it was a little difficult to visualise what would happen to the precipitated graphite. If it were precipitated in very fine particles, was some of it going to escape on analysis, or did Mr. Donaldson think it would all be estimated along with the other graphite?

Relative Values for Carbide Decomposition.

Mr. Donaldson said the question of manganese was dealt with in a previous Paper. He found that 2.75 per cent. manganese added to a 1.6 per cent. silicon iron gave a stability somewhat similar to 0.4 per cent. chromium. That was the only experience he had with reference to manganese. He had no experience of white iron at all. With regard to the question of an equilibrium value it was difficult to say, but he thought there was an equilibrium value for a particular temperature. With reference to graphite he had always assumed that all the graphite deposits came out in the analyses. In doing those analyses he usually did the total carbon and the graphite, and got the combined carbon by the difference. In some cases he did the combined carbon direct, but he preferred the former method.

Mr. Jolley asked whether Mr. Donaldson worked entirely on test pieces or had he used parts of castings, and had he at any time taken samples of ordinary irons which had been cast in the ordinary way and irons cast by the Perlit process? There was, no doubt, something in the Perlit process, but the trouble was the limitations in heating the moulds and controlling the temperatures so obtained.

Mr. Donaldson stated that the cylinder iron was taken from test bars cast separately, whilst the Pt. 1 bars were cast on a casting. Pt. 2, however, was supplied in the form of test bars, cast separately. He had tested irons made by different firms which he knew did not use the same pig-irons, because they bought from different sources, and he got more or less the same results from those different irons.

High Total Carbide Successful for Diesel Work.

Mr. Longden asked how the author had taken the Brinell hardness. Did he machine the test bars to a definite depth, and take it at exactly the same place in each bar? He had carried out a number of experiments in the production of pearlitic cast iron, and he did not agree with Mr. Shaw when he stated that the physical properties in other irons were equal to Perlit. The impact strength was a most important matter in Diesel engine work. If a bar of ordinary iron 1¼in. diameter was struck pretty forcibly it could be broken in a couple of blows, but Perlit iron would stand 200 or 250 blows. Why there was such a vast difference he could not say. There was an Italian firm which made a great success in the production of the Diesel engine, and particularly the breach ends. It had been brought out that low carbon was absolutely essential. Yet that particular firm made an iron with a total carbon content of 3.81; silicon, 1.36; manganese, 0.87; and sulphur, 0.28 per cent. If he were choosing metal for a heavy-oil engine, he would select Perlit iron for the breach end, the piston and the piston ring, and another iron for the liner. There was a place for all these metals.

Mr. Donaldson said that all the bars were standard test bars, and the Brinell hardness was carried out after the bar had been machined to the standard size and always at the same place.

The President remarked that in connection with many of the difficulties which had been referred to there was some fault on the engineering side as well as on the foundry side. When red-heat temperatures were reached it could not be expected that steel, cast iron or any ferrous or non-ferrous metal could withstand it, and it was as much the work of the engineer as of the foundryman to deal with the matter. He had seen cylinder heads taken out of an old engine showing clear signs of having been red hot. Something had been wrong in the engine apart altogether from the casting. With cylinder heads and pistons that had developed star cracks no reason was ever given for their presence, and on analysis the metal had been found to be satisfactory; in fact, very little different from when it was originally put in the casting.

Lancashire Branch (Junior Section).

AMERICAN FOUNDRY PRACTICE.

By W. Jolley (Member).

Although the author's visit was of somewhat longer duration than those of his colleagues who took the opportunity to attend the Detroit Conference, it only covered a period of seven weeks, including the voyage out and home, and during this time he was able to visit only six States out of a total of 52, and less than 40 foundries out of some 5,785 which statistics show to exist in the United States, and consequently it is impossible to give other than a brief outline of the foundry life of America.

These visits commenced on September 21 and concluded on October 21, and an effort was made to make them as representative as possible by including foundries dealing with iron, steel, brass, etc., both of the jobbing and repetition variety.

The visits were both in company with others of his party and also alone, and as opportunity was afforded of visiting some of the works closely allied with those of the company with which the author is associated and conducting personal inquiries, he was able to make critical comparisons advantageous to both parties as well as to himself.

Huge Productions and Orders.

Much has been written in regard to American methods, and it is largely correct, but our difficulty in appreciating its real meaning is due to our inability correctly to focus their conditions. It is difficult for Britishers to form a correct impression of an output of 1,500 tons of castings per day, or of an order for 3,000,000 castings, both of which are actual facts.

In their general jobbing foundries there is a very close resemblance to our own shops. In these shops, as in their repetition shops, there appears to be an absorbing consideration of labour conservation so far as the skilled moulder is concerned, and we see that the skill of one man is generally utilised in the control of a number of less skilled men, resembling to a somewhat exaggerated extent the gang method operated in some shops in this country. Thus they are able to make the best use of what skill is available, but little opportunity is afforded to develop a future generation of moulders.

Largest Castings Not Wanted.

One of the shops visited was engaged on some very big castings, weighing as much as 100 tons. but generally speaking efforts are made to reduce the size of castings by splitting them up into several pieces. Loam work is met with less frequently than in this country, although in some shops it is largely used, particularly upon such work as condensers, etc. In this respect Britain is probably more advanced, as there was no evidence of the use of either prodded or barred tackle, the old method of ramming up in pits being still in operation.

Sand Cutters.

Various types of moulding machines, such as sand slingers, and jarring machines, were met with, but opinions differed as to their advantages. Great use appears to be made of sand cutters for assisting to condition floor sand, and in several foundries visited they were in operation. There is unquestionably more endeavour made in the larger foundries at any rate to reclaim used sand. Thus with the aid of these tractor sand cutters, the whole of the floor is cut up and treated or the sand is conveyed to the sand plant, where it is restored with powdered dry clay, and treated by one or more of the mechanical devices used for milling purposes. In this way sand is reclaimed, and its properties such as bond and porosity maintained at standard.

Sand Reclamation.

It is doubtful whether it would be a paying proposition so to deal with our sand in this country. The technical work necessary efficiently to determine and closely watch such a process would be a heavy burden in view of the almost unlimited sand resources at our disposal. In America, however, sand appears to receive especial attention, and there is an almost widespread use of both handling and mixing devices, more or less complex, and one is made to wonder what finish could be obtained were we to adopt even some of their simplest methods of treatment.

Needless to say, some of these devices are admirable in their utility, and could and should be operated in our foundries to the ultimate good of our product. It is very well known that the British founder suffers much from the lack of attention given to sand, and to his apparent indifference to the demands of the engineer. It is, however, in regard to mass production work that the American founder has given and constantly gives special attention, and in this respect we have been left far behind.

Influence of Quantity Production.

Quantity production resulting from a more standardised product and a wide market has undoubtedly given him a decided advantage, and has enabled him to give concentrated attention and thought to highly specialised machinery and methods. Added to this is the readiness with which he replaces his machinery by more modern types with a consequent increase in production, and decrease in cost without any decrease in quality, and their machine castings have attained a high standard of excellence. This is all the more remarkable when one considers the unskilled and cosmopolitan nature of the labour available. Europeans from the more backward nations, and coloured men from the Southern States, men with a roaming disposition, almost entirely comprise the available labour. There appears to be an ever-present desire to move, and consequently great thought has been brought to bear upon shop layout and simplicity of operation.

Production Cheapens Research.

The job has been made to suit the man, and the immensity of the demand has materially assisted in this direction. It has made research economical and the installation of expensive machinery a necessity. In this direction there is the development of the conveyor and the sand handling plant. In the larger and more modern foundries there are conveyors of various descriptions, and where these are applied we see the added advantage of a decreased area of floor room per man. The sand-handling plants are of both the overhead and underground type, the latter method appears to have found great favour, although where the layout makes the overhead type possible it is used with advantage.

Extensive Use of Conveyors.

In one of the shops visited, the sand was knocked out of the boxes after casting over a grid, and conveyed by means of a belt and screw arrangement to the mixing troughs. After passing through these troughs it was still further conveyed to an overhead gallery and deposited in chutes, which in turn continuously supplied the moulders with reconditioned sand. This method particularly suited their general layout and greatly diminished their general labour. Similarly, belt conveyors were used for conveying moulds to the point where the casting took place, the mould being placed upon the belt and conveyed along, and after casting continuing along to a point over a grid where it was knocked out. The casting passed to the dressing shop and the boxes were placed upon a second conveyor and returned to the moulders. Later it is hoped to describe this in detail in dealing with the Ford plant.

Moulding Boxes.

Although moulding boxes were used in some shops, great advantage was taken of snap flasks and taper flasks. Of course, these are not an innovation, as they are, and have been, in constant use in some foundries in this country for a number of years. Their advantage lies in the fact that they do not involve a large capital outlay and are more easily stored than moulding boxes. This is best illustrated by the consideration of a daily output of 3/400 moulds per day from one man, a figure readily obtained on a suitable machine.

Types of Moulding Machines Used.

Casting conditions may necessitate this number of boxes, where the snap-flask method would only necessitate one flask, and possibly a dozen light slips for use during casting. There are many types of moulding machines in operation, including power-press and hand-ram types, such as sand slingers, Tabor, Pridmore, Arcade, Mumford, Hermann, Osborne, etc., and each of them possess advantages differing according to conditions, and great use is made of them, as will be understood from the foregoing remarks.

The Ford Motor Co. Methods.

The Ford Works are described at very great length in the several publications from the pen of Mr. Henry Ford, and it is therefore only necessary to describe some of the details given during the visit and to give personal opinion of the inspection of their plant. The Company started operations in 1903 with an output for that year of 195 cars. This had increased to such an extent that in 1925 over 2,000,000 cars were turned out. They employ approximately 150,000 men in America. Their interests include coal mines in West Virginia and Kentucky, together with iron-ore mines and forests in Northern Michigan. They operate their own blast-furnace plant, steel mills, machine shops, body-making plants, saw mills, coke ovens, cement plant, paper mill, glass works, Fordson tractor plant, loco repair shops, whilst they have their own railway system and docks. From this it will be readily understood it is a gigantic undertaking, built up and controlled by a master mind.

Their Highland Park Works occupy 278 acres, 105 of which are under roof, and approximately 50,000 men are employed. There is a very large brass and white metal foundry, where great use is made of die-casting plant both in white metal and aluminium. Quantity production enables them to spend much money both in plant and dies, and some of these are elaborately designed to ensure complete mechanical operation. One of the most interesting features met with here is the "waste eliminating department," and from this one can learn much towards increasing the efficiency of a works. Everything that can be included under the term "scrap," and is considered to be of no further use by the department concerned from which it emerges, is sent to this eliminating department, where it is scrutinised and an opinion is formed in regard to its utility.

Work may be done upon it and its original purpose transformed in some way, and as a result of this it was understood some £250,000 worth of material is returned to the works each month. This is truly a wonderful achievement, and a striking lesson of what can be done with material which has once been considered scrap.

River Rouge Works.

At the River Rouge Works some 55,000 men are employed, and this number is ever-increasing. It is difficult to do justice to these works, but a few particulars of the foundry will be welcomed by foundrymen. This foundry is the most complex place in the whole organisation. Mechanical methods are present to such an extent as to bewilder one. The output of castings was something in the neighbourhood of 1,500 tons per day.

Any comparison with domestic outputs will help one to realise how difficult it is to form a true conception of what such an output as 1,500 tons per day will involve. And yet their organisation is so efficient, and their layout so complete and orderly, that it appears to be easily achieved. Very little daylight is available, almost all work being done by artificial light. One of the first causes for amazement is the comparative absence of sand. We in this country cannot conceive a foundry without associating it with huge quantities of sand, in fact, we are accustomed to being surrounded with sand, and consequently cannot, or do not, give it its proper purpose; but at the Ford Works there are no sand floors such as we have. It is conveyed direct to the box or flask by means of chutes served by overhead conveyors. The moulds are made by the multiple method, that is, each man does so much, performs a specific operation, and as a result of the collective operations the castings are made.

The cylinder cores were rammed up by a sand-slinger, and then placed on a "roundabout" around which seven men were stationed, each doing some definite operation in the ultimate production of the perfect core. As a result of their efforts three cores per minute were placed upon the conveyor. The copes were rammed up on jar-ram machines and cylinders were being cast at the rate of 180 per hour per conveyor, of which there were six sets.

After being cast, which operation takes place whilst the mould is still on the conveyor, the mould continues its journey for some distance to a point where the box appears to do the Charleston, and is deflected off the original conveyor on to a secondary conveyor. During its progress thus far, it has passed over a grid where the sand is knocked out and sent upon its journey for reconditioning.

At this point two men are stationed, deflecting the now empty box on to the original conveyor on its return to the moulders. Thus they are in continuous use. The casting by this time is well on its way to the dressing shop. To get there it travels a great distance, and during its progress it is subjected to a very keen inspection at the hands of a host of inspectors stationed along its course.

There were about seven inspectors, each scrutinising some particular part of the casting, and each provided with a conveyor siding along which he sidetracks any casting which does not meet with his approval. Such castings as pass this inspection ultimately reach the dressing shop.

Dressing Shop.

This department is staffed by coloured labour, divided into operation groups, the first of which is the coring gang, who push out the cores and pass the castings along to the fettling gang.

Final dressing having been done, the castings again pass along for further inspection before being eventually despatched to the departments requiring them. During the whole of this time, from the delivery of the sand to the moulder and the tapping of the metal at the cupola, nothing appertaining to the casting has touched the floor, and even at the final stage alluded to, *i.e.*, delivery to the machine shop, the castings are still hot.

A 50-ton Electric Furnace.

The cupola plant is a source of amazement, and consists of 36 cupolas, each of 100 in. diameter, and are used in batches of 18 per day. It is difficult to visualise what this means. These cupolas are charged by hand, which is not in accordance with the latest American practice, but it is Mr. Ford's opinion that this operation cannot be efficiently performed by mechanical methods, a belief in which he is not alone.

It was the original intention to cast direct from the blast furnace, but after an extended trial this did not prove a success.

They are at present installing a 50-ton electric furnace into which it is intended to tap direct from the blast furnace, where it will be refined and sent to the foundry. By this means "pigging" and the consequent hand-charging methods will be eliminated and a considerable saving effected.

The amount of machinery such as chutes, conveyors, mono rails, etc., makes one wonder to what extent mechanical methods can be economically used, but everything appears to perform efficiently some necessary function in a wonderfully organised system.

Carburettors.

The carburettor for the Ford car is made by the Holley Carburettor Company by means of their "Longlife" mould process. This plant was engaged upon an order for 3,000,000 of these castings. The method has been described in recent foundry literature and through other channels, but perhaps a brief description will be of advantage. The moulds or dies, 16 in number, are arranged on a circular turntable, and are first treated with a composition which gives a white coating to the dies. These are then revolved and brought to a position where they come into contact with an acetylene flame, which causes a deposit of soot. Continuing their revolution around the table, such operations as the insertion of cores, closing of mould, casting, removal of casting, etc., in ordered sequence are performed. The castings so produced are then in what is known as a "white" condition, and, as such, machining is impossible. They therefore go to an annealing oven and go through the process of annealing for a period of 45 minutes. A rearrangement of their plant, now in progress, will result in the production of these castings without any handling previous to being annealed.

At another large and comparatively modern foundry similar use of mechanical methods were in operation. Moulding machines of one type only were installed. These machines were located under a sand-handling equipment which maintained a constant supply of sand in an overhead bin, so arranged that the operation of a lever caused the liberation of sufficient sand to fill the flask exactly on the moulding machine. Conveyors similar to those already described were in operation, and even runners and risers were similarly dealt with and returned to the cupola by this means.

Very great care was taken to ensure that correct metal thicknesses were obtained, and with this object in mind some of the cores used had their joint surfaces ground on Churchill grinders after assembling to ensure the correct depth of the assembled core. Defective castings were carefully inspected, and such as could be recovered without any ultimate risk were heated up in stoves and welded. This is a line of thought to which we should give some attention in this country. They also possessed a very large modern brass foundry in which 12 electric furnaces were installed.

Malleable and Steel Foundries.

In such details as have already been dealt with, similar conditions apply in the malleable and steel shops. Sand cutters are in operation, as also are similar sand-mixing plants. Beyond this, however, there are the annealing methods in operation in the malleable shops. The several shops visited were in some cases equipped with annealing furnaces fired with pulverised fuel, whilst others were gas fired, one annealing oven being 167 ft. long with a conveyor running through.

Elaborate temperature control was practised during the annealing operations, and the operations differed inasmuch as some firms used packing material during annealing whilst others did not.

Core Shops.

The author paid special attention to the core shops, and found that greater use was made of machinery in this department than is the practice in this country. He was particularly interested in, and more than a little convinced by, the efficiency of a blowing machine which he had not previously encountered. There were several types of these machines, but he was greatly impressed by the work done by one of these types, of which the construction was very simple and which appeared to give a correct core. Repetition work is necessary if these machines are to be efficient, and owing to the sand being deposited into the boxes by means of compressed air, metal boxes are essential. Careful consideration has to be given to their design, and intricacies have to be specially considered. Speedy output is easily obtained, and probably its use can be widely applied.

Core-shop design and arrangement appear to receive very careful consideration, and they are probably far in advance of our own. In the first place greater use is made of core-making machines, similar to the ones just described. Metal core-boxes are very largely used, care being taken both in their design and manufacture to ensure the most perfect cores. Drying arrangements are very efficient, and the old-fashioned coke-fired stoves, so common in this country, are rarely if ever met with. Instead of this, gas firing or hot-air drying is usually installed. In one of the foundries visited the author was fortunate enough to find one where electricity was used as a medium for providing the necessary heat. It was somewhat novel in design and closely resembled our present-day electric cooking stove used for domestic purposes, except that the shelves were of the revolving type.

Temperature Control.

Temperature control is very largely in evidence, and is very closely adhered to In some shops oil-sand cores are solely used; in one instance, where radiator castings were manufactured, it was stated they used 100 tons of oil sand per day. In many instances the cores are fixed in cradles whilst being dried.

Stocking and Distributing Cores.

Particular attention appears to be given to maintaining a dry atmosphere for the purpose of stocking cores. This obviously reduces a period of waiting time whilst the cores are being made, and to make this possible underground fires are arranged in their stock room, consequently their cores are not subject to moisture variations and its harmful effects. The distribution of cores has also been closely studied, and in many instances they are conveyed about the shop upon telphers fitted with spring trays, which considerably diminishes the possibility of damage during handling.

Sand Control.

Sand control was a special point of interest as it is so largely neglected in this country. The milling and distributing operations have been mentioned, but the steps taken to ensure the best conditions of the raw material are of paramount importance. Of course, this is governed by the nature and size of the shop, but it is given close attention in some of the largest and more modern shops, and advantage is taken of the standard tests as applied by the American Foundrymen's Association. In this test a weighed quantity of sand is subjected to a standard method of ramming and the difference in the length or height of the resulting body of sand when compared with a standard figure for dry sand indicates the amount of moisture present, as it is well known that the moisture present governs the closeness of the ramming. These cores are then placed under a permeability test, which consists of passing a known volume of air through the core and the time taken for its passage indicates its permeability.

A third test is then applied for the estimation of the strength, when pressure is carefully applied by means of a recording press, and the pressure applied before the collapse of the core indicates the bond of the sand.

Some of the foundries exercise very great care in controlling the moisture content of the raw sand, and in one of the shops visited provision was being made by the erection of 10 huge ferro-concrete covered bins for the storage of some 2,000 tons of sand. This was a striking contrast to the usual crude methods so common over here.

Fettling Shops.

Their dressing shops were usually supplied with sand-blast plants, such as the Pangborn and Sly-blast, etc., all of which appear to be very efficient and certainly give an added attraction to the dressed castings. Some of these machines have mechanical loading attachments which greatly add to the saving of labour. Another interesting feature observed in one foundry was the removal of the cores by means of water, using a jet emitting water at a pressure of 400 lbs. per sq. in. This was a very expensive installation, and was used on account of the difficulty experienced in getting suitable labour, and also owing to the fact that their core sand was prepared in such a manner that when baked it attained a great degree of hardness.

It is difficult to see this method being either necessary or advantageous with our method of coremaking.

Having thus dealt with the impressions gained of the working of typical American foundries, which also explains much, if not all, of what was to be seen at the Detroit Exhibition, the conclusions arrived at after the visit may be summarised as follows: —

Firstly, there is the comparison between the worker over there and the worker in England. When one arrives in America he is immediately impressed by the enthusiasm shown by the worker, his infectious habit of praising everything American, including his job, his shop, his town and his capability of earning high wages.

In a few words, he starts off with a much greater advantage than his fellow worker over here, who usually grumbles at every condition, however good it may be, and views with distrust every effort made by his employer. If we could create the same atmosphere and change a man's temperament and his general outlook on life there is no doubt it would be beneficial to all.

The author has obtained much information concerning times and prices, and since his return has compared them with similar jobs worked in the foundry with which he is connected. In many cases our prices are more advantageous to the man, and excluding comparisons with shops where mechanism seems to have run riot, conditions are similar, but except in a few special cases production is considerably higher in America.

The Americans have beaten us on mass production both in cast iron and malleable. One reason for this is that with the possibility of mass methods they are thus compelled to make a much closer study of the details involved. They are not afraid of scrapping any plant, however costly, if something better can be installed, as they know it will be worked to the best possible advantage by the men.

Their shops appeared to be either very bad or exceptionally good, there being no medium.

When asked what they were going to do for the next generation of moulders, as very few youths were seen in any of the foundries, the invariable answer was that they did not know. It was said many times that their greatest need was the technically-trained moulder who could take charge of large plants. The author's answer was that this type of man could readily obtain a situation in this country. The future development of the British foundry industry depends upon several factors, viz.:—(1) The greatly increased use of compressed air for rammers, machines and drying; (2) the complete conversion of our drying methods either to electricity, gas or hot air with efficient temperature control; (3) the closer supervision of raw materials, and the development of modern methods of sand conditioning; (4) new types and wider use of ramming machines and other mechanical methods; (5) a sufficiency of crane power, speeded up to give the best possible efficiency; (6) a complete change in the temperament of the worker; and (7) the best possible working conditions.

In this last connection the author was much impressed by the cleanly conditions apparent in some of the shops. The time has gone when it was true to say a dirty shop was a busy shop. Cleanliness has a marked effect, not only upon the work produced, but also upon the worker. So much is thought of this in America in the modern shops that competition is encouraged between the various departments.

In one shop a banner is held for a period of three months by the section considered to be the cleanest, and the possession of this banner brings with it a small monetary reward for each of the workers in that section. The aluminium foundry were the possessors at the time of the author's visit. The men were enthusiastic and competition was very keen, and the general effect upon the appearance of the whole place was very pleasing.

The Safety First Movement was very energetically pushed in all shops, and everything is being done to get workers to realise that it is disadvantageous to everyone to get damaged.

The author's party was composed of representatives from France, Belgium, Germany, Holland, Denmark, Italy, Spain, Sweden and Great Britain. One of the most unsatisfactory features of the British party was that they were by far the oldest representatives—there was a dearth of young men, and it was obviously a trip which should have been taken advantage of by the younger element who will be the industry's controllers of to-morrow.

DISCUSSION.

Relative Status.

Mr. Spedding asked for some information regarding the status and prospects of craftsmen in America. Was the technically trained man wanted in the foundries there? Could the technically trained man reasonably look forward to getting high wages with a soft job. In America specialisation was carried very far; did it result in the foundrymen showing a lack of interest in their jobs?

Mr. Jolley said the craftsman, as he was known in England, the practical foundryman, was not wanted in America except in jobbing shops. Having seen how operations were carried on, the statement in Mr. Henry Ford's book that he could make a moulder in a day and a half did not surprise him. Seven men stood by the rails on which the mould moved. One man's job was simply to pick two bosses out of a core, then turn round to pick another two out, as he did so the core moved on and there was another in its place. That was his work, and he was called a moulder.

The technically trained man was wanted in every country. In the world to-day no industry offered better prospects than the foundry did to the practical man who had got some technical training.

He did not observe that the workmen showed a lack of interest in their jobs. Those he asked questions seemed to know more about the work they had in hand than the average moulder in this country would. They were of the multi-partner type, and could tell what a casting was intended for, where it was machined, how much scrap was made, and similar data. In his opinion that was a good sign; he liked the man who knew a little more than just the particular thing he happened to be doing himself. But it must be remembered that the people he got into touch with spoke English; a great many workmen did not speak English, and he could not give any information as to their views.

The immensely bigger demand led to specialisation, and because of that specialisation they had not the same need for the craftsman as there was in this country.

In almost every shop there was some method of stimulating the workmen and creating a spirit of competition amongst them. Sometimes a broom was treated as a trophy and hung up in the shop of the winners. In most shops a small monetary reward was given. Where this spirit of competition was encouraged the men appeared to get along with their work better and the shops were kept tidy.

Industrial Relationship.

Mr. S. G. Smith said he was glad Mr. Jolley had qualified the statement that the skilled moulder was not wanted in America with the proviso "except in jobbing shops." It could certainly be claimed for the credit of the British skilled moulder that when he got into an American jobbing shop he had not much difficulty in stopping there. The Ford system was undoubtedly a revelation. As one man expressed it a little while ago, everything was moving in that factory except the men.

Had Mr. Jolley gone into the question of the relations between employers and employed in the American foundries? It certainly appeared that in some of the factories the employees were looked after much better than they were in this country. Perhaps Mr. Jolley could also throw a little light on the question of the status of the moulder. He had heard a tale that a gentleman who visited America as one of a delegation some time ago wanted to make inquiries of one of the ordinary moulders, and went to see him at his house after working hours and found him at dinner in evening dress.

They had heard how the time allowed to particular operations was cut down. Did the figures which were given apply to work actually done under ordinary circumstances or did they represent bursts of speed?

Time Apportionment for Machine Moulders.

Mr. Jolley said he agreed that skilled moulders were required in the jobbing shops and there only. When they came into a specialised shop they were apt to become a nuisance; they would not take the risk of eliminating.

It was a fact that in the Ford establishment everything moved except the workman. In one case he was told a casting travelled a mile and a-half backwards and forwards in one building. He was told that as the casting did not get as cold as they wanted it to be, they intended making a runway over the roof and taking the casting over the roof. Wherever he went the relations between employers and employed appeared to be very cordial. In the shop the people connected with the management spoke to the workmen in a very friendly way, and the spirit of courtesy appeared to go right through.

Reply to Mr. Smith's question about the times allowed for moulding operations, Mr. Jolley said:—

Here is a statement of the times in which moulding operations can be carried out. It is desired to emphasise that these times do not represent bursts of speed, but reasonably energetic work by a trained man, such as is done in very many foundries in the United States; probably they are being beaten regularly every day in Great Britain:—

	Seconds
(1) Pick up match with patterns and place in working position	4
(2) Place drag on match	4
(3) Sprinkle parting material	3
(4) Riddle on sand	6
(5) Fill mould with sand	8
(6) Peen round edges of the mould... ...	8
(7) Ram with flat rammer	15
(8) Strickle off surplus sand	6
(9) Put on bottom board	5
(10) Roll mould over	4
(11) Remove match	5
(12) Put cope on drag and place down tube for gate in position	8
(13) Put on parting material	3
(14) Riddle on sand	6
(15) Fill cope and fill riddle	11
(16) Peen round edges	8
(17) Flat ram	15
(18) Strickle	7
(19) Withdraw tube for gate and make pouring basin	10
(20) Rap and lift cope	8
(21) Place cope on side shelf	3
(22) Rap patterns	10
(23) Lift patterns	20
(24) Clean and replace patterns in match ...	8
(25) Cut gates	15
(26) Repair mould (very variable say average)	15
(27) Close mould	7
(28) Carry out and place on floor	12
Total	234

On a rough analysis it will be seen that many of these operations are identical whatever the patterns and with any machine, for machines are concerned only with ramming the mould and drawing the cope and patterns and do not, for example, place bottom boards in position or place the mould on the floor.

Operations 2, 3, 4, 5, 8, 9, 10, 12, 13, 14, 15, 18, 21, 27 and 28 come under this heading. The time spent on them amounts to 93 seconds, or 40 per cent. of the total time for one mould. Other operations may be entirely changed by changing the patterns; these are 1, 11, 19, 22, 23, 24, 25 and 26; for example, the fixing of the patterns on a plate with a runner pattern fixed to them eliminates 1 and 11 and reduces the remainder considerably. On the other hand, the use of poor or damaged patterns may raise 23 and 26 to almost any figure. The total time occupied in these operations which are liable to alteration through pattern changes is 87 seconds, or 38 per cent. of the time for one mould. Certain of these operations concerned with patterns Nos. 22, 23 and 26, are also susceptible to alteration if a machine is provided with arrangements by which the cope can be disengaged perpendicularly from the pattern and the pattern from the drag while a mechanical vibrator of some sort is shaking the pattern so that the withdrawal is facilitated.

These have therefore to be classed with No. 20, giving 53 seconds, or 23 per cent. of total time. The only items remaining are Nos. 6, 7, 16 and 17, which are concerned with ramming, and on which it is to be expected that time will be saved by the introduction of a machine embodying a mechanical ramming device; these take 46 seconds, or 20 per cent. of total.

Summarising:—

Time depending on manual operations alone, 40 per cent.

Time depending on patterns alone, 17 per cent.

Time variable by use of proper patterns and pattern-drawing machine, 23 per cent.

Time variable by use of ramming machine, 20 per cent.

Sand Slingers.

Mr. Key said he would be very glad if Mr. Jolley would state what he had seen of the advantages or otherwise of sand-slinging machines.

Mr. Jolley said he saw such machines in operation in, he should think, 50 per cent. probably more of the foundries he visited. They were of many types, and were used in many different ways—stationary, tractor, portable and locomotive types. Some were of prodigious size. One occupied a space of 40 to 50 feet long, 12 feet wide, and had a span of 27 feet. That type required a special shop to accommodate it. It was a striking feature of the American foundries that they appeared to go in for a bigger type of machine than was usual in this country. He saw one machine of a portable type, to which two roundabouts had been fitted, and they were kept going the whole of the day. In another place a machine of the very big type was working, but the superintendent of the place did not seem very happy with regard to it; the trouble apparently was that the machine had cost an enormous sum, and he could not keep it going full time. There was no doubt such machines were good for certain jobs. He was led to believe such improvements had been made that the American machine to-day was a very different article from that which was in use three or four years ago.

Electric Resistance Grids.

Mr. A. Sutcliffe said it appeared from the catalogue of an American company in his possession that 5 per cent. of nickel was used in manufacturing electric resistance grids. This must increase the cost. What was the reason for it? He would like to know Mr. Jolley's views on the subject. Then another point he was interested in was the way in which the metal was transferred from the cupolas. What methods were used for that operation?

Mr. Jolley said he visited some places where electric resistance grids were made. These were liable to be subject to rough treatment, and he observed in the moulding shop how the inspector threw them across to another man standing four or five yards away. Then they had to be sent great distances, sometimes as much as 600 miles. The addition of nickel to cast iron made a very tough metal, which would bend and not break. He believed that was the reason the nickel was added, because, without that addition, it would be almost impossible for the grids to get to their destination whole. It did add to the price, but it was justified on those particular jobs.

With regard to transferring metal about the shop, the conditions in America were very different from those which existed in this country. Every shop had its own peculiar method. In the Ford works there was a telfer, which served 36 cupolas, and a gang of men were constantly employed taking metal to the moulds. They were largely worked by coloured labour.

Mr. Sutcliffe: What is the weight of the ladle?

The Chairman replied that it was about 1,000 lbs. In another place that he visited, which turned out 170 to 200 tons per day, all the metal was taken away from the cupola by automatic trucks. It appeared to him a very good system, very labour saving. It was so arranged that they could pour the metal from the ladle into the shank.

Birmingham, Coventry and West Midlands Branch.

SOME EXPERIENCES WITH MALLEABLE CAST IRON.

By H. Field (Member).

The concern with which the author is associated having now ceased to make malleable cast iron, of which, incidentally, they were one of the oldest makers in the country, it has become possible and perhaps desirable to sum up the experience gained therein, and pass it on to those still interested in this trade before it shall have slipped from memory. The Paper is not intended to be a comprehensive guide to malleable founding and annealing, but simply includes notes on a number of interesting points which have arisen from time to time. As far as possible, practice rather than theory will be dealt with.

The pig-iron used for this work is necessarily hematite, since only such irons contain that low phosphorus-content of under 0.1 per cent. which is essential for the production of a malleable product. Attempts have been made to use other irons with higher phosphorus content, more especially when pig-iron was so scarce during the Great War, but it may be taken as impracticable to use iron with 0.2 per cent. phosphorus or over, whilst standard tests cannot be obtained except with less than 0.1 per cent.

Many of the irons offered for this purpose are termed "refined," but it has always been difficult to get information as to the nature and purpose of the refining process. Generally, it seems to consist of melting in a species of cupola, with high pressure blast, so that to a small extent the molten metal is Bessemerised and its carbon, manganese and silicon contents reduced. This was apparently the general practice in days prior to the present decade, but the author surmises—perhaps incorrectly—that of recent years there has been a tendency to produce the "steel effect by the simple addition of steel scrap to the original hematite pig in the cupola. In any case experience suggests that better malleable castings can be made from "refined" irons than from the coarser grades.

The fractures chosen for this work extend from white to soft mottled, corresponding generally to a silicon content of 0.5 per cent. to 1.0 per cent.

Fig. 1. × 50.

Clumps of Free Graphite in an otherwise White Iron.

The requirements in this direction naturally vary between the Coventry motor trade and the Walsall saddlery trade, but hard mottled iron with 0.75 per cent. silicon will produce a very wide range of castings if annealed correctly.

For some years now there has been on the market an East Coast refined iron cast in chill moulds, and in the use of this brand mixing by fracture breaks down, for the small section of the pig has a wholly white fracture over a very wide range of silicon content. Pigs have been found in the same truck with silicon from 0.6 per cent. to 1.65 per cent., yet quite indistinguishable by a mere visual examination. Such iron is rendered white by chilling, and not by its analysis, hence after remelting, when the chill effect disappears and the analysis regains control, the resulting metal will have a totally different fracture and may even contain some primary graphite spots. In an experiment some of this iron containing 1.2 per cent. silicon was melted

Fig. 2. × 50.

As Fig. 1 Etched. Showing Alternate Patches of Grey Iron and White Iron.

in a crucible and cast into a varied size of bars. At the same time a melt was made with a West Coast iron containing equal silicon but of a fracture so grey that the pig could easily be drilled. The fractures of the two sets of bars when placed side by side were indistinguishable whilst the analyses were also practically identical. The results of the experiment are shown in Table I.

TABLE I.—*Chill Cast and Sand Cast Pig-Iron.*

Pig-Iron Used.	Sand Cast.	Chill Cast.
Fracture of pig	Grey.	White.
	Per cent.	Per cent.
Analysis of Pig-Iron : Si. ..	1.15	1.19
S. ..	0.22	0.20
P. ..	0.13	0.065
Mn. ..	0.32	0.28
T.C. ..	3.47	3.50
C.C. ..	1.0	3.50
Fracture of 1 in. sq. test bar	Grey.	Grey.
$\frac{7}{8}$ in. rd. test bar	Grey.	Grey.
1 in. × $\frac{3}{8}$ in. test bar	Grey centre, White edges.	Grey centre, White edges.
	Per cent.	Per cent.
C. C. in 1 in. bar	1.20	1.20
Transverse test on bar 12 in. × 1 in. × 1 in. ..	Cwts. 28.3	Cwts. 25.3
Deflection	0.120 in.	0.110 in.

The test bars from these melts were annealed along with other malleable work, and the results can be used to demonstrate the influence of primary graphite in malleable cast iron. There is no more powerful weakening influence in cast iron than large flakes of graphite, and when present in annealed malleable these flakes readily lead to breakdown. The 1 in × $\frac{3}{8}$ in. bars which before annealing had grey centres and white edges gave after annealing only 5 per cent. bend in each case, whilst the annealed $\frac{7}{8}$ in. bars when turned down for tensile tests broke at 11.2 tons and 12.0 tons respectively, without measurable elongation. Where this form of graphite is present there is no pearlite formed on annealing, and therefore a lower tensile results, and since the graphite breaks up the continuity of the metal this prevents any reasonable elongation of the ferrite matrix Such graphite spots generally occur near the centre of the casting, the outer portions remaining white, and as this white iron after heat treatment yields pearlite, there occurs the unusual phenomenon of the outside of the malleable casting being higher in combined carbon, and consequently harder, than the centre.

Fig. 3. × 50.

After Annealing. Large Patches of Primary Graphite still Persisting Together with Small Dots of Secondary Graphite.

Figs. 1 to 6 illustrate these points.

It is essential that the pig-iron used should be as low as possible in sulphur. The malleable founder is fortunate in that he can produce good castings with iron much higher in sulphur than could be tolerated in any other branch of the iron or steel industry. Were it not so he would long since have been compelled to abandon cupola melting, for with the rather large proportion of coke required for melting, and the heavy percentage of scrap, produced by runners and feeders and necessarily included in the furnace charge, it is difficult to run a malleable foundry and consistently keep the cupola metal below 0.3 per cent.

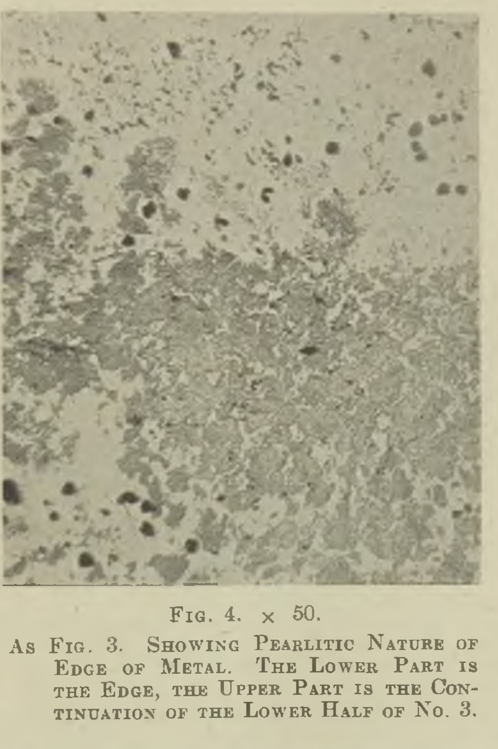

FIG. 4. × 50.

AS FIG. 3. SHOWING PEARLITIC NATURE OF EDGE OF METAL. THE LOWER PART IS THE EDGE, THE UPPER PART IS THE CONTINUATION OF THE LOWER HALF OF NO. 3.

in sulphur. Some pigs on the market regularly contain 0.4 per cent. and the author has handled certain brands with as much as 0.85 per cent. sulphur, under which conditions it will be difficult to keep the cupola metal under 1.0 per cent. of sulphur.

Sources of Pig-Iron.

The chief centres for producing this pig-iron are the North-East and North-West Coasts, and it may be taken that the West Coast irons are generally characterised by higher manganese contents than the East Coast ones. In addition to the refined irons, there are well-known brands of first quality such as Lorn charcoal iron, produced under conditions favourable to purity, but their price is too high to allow of universal adoption. Pig-iron of suitable quality for malleable work is also pro-

FIG. 5. × 100.

WHITE IRON. SILICON 0.69 PER CENT.
SULPHUR 0.068 PER CENT.

duced in the Midland district, and is establishing a reputation for itself.

Melting Conditions.

As a result of the comparative purity of these white pig-irons as compared with ordinary grey iron, the melting point is higher and the range of useful fluidity more restricted in malleable practice than in grey. Thus it is essential to melt at a higher temperature, which is accomplished partly by the use of higher coke ratio and partly by a lessened tuyere ratio—which latter results in an increase blast pressure. It may be taken as excellent melting practice if 1 cwt. of coke will melt 8 cwt. of iron exclusive of bed, and from 14 to 16 ozs. blast pressure is quite usual.

FIG. 6. × 100.

WHITE IRON. SILICON 0.76 PER CENT.
SULPHUR 0.345 PER CENT.

These pig-irons exhibit larger liquid and solid shrinkage than does grey iron. The increased liquid shrinkage necessitates the use of larger feeding heads and of chills, whilst the increased shrinkage after solidification renders it advisable to provide a "letting-down" muffle for all heavy or intricate castings, so that cracking may be avoided. Such a muffle is kept at about 600 to 700 deg. C. during casting time and allowed to cool down very slowly over night.

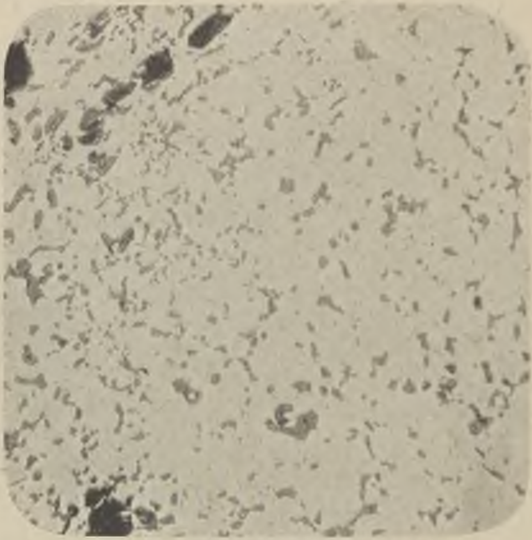

Fig. 7. × 50.

Iron with 1.8 per cent. Silicon. $\frac{1}{4}$-in. Section was very Badly Oxidised in Annealing. Dark Patches are all Oxide.

Some remarks have already been made upon the analysis of the melted metal. This depends to a large extent on the weight and section of casting under review. Under proper control much variation in analysis can be rectified in annealing, but even so the author found it impossible to produce malleable iron from pig with 1.8 per cent. silicon, when none other was available, as oxidation sets in as soon as annealing is commenced, and even after a short time in the oven sections $\frac{1}{4}$ in. thick contained oxide right to their centres. Such metal is shown in Fig. 7.

At another time during the scarcity of pig-iron the only supply of pig-iron showed 0.85 per cent. sulphur, resulting in a casting with over 1.0 per cent. sulphur, but after one or two failures this obstacle was successfully surmounted in annealing.

It is well known that manganese above 0.4 per cent. retards annealing as a result of the stability of manganese carbide. Some of the West Coast irons contain 0.5 to 0.6 per cent. manganese, but the high sulphur in the cupola metal carries away so large a proportion of this percentage that the final amount in the melted metal is rarely over 0.25 per cent., which is not sufficient to retard annealing. In the manufacture of can-metal with over 1.0 per cent. manganese it is found necessary to use in the cupola charge about double the manganese desired in the melted metal. After a normal annealing this high-manganese metal gave 31.5 tons tensile, 10 deg. bend, and 8.0 per cent. elongation. Whereas ordinary malleable bars annealed in the same can gave 22.8 tons tensile, 75 deg. bend, and 11.1 per cent. elongation.

Size Limitations.

There are upwards limits of section which cannot be successfully malleablised. Heavy castings 4 or 5 in. thick can be repeatedly annealed so that the true malleablising penetrates for a distance of 1 in. or so and the whole casting is thus rendered exceedingly strong; but in the author's experience there always remains over 2 per cent. of carbon at any depth greater than $1\frac{1}{2}$ in., and under these circumstances the interior metal, although soft to a drill, would, if cut into test-bar form, show only a very low extension and bend properties. Such castings find extensive use in engineering construction, but it should be clearly realised that for true malleable iron, to give 45 deg. bend or 5 per cent. elongation, a section of $\frac{3}{4}$ in. represents the practical maximum.

The difficulty most often encountered is not, however, the malleablisation of such heavy sections, but the successful annealing of the combined light and heavy sections which go to make up so many of the castings called for by engineers. Sudden changes in section from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. are encountered and are most difficult to deal with. If the buyer would expect from the heavier parts of such castings nothing more than machinability it would be possible to meet his requirements, but when ductility is demanded in every part of the casting the proposition is an exceedingly stiff one. Again, a heavy boss, perhaps $1\frac{1}{2}$ in. in thickness, attached to an otherwise light casting, often renders at least double annealing time necessary, apart from the difficulty of uniform annealing already referred to. This hinders production, and thus arises one of the greatest handicaps from which malleable castings suffer, *i.e.*, time required for delivery after receipt of order. Every opportunity should be taken to lighten such bosses by using maximum-sized cores possible, for a $\frac{3}{8}$ in. core often saves three days' annealing. In the author's experience all varieties of levers called for by different sections of engineers are great defaulters along these lines.

Whilst there is a modicum of truth in all the talk of co-operation between engineer and malleable foundry, the founder might also save much trouble for himself if he would seek a true realisation of the needs of the user of malleable iron. Speaking generally, there is a continual flow of castings back from the engineer to founder for re-annealing owing to hardness, and if the founder would set himself to ascertain the machining speeds used or desired by his customer and set up a simple machine to test his castings in this direction, there would be far fewer rejects than now obtain. Beyond the border line of obviously hard metal there are many degrees of annealing before a maximum toughness is reached, and the requirements of the user can be met if they are studied and allowed for in annealing. The author's firm, after being makers for many years, are now buyers of malleable castings, and thus he can speak for both sides of the industry.

It is not proposed to deal with the annealing oven design in this Paper. The old rectangular coal-fire oven, with grates running about three-quarters of the length down each side, is now much despised, but its one great advantage is its varying temperature from wicket to fire-hole, thus providing for the careful worker a means of dealing with a variety of sections in one oven. In such ovens there is no difficulty in annealing maximum and minimum sizes of castings in one anneal, for the temperature variation covers a range of 50 deg. C. more or less, and this compensates for the difference in section. In circular ovens more difficulty is encountered, and it is necessary to run separate heats for light and heavy work, a necessity which in a small concern often causes delay. In the rectangular ovens referred to the temperature in the hottest part of the oven should be maintained at 960 to 980 deg. C. for iron of generally suitable analysis. It is, of course, desirable to equip ovens with recording pyrometers, but where the cost is prohibitive very successful control can be maintained by recorders of the Watkins type or by Seger cones.

Jolt-Filling of Annealing Cans.

The production of good castings is in one sense largely dependent on the careful packing of the hard castings in the cans. With work of intricate shape and in hollow forms any careless filling will result in such badly distorted castings that correction in the dressing shop may be impracticable. In the States these cans are generally filled by jolt rams, and in a few simple tests the author found this an excellent method—provided plant is available. Distorted castings are often strained during cold straightening, and were it not for the large margin of safety adopted by the designer, failures in such castings would result.

Types of Ore Used.

For successful annealing two distinct types of ore are necessary—old or used ore and new unused ore. The new ore is red hematite, and can be obtained in varying sizes, that known as 60 kibble being most suitable for ordinary work. The quality of this material from different mines varies considerably, and may also vary from the same mine. The only constituent of value is ferric or iron oxide, Fe_2O_3, and a good ore should contain from 80 to 90 per cent. of this, the remainder being principally silica in the form of quartz. In poor ores abundant white pieces of this quartz are visible after washing, and if present in excessive quantity, will cause the ore to stick to castings. Lime, when present above 2 or 3 per cent., has the same effect but in a more marked degree, and in the author's experience ores with over 6 per cent. lime have given disastrous results. Table II gives details of some red hematite ores.

TABLE II.—*Annealing Ores.*

Description.	FeO	Fe_2O_3	Fe_3O_4	SiO_2	CaO
New ore. Good supply	—	90.7	—	4.7	0.85
Poor ore. Same supply	—	68.7	—	23.8	2.0
Poor ore. Same supply	—	63.7	—	30.3	1.95
Poor ores, all satisfactory in use..	0.6	70.0	—	19.4	3.8
	—	67.8	—	11.9	7.35
	Nil	74.1	—	7.9	8.3
	1.3	71.6	—	12.3	10.3
Used annealing ore	—	Nil	79.3	20.3	0.8

When heated in contact with iron, whether of the casting or the annealing can, red hematite ore blackens and changes almost entirely to Fe_3O_4, the magnetic oxide. This form of ore and oxide is essential for annealing, as apart from any question of cost, new ore alone will not do the work properly. When the red ore alone is used it so strongly oxidises that all carbon is rapidly removed from the outer layers of metal, and oxidation of the iron then commences so that a layer of scale is found on each casting. When removed, this leaves the casting rough and under size, and of course there is always a more or less oxidised layer remaining which is unsuited for either a machining or a finished surface. In such cases the removal of carbon from the surface is accomplished at a rate faster than it can be supplied by diffusion from the interior, and the net result is that complete annealing, *i.e.*, malleablising right to the centre, is often less rapid with all new ore than with standard mixture. Fig. 8 illustrates such a case where similar castings were annealed under conditions alike in every way except strength of ore. The lower casting annealed in all old ore has a faint core of unannealed metal, while the upper one from all new ore is not more than half-annealed. The correct ore strength varies according to requirements, but four parts old ore and one part new ore is a good working standard. Annealing cannot be hastened by increasing the strength of the ore mixture much above this level or the castings will suffer.

Fig. 8. Twice Full Size.

Fractures of Castings Annealed in Old Ore and New Ore. Polished and Etched. Centre Dark Portions are Hard Metal.

Upper.—New Ore. Lower.—Old Ore.

From these considerations it becomes evident that not new ore only but also old ore must be regarded as one of the essential raw materials of the annealing process. With sudden increase of requirements there may be a shortage of old ore, and unless it can be acquired from a neighbouring foundry the shortage will be serious and costly. There is no ready method of converting red ore to black except by its use in annealing. It has been suggested that in such cases the old ore be replaced by scale from cans, but the author's experience has been that such a mixture is still strongly oxidising towards the skin of castings, although certainly less so than new ore alone. The use of turnings is more satisfactory, but these should be from steel, not high phosphoric cast iron, as in the latter case they will tend to fuse with the ore. There is, in fact, no cheap and simple method for this conversion, and the safest plan is to mix the new ore and turnings, or, better still, scrap unannealed castings and charge these into the cans in the usual way without any work for annealing. After a few days' firing a good stock of old ore is obtained without risk of spoiling an oven full of work. The conversion cannot be brought about by the simple application of heat to new ore, but contact with metallic iron is necessary.

To obtain a good skin on the thinnest castings it is advisable to sieve the ore from time to time in order to remove fine particles, amongst which will be found a major portion of the more fusible components. In neglected stocks of ore this riddling may reduce the available ore by 30 to 50 per cent. and will then necessitate renewal of stocks as just described.

When the annealing ore is used there is a considerable increase in its sulphur content. Some of this sulphur can be detected as H_2S by adding dilute hydrochloric acid, but the proportion held in this way is really very small, the bulk being present in the oxidised condition. Part of this increase is due to oxidation of the can material, some possibly to contact with gases, but in the major part it is obtained from the castings themselves. This is shown by the increased sulphur in the ore which is found adhering to a casting, the sulphur contents of such ore being above the average of the old ore pile, even when the casting is under-annealed. As soon, however, as the metal reaches the stage of decarburisation at the outer edge, oxidation sets in and there is then a rapid removal of sulphur, and consequent increase in the closer layer of ore. This removal of sulphur from the iron has been dealt with more fully in a study of "peeling," but it may be mentioned here that the particular "peeled" casting referred to in Table III contained 0.59 per cent.

sulphur in the centre, but only 0.22 per cent. at the edge. This table gives some further figures for sulphur in annealing ores.

Annealing Pots.

One of the largest contributors to the cost of malleable castings is the annealing cans in which the ore and castings are placed for annealing. Poor quality cans give short life, but they also lead to wastage through "scaled" castings, where holes develop in the can and in addition entail extra labour in removing the large accumulation of scale from the ovens.

Table III.—*Sulphur in Annealing Ores.*

	Total S.	S. as Sulphide.
	Per cent.	
New ore	0.26	Nil.
Same ore after using once	0.47	0.027
Used ore from stock heap	0.67	Not determined.
Fine ore from surface of hard castings	0.65	—
Ditto well annealed ..	0.85	—
Ditto "peeled"	2.03	—
Scale from castings annealed in new ore	0.21	—

The development of a first-class annealing can along scientific lines has for many years been one of the greatest needs of the industry. The general practice, both of large can makers and of founders making their own cans, has been to market the cheapest possible product, irrespective of quality. The cupola charge consists mainly of old cans, heavily charged with scale, supplemented by scrap-iron and steel of the most variable character imaginable. The product then is a white iron, presenting a fracture honeycombed with blowholes, the life of which is determined by its weakest point. By a study of the heat-resisting properties of cast iron it is possible to develop a sound can of greatly-improved service value, which will give a lower annealing cost per cwt. of work than the cheaper but unsound can.

For this purpose the desirable chemical properties are low silicon and phosphorus, medium sulphur and high manganese, together with low carbon. If silicon is allowed to fall too low, say below 0.4 per cent., the metal will always be unsound, whilst if phosphorus rises over 0.3 per cent. the can will soften and bulge at the annealing temperature. Such metal is illustrated in Fig. 9, being taken from a can which collapsed. High manganese is essential for maximum life and

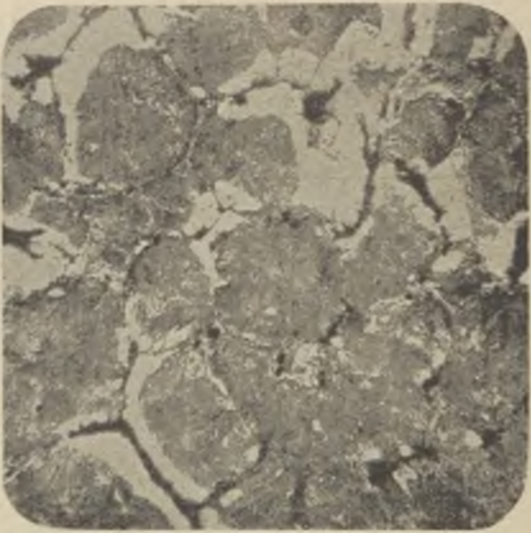

Fig. 9. × 50.

Annealing Can, 0.45 per cent. Phosphorus. Collapsed in the Oven. Phosphorus is seen in Crystal Boundaries.

should be over 1 per cent. in all cases. The author has repeatedly made cans along these lines and obtained greatly improved results compared with the ordinary commercial can. More recently this specification has been adopted by one large can maker and is being worked to as near as practical and economic considerations permit. Owing to the varying length of annealing time used by various founders for the different sections of castings within their trade it is difficult to give details of service tests which could be comparable with other workers, but the tests have always been conducted by finding the can cost per cwt. of work annealed, by recording the number of days service given by individual cans, and by weighing batches of cans every time they come from the oven. A batch of cans made with 2 per cent. chromium was carefully followed through on these lines, but, contrary to expectation, no improved result was obtained.

Nickel Chrome Cans.

A few years ago six nickel-chromium cans were received for test. This metal was an alloy of nickel and chromium with about 10 per cent. of iron, and as it had been successfully used for many heat-resisting jobs there seemed a possibility of an almost indefinite life for malleable annealing cans made from it. The cans were made of lighter section than ordinary iron ones, but even then a 14-in. round can weighed about 80 lbs. and cost £24, against a similar sized iron can weighing roughly 2 cwts. and costing at that time about 12s. Since the latter can gives, say, 7 heats, the nickel-chrome can would be required to give something in the neighbourhood of 200 heats to be an economic proposition, apart from the large capital outlay involved in purchasing 250 or 300 such cans. The actual life obtained was 48 heats, or about 7 times the life of an iron can, but in view of the cost the experiment was deemed a failure. In considering such a proposition two further considerations must be borne in mind: the labour-saving through the decreased weight of the alloy can, and the absence of scale in the ovens, which causes much work in removal and wear and tear of firebricks.

In spite of this failure, the experiment was a most interesting one, and opens up the possibility that somewhere between these two extremes—on the one hand cheap iron with all its disadvantages, and on the other hand expensive nickel-chrome alloy practically non-scaling—there may in the future be found a new material for this purpose.

Apart from test bars called for by the buyer of malleable castings, every oven should contain a selection of such bars distributed at those points known to give lowest, medium and maximum temperatures. Pieces from scrap castings comparable in section with the work being done should be included and used for drilling, turning and bending tests. Reference has already been made to the need for an appreciation of the buyer's machining requirements, and the author has found that a machining speed of about 90 ft. per sec. is a very good test of the machinability of the castings. This can be translated to drilling speeds for various sizes of drills and all sorts of bosses and sections subjected to test. Such a test will not only lessen rejects from the machinists, but will save labour on dressing, barrelling, etc., of castings whose only ultimate fate can be re-annealing. It should be needless

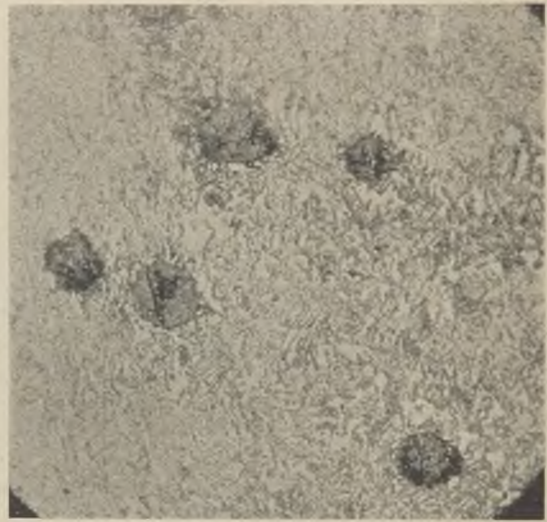

Fig. 10 × 100.
Hard Malleable Iron.
Centre.—Plenty of Cementite.

to urge some such inspection, but the writer is personally aware that in some malleable foundries no such test is ever imposed, and all castings from the ovens are despatched direct to the customer.

Specifications.

Coming now to the question of the actual physical testing of cast iron, the B.E.S.A. have recently issued a specification (5,022/1923) for whiteheart malleable iron as follows:—*Ultimate tensile strength*, not less than 20 tons per sq. in.; *minimum elongation*, not less than 5 per cent. in 2 ins.; and *bend test*, 45 deg. round $\frac{3}{4}$-in. radius. (The tensile test bar is $\frac{5}{8}$-in. dia. in the central part.)

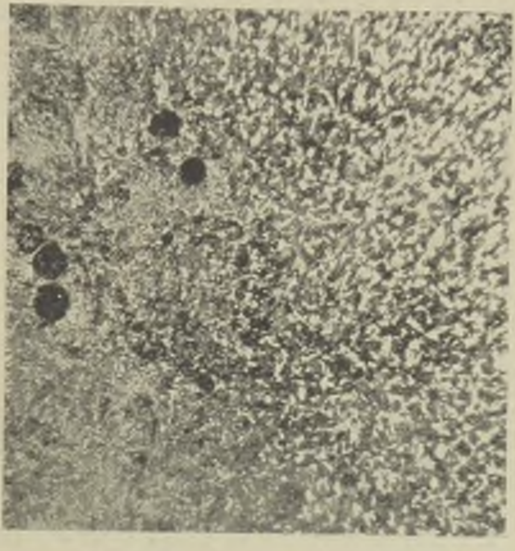

FIG. 11. × 50.
HARD MALLEABLE IRON.
EDGE.—THERE IS STILL A GOOD PROPORTION OF COMBINED CARBON EVEN ON THE EXTREME RIGHT.

Although the writer assisted in the drawing up of this specification, he has always felt that the diameter of the test bar is on the large size. The tensile strength of 20 tons and the bend test of 45 deg. present no difficulty if the iron is of reasonable quality, but a $\frac{5}{8}$-in. bar needs to be well annealed to give 5 per cent. elongation. The purpose of the specification is in part to encourage the manufacturer to produce malleable iron of standard quality, and probably this purpose would be better served by requiring 5 per cent. elongation in 2 in. on a $\frac{1}{2}$-in. diameter bar. Castings of section equal to these test bars will machine without difficulty if annealed under such conditions as enable the bars to give the specified tests, but on the other hand, bend test bars do not readily drill at the speeds previously referred to, unless the bend reaches about 40 deg.

The B.E.S.A. specification makes some suggestions regarding chemical analysis, but its demands are quite reasonable, since good malleable iron cannot be made outside the limits set forth, which read as follow:—The iron shall contain: *Silicon*, between 0.5 and 1.0 per cent.; *manganese*, not more than 0.4 per cent.; *sulphur*, not more than 0.4 per cent.; and *phosphorus*, not more than 0.20 per cent.

Against this may be set the specification issued by one of the principal makers of heavy automobiles, which specified six items in a chemical analysis and four in physical tests. In addition, samples were to be examined microscopically for defects, and might be rejected on the results of such an examination. The complete specification read as follows:—

Chemical Specification.—Total carbon, under 3.00; combined carbon, under 0.50; silicon, under 0.80; manganese, under 0.50; sulphur, under 0.25; and phosphorus, under 0.09 per cent.

A percentage of deliveries will be examined microscopically. If not clean, consignment will be rejected.

Good, clean castings, free from porosity, to be well annealed, and must fulfil the following physical specification:—*Tensile breaking strength*, over 22 tons per sq. in.; *yield ratio*, over 70 per cent.; *elongation*, over 15 per cent.; and reduction of area, over 10 per cent.

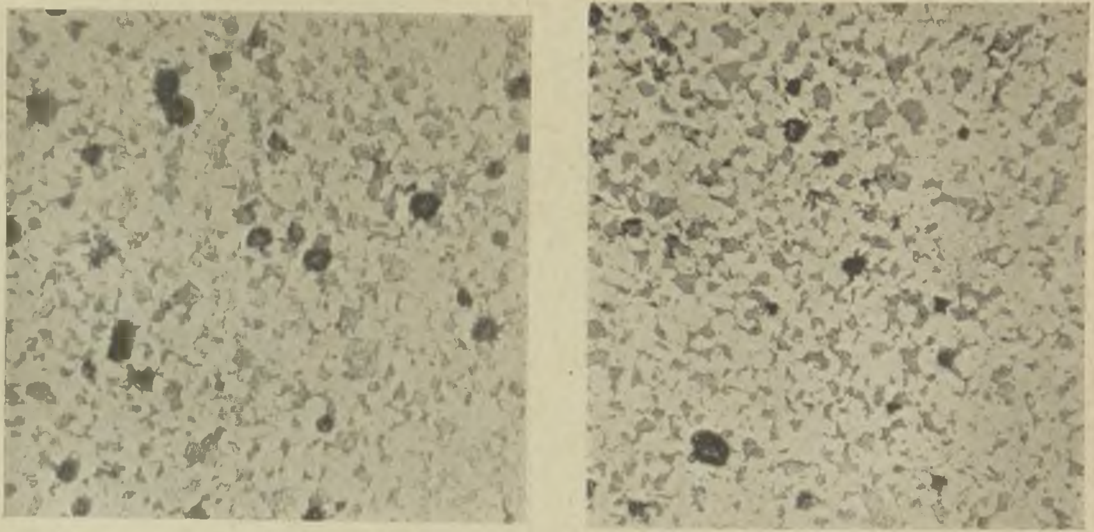

Fig. 12. × 50.

Fig. 13. × 50.

Malleable Iron with High Elongation and Bend.

Centre.

Edge.

All tests to be carried out on a special test piece cast on and annealed with the particular part and tested without machining.

Please supply — test bars 12 in. long × 1 in. dia. with this order.

It is evident that the person responsible for drawing up the specification had no practical experience in making or testing malleable castings, and on representations being made of the impracticability of the demands a vastly different specification was sent down and adopted. It is undoubtedly within the province of the buyer to limit the amount of any such dangerous element as phosphorus in malleable iron, since good malleable cannot be made with high-phosphorus, but to tie the manufacturer hand and foot is both unreasonable and impracticable.

During the writer's practice with malleable iron a ⅜-in. diameter tensile bar was used, and the bend bar 1 in. × ⅜ in. Table IV summarises the results obtained in each of the years 1923-1924.

Table IV.—*Physical Tests.*

	Tensile.	Elongation.	Bend.
Short anneal. Average of 17 tests. 1923	24.3	6.8	53
Short anneal. Average of 25 tests. 1924	25.1	6.7	43
Long anneal. Average of 80 tests. 1923	24.3	9.2	64
Long anneal. Average of 40 tests. 1924	25.1	8.0	55
Highest tensile test	31.0	4.0	30
Highest elongation ..	25.6	15.3	60
Highest bend test	22.8	8.0	95

The fracture of the most ductile of these bars, those, for instance, with over 10 per cent. elongation, is dark grey in colour and amorphous in character. The fracture of malleable iron is an excellent indication of its quality. Fractures of metal very much unannealed are of a bright crystalline character, and this gives place gradually to the darker amorphous type of fracture, the centre being last to change. Where there is

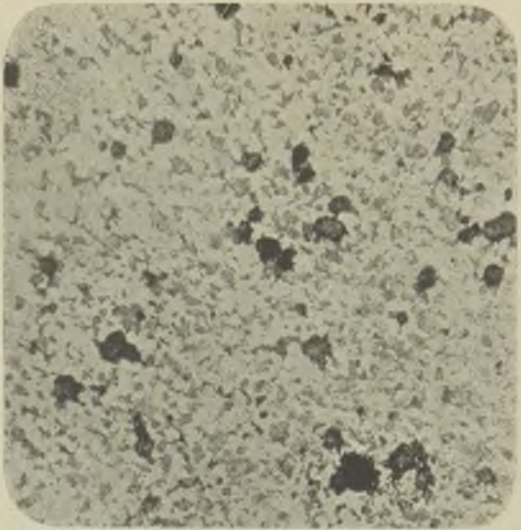

Fig. 14. × 50.

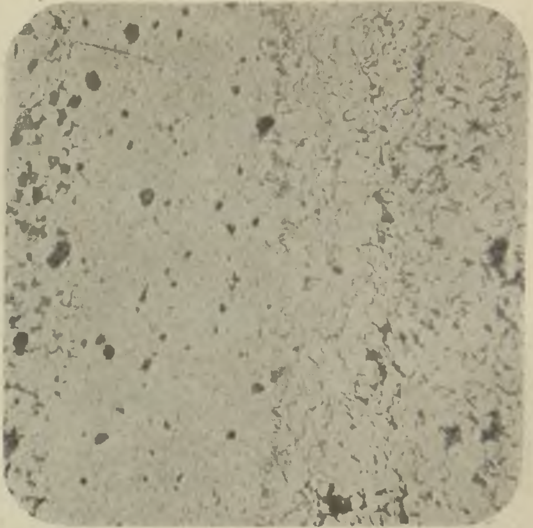

Fig. 15. × 50.

Showing How the Effort to Obtain very Low Carbon in the Bar Results in an Oxidised Edge. Oxide Penetration on the Right.

Centre.

Edge.

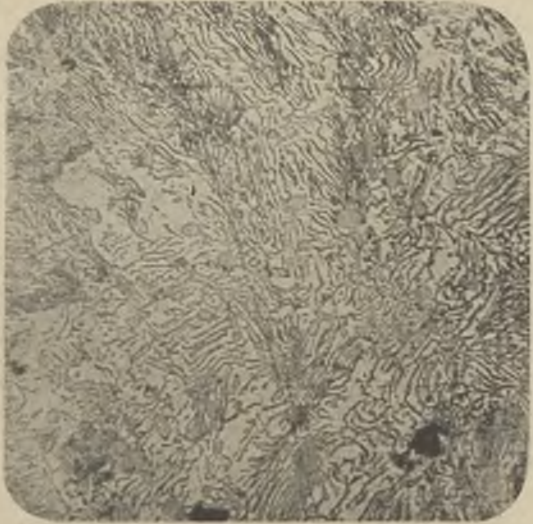

FIG. 16. × 250.

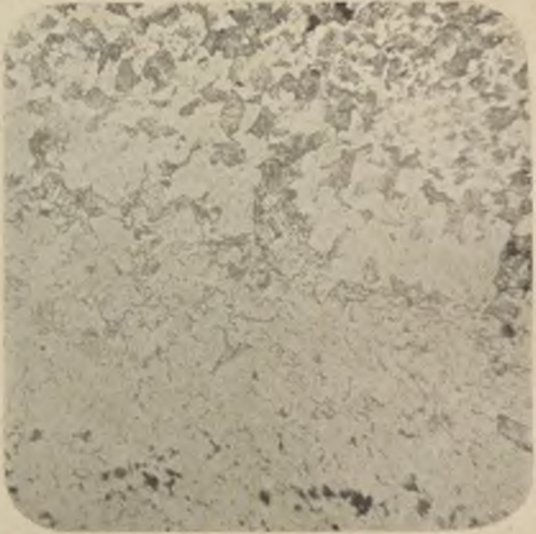

FIG. 17 × 50.

SHOWING HOW MALLEABLE WITH A HARD CENTRE MAY STILL HAVE AN OXIDISED EDGE.

CENTRE.

EDGE.

much brightness, brittleness naturally follows, and on the other hand, no fear may be entertained for metal with the dark fracture, as it will always be of excellent character.

Under the microscope the very bright fracture is found to correspond to combined carbon well over 1.0 per cent., *i.e.*, metal with free carbide. Such a case is shown in Figs. 10 and 11, which show the unannealed centre × 100 and the edge × 50, the latter still containing plenty of combined carbon. On the other hand, the ductile metal contains only 0.3 to 0.4 per cent. combined carbon at the centre and practically none at the edges. this being illustrated in Figs. 12 and 13.

FIG. 18. × 50.

BURNT (I.E. OVERHEATED) MALLEABLE IRON.

It has been stated by some authorities that good whiteheart malleable iron should contain no pearlite, this being replaced entirely by ferrite and annealing carbon. No doubt this is a very desirable structure, but the writer has never found a piece of good whiteheart malleable iron without some pearlite at the centre, and thinks it unlikely that such metal is attainable in practice. The edge can be rendered free from carbon, but some pearlite always remains in the centre. If the annealing be carried any further, oxidation of the edges sets in and the iron then ceases to be of good ductile quality. Such iron is shown in Figs. 14 and 15, although even here some pearlite remains in the interior. As the annealing medium is strongly oxidising in character, it is natural that as soon as carbon is fully oxidised at the edge, the ore should attack the carbonless iron and the penetration of oxide commences. Indeed, if the annealing process be unduly hastened by the use of too strong an ore, the removal of carbon at the outer surface may take place at a rate greater than its replacement from within, and an iron with a hard centre may then have an oxidised skin. This is shown in Figs. 16 and 17, the centre being × 250 and the edge × 50.

The oxide penetration causes brittleness, but it is not to be confused with the effect of overheating. Fig. 18 shows the microstructure of overheated malleable iron × 50 diameters, and the structure is seen to be similar in character to that of other overheated metals.

A number of the commonest defects in malleable castings have already been mentioned. These are hardness in machining, brittleness through under-annealing, distortion, under-size through surface oxidation and "peeling." This latter defect must not be confused with ordinary scaling of surface, due to excessively strong ore, or admission of gases through broken cans. Castings suffering from the "peeling" defect present a normal outward appearance, but the fracture after breaking reveals an inner core, surrounded by one or more layers of "skin" or "peel," these layers being so loosely attached to the core and to one another that they either become detached in the breaking or can be removed by a few blows with a hammer. Fig. 20 shows fractures of "peeled" malleable iron. In extreme cases, or where the castings are very thin, there is at times no core remaining but only this series of layers or skins. The principal trouble with "peeled" castings arises when they are machined, as in either planing or screwing, the entire skin may come away from the core, or screw threads peel off as a string. Barrelling for polishing purposes produces the same effect. For such defective castings there is no remedy to restore the metal to normal quality.

"Peeling" has an exasperating way of appearing without apparent reason, with the result that it has been attributed to many different causes. A few years since, the author, in association with Dr. D. H. Ingall, of Wednesbury, conducted a research on this point, full details of which can be seen in the *Iron and Steel Institute Journal*, 1925, volume 1. The principal points to be watched in avoiding this defect are too high silicon in the metal, and too fast a rate of heating at annealing temperature. The trouble seems due to removal of carbon at the surface at a rate

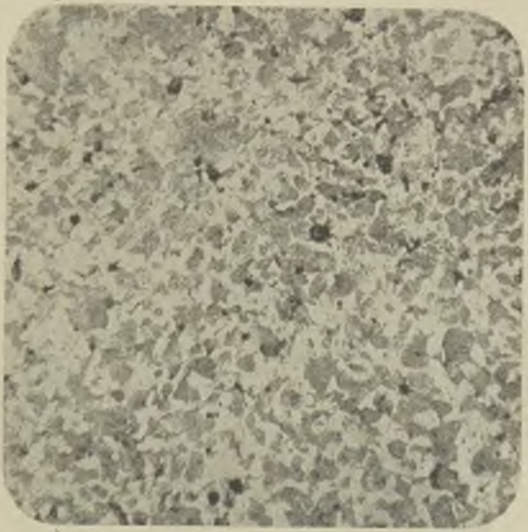

Fig. 19 × 50.

Malleable Iron of Highest Permeability.

greater than its diffusion from the interior. Thus oxidation sets in and proceeds to advance rapidly into the interior of the metal. Sulphur is very

Fig. 20.
Sections of "Peeled" Malleable.

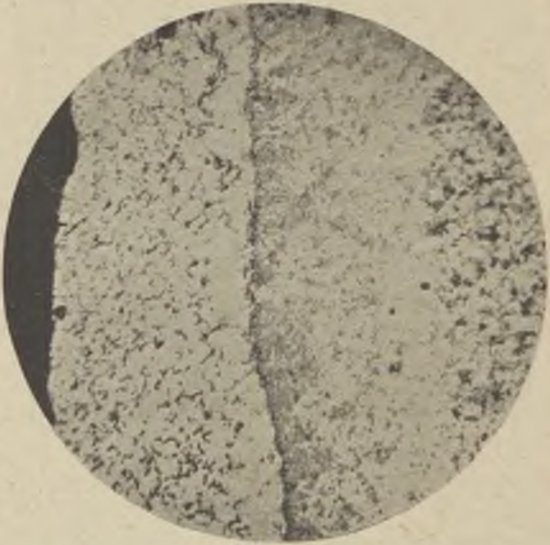

Fig. 21. × 50.
Showing the Three Zones in "Peeled" Malleable.

susceptible to this oxidation process, with the result that the "peel" contains a great deal less of this element than did the original metal. The microstructure of such defective metal is found to consist of three zones in the centre, ferrite and pearlite, around this a zone of ferrite, and an outer zone with oxide penetration. Fig. 21 is an actual case where the three zones are shown × 50 diams.

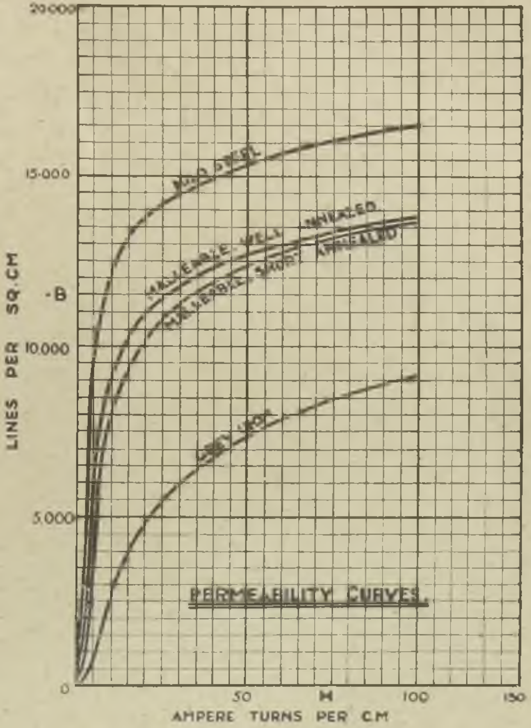

FIG. 22.—RELATIVE PERMEABILITY CURVES OF MILD STEEL, MALLEABLE AND GREY IRON.

Malleable cast iron has a low electrical resistance, but a high permeability. The relation between the permeability of cast iron, malleable iron and mild steel is shown in the diagram (Fig. 22), which also illustrates the necessity for thorough annealing if maximum values are to be obtained. Fig. 19 shows the low amount of combined carbon remaining in the sample from the upper curve.

The author desires to thank Messrs. John Harper & Company, Limited, of Willenhall, for permission to write the Paper, and Mr. G. C. Lloyd, of the Iron and Steel Institute, for permission to reproduce Figs. Nos. 20 and 21 and Table V from the pages of the Institute Journal.

Table V.—*Sulphur in "Peeled" Malleable Iron.*

Silicon.			Sulphur.		
Outside.	Second Position.	Centre	Outside.	Second Position.	Centre
0.378	0.360	0.377	0.218	0.48	0.520
0.575	0.638	0.600	0.161	0.392	0.60
0.550	0.518	0.540	0.084	0.535	0.79
0.745	0.745	0.770	0.127	0.351	0.64
0.74	0.74	0.755	0.139	0.198	0.172
0.865	0.865	0.820	0.298	0.378	0.426
0.90	0.795	0.80	0.128	0.530	0.70
0.750	0.750	0.71	0.066	0.061	0.061

DISCUSSION.

Mr. E. R. Taylor, F.I.C., commended the Paper on account of the practical data which it contained, and asked if it was possible to determine any difference in the properties of malleable iron containing 0.1 per cent. of phosphorus as against 0.05. Trouble with under-annealed metal seemed to be very common. Too much re-annealing was done and he attributed it to the fact that so little information had been published as to the correct annealing time. The Cast Iron Research Association had carried out an investigation into annealing time *versus* total carbon content, and a report would be issued dealing with this. Curves have been drawn showing what mechanical properties may be expected from any total carbon. Very little literature hitherto existed with relation to total carbon in white iron, that was to say in the iron intended to be annealed; yet very few people knew what a vast difference total carbon in the original white iron made. If they began with a high total-carbon in their white iron they were up against trouble all the way in producing good malleable. The figures given by Mr. Field concerning the elimination of sulphur were exceedingly interesting, but he did not seem to discriminate between the elimination of sulphur when it existed as manganese sulphide and when it was present as iron sulphide. His own experience was that when sulphur existed as iron sulphide in a casting there was elimination up to as much as 50 per cent., but if it existed as manganese sulphide there was no elimination, but an increase due to absorption from the ore mixture. Regarding test pieces, the bend test was usually carried out on a $\frac{3}{8}$-in. × 1-in. bar, 8 in. long. The tensile test used to be carried out on a $\frac{5}{8}$-in. bar, and at the present time a $\frac{1}{2}$-in. bar was usually used for the test. He suggested that it was difficult to correlate the results with these variations in the size of test bar used. As to peeling, the speaker considered it was due to carelessness. Ordinary care in watching the composition, seeing that the heating up was correct, and not leaving too much to the workman in charge would help to abolish peeling.

Mr. J. V. Murray described the malleable section as the Cinderella of the iron trade. A great number of present-day British foundries were simply muddling through. There was no real reason why the percentage of scrap castings should be so high, scientific control being necessary and vital, nor was there any reason why malleable castings should not in many cases replace mild steel stampings. Many founders were too ready to blame the maker of the iron. Mr. Field had indicated that his firm had ceased to produce malleable castings, but judging from what they had heard, it appeared to him to be one of the firms that should remain in the trade. With regard to high phosphorus pig-iron, he once had a 0.2 per cent. iron, and after annealing he held it in his hand and hit it with a hammer. It was so brittle that it broke.

Replying, Mr. Field said that from the point of view of the standard tests of malleable iron to-day there was no harm in going up to 0.1 per cent. of phosphorus, but there was in getting the percentage up to 0.2. When they got bad peeling he advised them to look at the can and see how thin it was. The heating up of the casting at too rapid a rate might determine the setting in of peeling which then never stopped. With regard to the proportions of "peeled" scrap that could be used in the cupola, he pointed out that if a large proportion of oxidised scrap was used they would be running the risk of blowholes. He had never had any trouble through the embrittling of malleable iron in galvanising, and thought that this would only occur where the annealed metal contained much combined carbon.

Vote of Thanks.

Mr. R. P. Bethell, proposing a vote of thanks to Mr. Field, said he was glad the lecturer did not blame the iron for all the troubles of the foundry. He had had complaints about some of the best iron it was possible to make, and when they investigated the matter they frequently found themselves up against a man who did not know his own mind. In 90 per cent. of cases the trouble was in the annealing.

Mr. E. J. Lewis, in seconding the motion, said that while the lecture was in the main scientific, there was a great deal that the ordinary foundryman could follow, and he regretted that more members were not present.

Mr. J. Ellis, a Past-President of the Institute, supported the vote of thanks. The scientific men, he said, were always ready to come forward and give Papers and he regretted that the practical men were more backward. He hoped that as a result of intensive propaganda work they would see more of the moulder.

The President also supported the motion, which was heartily approved by the meeting.

Mr. Field briefly returned thanks.

Birmingham, Coventry and West Midlands Branch.

OIL SAND AND MOTOR CASTINGS.

By W. West (Member) and W. Aston.

[*A cinematograph film 1,000 ft. long was exhibited prior to the lecture, and illustrated in complete detail the methods employed for the manufacture of cylinders and other castings in use at the Leyland Works.*]

The application of oil sand to the making of intricate cores has been widely recognised by foundrymen, because of the outstanding advantages which are derived from its use. It is, however, probable that its potential value may yet be exploited in other directions, such as the production of castings entirely in it, or its substitution for ordinary facing sands. Where the work to be made is of special character carrying requirements of very fine limits of machining, positive dimensions, accuracy of shape, and in all a smooth surface skin, it can be imagined that the use of an oil-sand facing or of moulds made entirely from it, castings should be produced with such accuracy from the pattern and the fitting of the cores in the mould that the dimensional inaccuracies would be greatly eliminated.

This is the view-point from which the subject here is considered. Other points of view must necessarily exist in connection with foundry work in all its varied phases, so that where ordinary jobbing work is the rule or the class of castings such that competition of a keen character limits the founder to the narrowest margin of profit, the end may not justify the extra expenditure incurred.

Mass production also has its own peculiar requirements according to the nature of the work in hand, so that no set of conditions or results obtained from the application of anything of a special character can be accepted without certain reservations.

Before dealing more especially with the practical side of oil-sand application, a little consideration might be helpful regarding the type of oil or oil mixture mixed with the sand. Most of the properties required of an oil core sand are well defined and known to all foundrymen who have taken interest in the subject. The most important, perhaps, may be summarised: (1) The strength of the core in the green state; (2) the rate at which the mixture will dry and harden in the oven; (3) the strength of the dried core sand; (4) the character of the bond and its resistance to moisture; and (5) the cost of the mixture.

The relative importance of the properties is decided by the character of the work engaged upon.

One of the great difficulties which has confronted foundrymen in the use of oil sand has been that most of the oil mixtures in general use have not imparted sufficient strength to maintain the shape of the core in the green state, when the size has extended over certain dimensions in height and width. Molasses is a useful agent to this end and to a large extent is capable of holding up against the weight of the sand; but the limit of its power is soon reached, after which the mixture actually becomes weaker, consequent upon the constant working of the sand grains against each other through the excess of molasses present.

Good results are generally obtained by the use of emulsions of various oils and water, the permanence of the emulsion being maintained by the addition of Dextrine or core gum. The water acts very effectively as a green bond; the one and only drawback is the increased time required for the baking of the core, which is a serious item where production is concerned.

Where intensive production is the rule and not the exception, the rate at which the oil-sand mixture dries and hardens in the core ovens is of great moment. This precludes the use of any type of *crême* or emulsion, which invariably contains a large proportion of water. It therefore depends upon the use of a very quick-drying oil, with the addition of other ingredients capable of providing the green strength where necessary.

Successful results in this direction depend solely upon the character of the individual items constituting the oil mixture, the most important of these being the type of oil used to form the base, the other ingredients being present to give one or other of the necessary physical properties to the sand in the green state.

Of all the different varieties and classes of oils which are presented for choice, it is of distinct advantage, when production is one of the main features, that the oil or oils used should be entirely of the drying class and of vegetable origin. Fish oils could be used but are too objectionable, owing to the odour thrown out during the drying period.

The broad principles of oil selection have been dealt with in a lecture given before the Burnley section of the Institute,* which shows clearly the superiority of linseed oil as a core-binder, the extended use of it bearing confirmation of this fact.

It is generally known that the tough elastic compound composing the bonding medium is formed by the oxidation of certain unsaturated acids which constitute a large part of the composition of the oil. By the word unsaturated is meant that these acids are present in a very unstable condition, being very ready to break up in order to unite with certain other elements to form other compounds.

It is a very difficult matter to determine chemically the percentage of oxygen such unsaturated acids actually take into combination, but a fairly accurate idea can be obtained from the fact that the acids combine with iodine to precisely the same degree as oxygen. As therefore the presence of iodine can be chemically determined with comparative ease, the results expressed as the iodine value bear a definite ratio to the oxygen-absorption value of the oil or its drying power. The more important unsaturated

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* Proceedings, I.B.F., vol. xix., page 451.

acids occurring in linseed oil are known as linolic acid, linolenic acid, and oleic acid. The presence of the latter is in much smaller proportion than the other acids, and consequently does not play such an active part in the reactions which occur during the drying process.

A very wide variation occurs in the general composition of linseed oil according to the source of the seed and the method of extraction, which shows a like variation in the properties of the oil. An approximate composition of it can only therefore be given. An average estimation has been given as follows:—

	Per cent.	Iodine value.
Linolic acid	53	181.4
Linolenic acid (and its isomerides, if any) ...	27	273.8
Oleic acid	5	90.1
Glycerine radicle ...		4.6

It is gathered from the above composition that linolenic acid, which exhibits the highest degree of unsaturation and has therefore the highest iodine value, greatly increases the drying power of an oil in proportion to the amount of it present. The percentage, however, rarely exceeds the figure quoted above, so that the combined amount of linolic and linolenic acids present in linseed oil is the controlling factor of its iodine value, which in turn is an index to its value as drying oil.

The strength of the dried core comes from the use of an oil mixture which gives the maximum of bonding compound between the sand grains, and varies also according to the temperature to which the core is raised during drying. This strength is often expressed in terms of tensile strength, but it is open to question whether such determinations are of any real value except for comparison purposes.

The authors have found, however, that the introduction of resin into an oil-sand mixture has given excellent results, by increasing the green strength of the core sand, the strength of the dried core, and making it more impervious to moisture. Its application to foundry core mixture is by no means of recent date, much of the naturally bonded sand used more particularly for making cores contains a little powdered resin. It is interesting to note that resin completely dissolves in hot linseed oil, which provides a convenient way of addition.

Permeability of the core does not in any way suffer by the use of resin, in spite of the extremely smooth face obtained by its use.

Herein lie distinct advantages such as will be exemplified by a later description and illustration of methods and results obtained.

The smoothness of the hard face when resin additions are used in the oil-sand mixture, provides a perfect surface on which the metal can rest without undue ebullition, this ensures a perfectly clean casting and gives a skin which is ideal in its smoothness.

At this juncture what has been outlined is in perfect harmony with expressions that have been recently given that there is much to be said in favour of very smooth-faced moulds, such ideal smoothness supplying only the minimum of surface area exposed for re-action. This theoretical consideration has been amply proved in practice by the authors in their foundry where an oil-sand mixture with resin addition is in every-day use for the facing of motor car cylinder moulds. With such a sand the impressions of the patterns are taken much more sharply, and where stripping plates are used these become more effective, the internal oil sand cores make closer fit, and the resultant cylinder is truer to pattern, cleaner and of improved appearance.

Oil Sand Cylinder Moulds.

To gain general approbation, such a method should possess outstanding advantages over the ordinary sand mould, and from the results obtained the authors are satisfied that this is the case. The use of oil sand holds advantages in the actual moulding or bumping period, also, where stripping plates are used, the impressions are much sharper, and after baking, the sharp corners have the distinct advantage of being much more permanent than the natural sand mould. This is an important factor, for not only does such a mould reduce the risk of damage in closing, but actually makes this part of the process easier to carry out. Further to this, where oil-sand cores are used in an oil-sand mould the accuracy of shape and dimensions of the prints make it possible to allow only the barest clearance, with the consequent accuracy in the finer details of the casting.

The extent of the use of oil-sand moulds is not known to the authors, but here will be recorded such experiments which have become more or less production methods, for the manufacture of the double two-bore cylinders of the "Leyland Lion." Many minor details are yet to be revised as the method is gradually applied on an increasing scale in the cylinder foundry.

For the sake of explanation the mould may be looked upon as being built up in three parts. (1) Bottom middle part; (2) top middle part, and (3) top cake core.

FIG. 1.—TOP MIDDLE PART; BOTTOM MIDDLE PART AND TOP CAKE CORE.

Moulding of the Bottom Middle Part. A (Group 1)

A machined plate having two pins with which to locate an aluminium frame or box is fixed on a small roll-over moulding machine. After thus fixing the frame a stripping plate and four corner pieces, together with the pattern, are suitably arranged in their necessary order inside the box (Figs. 2 and 3).

The mould is now partially filled with a tough well bonded oil sand, and rammed to the half-way line, when a flat core iron 1 in. × $\frac{1}{16}$ in. thick, bent to shape is embedded in the sand to reinforce the sides of the mould against any possible chance of a burst during casting.

The mould is filled with sand, and after ramming, the unnecessary sand is sleeked off. A core

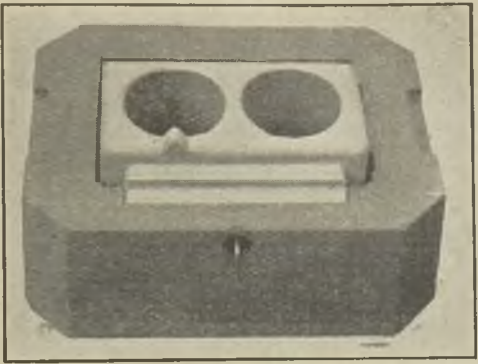

FIG. 2.—BOTTOM MIDDLE PART.

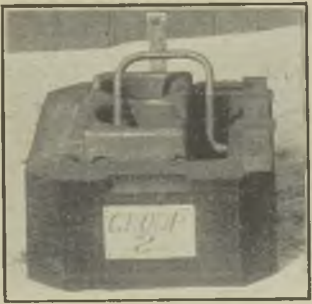

FIG. 3.—BOTTOM MIDDLE PART.

plate clamped on the top of a frame enables the whole to be turned over either by hand or mechanically. After removing the plate the pattern is slightly rapped, and drawn through the stripping plate, which is held down by weights. It will be seen that the four corner pieces previously inserted support the stripping plate, and the weights, incidentally, economising the sand required.

It is worthy of note that no mending or patching is necessary after withdrawal of the pattern.

Top Middle Part. B (Group 1).

This part of the mould, shown in Fig. 1, is made in a precisely similar manner, except that the stripping plate is reversed, and the extension to the top of the frame which is necessary to the making of the bottom middle part is left off. There is also a loose flange on this part of the pattern, which is removed before the core plate is clamped on for rolling over, the space in the mould being filled with moderately dry floor sand until the core is dried.

In this part of the mould a fixed down runner is rammed up in position, the gate being a clearance left over the water jacket core print; this gate measures approximately 7 in. long by $\frac{3}{32}$ in. thick, and allows the metal to flow without any sand or dirt entering the mould.-

Top Cake Core. C (Group 1).

This, also shown in Fig. 1, is made in a simple aluminium frame provided with two prints for the top of the barrel cores, and three smaller impressions for three studs or buttons required for machine-shop purposes.

Internal Cores. E and F (Group 1).

Two cores are required to complete the mould, and these, the water-jacket core and the blocking out core, are straightforward core-making jobs, requiring no special description beyond that in each case a hook is placed in a slot in the corebox for fixing purposes during assembly.

Assembling.

A bed of floor sand is first struck up between two rails which carry the weight of moulds and which effectively prevents the possibility of the mould swelling under liquid pressure (Fig. 4). After the joint face of the bottom middle core has been slightly rubbed on a machined plate, the mould is placed on the rails with an overhang at each side of a few inches, for clamping purposes. The jacket core is lowered into position having the wire hook previously mentioned projecting through a corresponding recess in the mould, a wedge is sufficient to secure the core in position.

In order that the jacket core can be accurately jigged in position, a clearance of $\frac{3}{32}$ in. is allowed behind the print, and a ring of clay is inserted so as to allow the core to be set. The jigging is between the outer walls of the barrels and the outer wall of the mould. The top middle core is now placed in position, and located to make a perfectly flush joint in the mould, by looking or feeling inside the wall; in this manner a twisted joint rarely occurs.

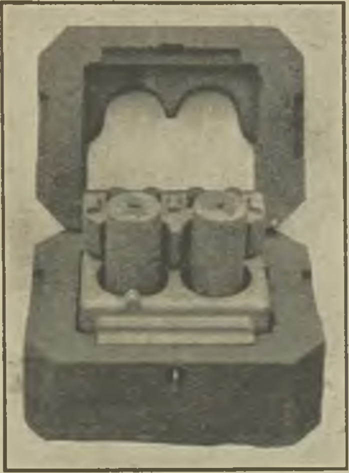

Fig. 4.

The blocking out core is now carefully lowered into position, jigged and wedged in a similar manner to the jacket core; two perforated chaplets on the jacket core and one on the block core prevent any misplacement taking place during pouring.

To complete the mould two round barrel cores and four tappet-hole cores are now easily put in by hand and the assembling completed by the addition of the top cake core, the mould is firmly clamped together with two large clamps and the pouring basin put on ready for the metal.

One of the outstanding features of this oil type of mould is the ease with which the casting is subsequently stripped, sandblasting and fettling times are particularly reduced through the absence of burnt sand and fins of metal at the core prints.

FIG. 5.—MOULD FOR CYLINDER HEAD.

Cylinder Head.

This casting (Fig. 5) is made in much the same way as the cylinder, the internal cores being easy to fit and accessible for checking in position. Before leaving the foundry each casting is subjected to a water-pressure test, after which it is set up on the three studs or buttons on a surface table to be jigged (Fig. 6). The jig has two fixed projecting pins from the lower part and two sliding pins from the upper portion. By applying the jig to the casting while it rests upon three studs, the lower pins touch the outer and lower portions of the cylinder barrels, while the upper and sliding pins are pushed inwards to make contact with the outer walls of the barrels through the water jacket.

By means of recesses on the movable rods any discrepancy of the barrels from the vertical in

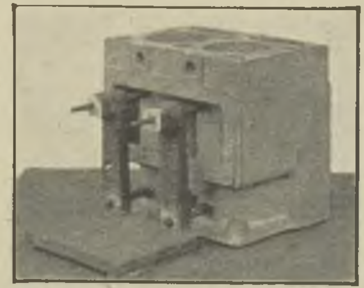

Fig. 6.—Jigging the Cylinder Head.

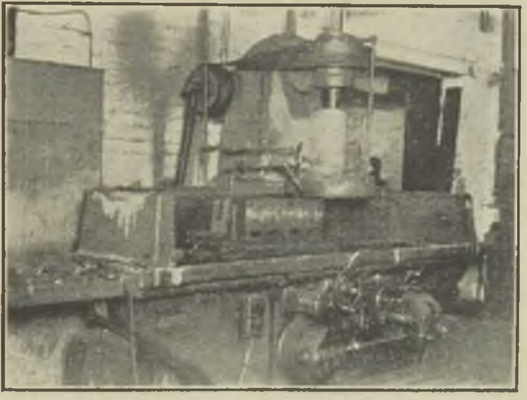

Fig. 7.—First Operation in Machining Cylinders.

relation to the face upon which the cylinder rests can be detected. Should incorrectness occur through a slight variation in the assembling, adjustment can be made by filing or chipping one or other of the studs. The face holding the three studs now becomes the setting off plane for all subsequent machining operations.

This preliminary checking of the cylinders before despatch is of real assistance to the machine shop. The first operation, shown in Fig. 7, towards the finished casting is securely to fasten six of the cylinders with the studs on the bottom face making contact with the machine table. This position assures a true setting off point for the grinding of the top face. By turning over the cylinder with the ground face lying on the machine table the bottom face after removal of the studs is also ground. Two parallel planes having been obtained, the cylinders in batches of four are put into a jig as illustrated and the valve side of the cylinder is similarly ground—the opposite side being also ground from off this face by reversion of the casting.

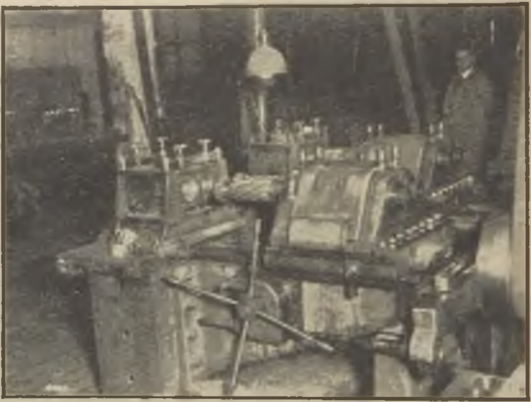

Fig. 8.—Boring the Barrel.

Having performed the more important facing operations the boring of the barrel is carried out by a machine with double headstock, as in Fig. 8, showing the rough boring and the finishing. These machine operations are the only ones which immediately concern the foundry, as any incorrectness in the shape of the castings will be exposed during this period. Fig. 9 shows the famous "Leyland Eight" cylinder block, which was made entirely in oil-sand facing.

Multiple Castings.

There is a certain type of casting which calls for special initiative from the foundrymen if production of any appreciable extent is required. This occurs when the sizes of the castings are small and the shapes depart from the plain, cubic, or rectangular; having undercut portions which in themselves are complications. One method would be to block out those parts of the pattern which prevent a straight lift so that the use of several patterns would then lend the proposition to one of machine moulding, when an extra number of cores would be required. It is here, however, that the making of castings in a stack mould made in oil sand has very many advantages in the way of production and accuracy of dimensions.

Fig. 9.—Leyland Eight Cylinder.

The Rocker Shaft Brackets.

These castings, shown in Fig. 10, were formerly machine moulded with the pattern in halves in the ordinary way, using green-sand moulds, the number produced in one mould depending upon the size of box available. This method, while satisfactory enough for a small number, gave irregular and cross-jointed castings. The present adaptation, as shown, gives 48 castings at one

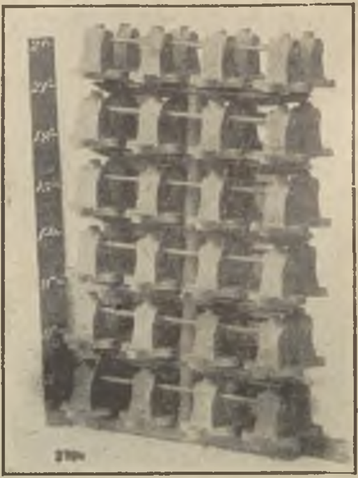

Fig. 10.—Rocker Shaft Brackets.

Fig. 11.—Pump Covers.

pouring. The cores are easily made in oil sand; one boy is able to produce the equivalent of 250 castings per day, while it remains the duty of a labourer only to assemble the stacks.

The advantages of this particular case can be summed up by results. Little or no scrap occurs through twisted castings, the grinding allowance on each face is considerably reduced and the arrangement of them allows of one row being ground at one time in place of individual ones.

Pump Covers.

These castings (Fig. 11) were made previously in 14-in. square boxes, four castings in each,

FIG. 12.—VALVE CAPS.

which meant for 48 covers 12 boxes were required. By the multiple method this number is produced on one stem, the time necessary for coring, weighting and clamping being considerably reduced. The castings by the old method had not the same class of finish as those made in oil sand and more often than not contained dirt and sand swilled by the flow of the metal. A greater accuracy of dimensions is also obtained which greatly assists the machining, as a smaller allowance, which can be more or less guaranteed, converts the operation into one of grinding.

Chassis Packing Pieces.

Originally made in a three-parted mould or a blocked-out pattern—the moulds now are made by pasting two cores together, a gauge being necessary to check the depth of the casting in order to ensure 1/64 grinding allowance.

Valve Caps.

This type of casting (Fig. 12) is made in the same way and provides a further example of many more, which are being produced on a production basis.

DISCUSSION.

Preparation of Oil Sand.

Mr. F. J. Cook (Past-President) remarked that he had had considerable experience with oil sand, and was acquainted with the excellence of the results that could be obtained from its application in the foundry. He would like to know in what manner the lecturers added the necessary oil to the sand, because he had found from practical experience that to make the mixture in a mill with heavy rollers caused the sand grains to be broken up into finer particles and thereby causing the sand to be less permeable to escaping gas The best method was to add the oil to the dry sand, and after making a known addition of water, to rub the mixture through a sieve of suitable mesh. In this way thorough mixing of the water and oil was made, and further, each and all the grains of sand were properly covered with oil emulsion. He would also add that in all his experience he had not met with a more suitable sand than that to be obtained from Southport.

Southport Sand.

Mr. West replied that the mixtures which had been used for the cores on exhibition and those shown on the cinematograph film were not of a simple oil-and-sand character, but were composed of various quantities of several ingredients such as gums, molasses and oils, and in some cases a further addition of rosin. Eight different types of mixtures were in use at Leyland, each having some function to perform necessary to obtaining a thoroughly reliable casting. Regarding the type of sand, he agreed that Southport was of the most suitable grain size for oil-sand cores; however, a little exemplification of the name was necessary because of the fact that sand from the Southport end of the dunes was not so even in texture or grain size, nor yet so free from carbonaceous matter as sand from the Birkdale end. It was necessary to emphasise the source of supply when ordering.

Mixing Oil and Water.

Emulsified oil-sand was in use at the Leyland Works, but instead of mixing in the manner Mr. Cook had described, the oil and water in proportion of four parts of the latter to one part of the former is contained in a cylindrical vessel, at the bottom of which internally a length of ordinary gas piping is fixed with holes drilled along its length, the end being stopped with a threaded plug. The pipe serves to lead in compressed air, and has a regulating valve at a convenient point. By turning on the air cock the oil and water are thoroughly mixed together, and by the addition of a little dextrine a permanent emulsion is obtained.

Oil Sand Cores and Machining Allowances.

Mr. Dicken remarked that he was very interested in the subject of the lecture, inasmuch as that he had had a very extensive experience in cylinder making. One thing that struck him as remarkable was the very simple design of the cylinder section, which was on the lecture table, and he thought that no difficulty should be experienced in the manufacture of it. However, he would like to know what percentage waste had been experienced during its manufacture, and whether the cost of production in the oil-sand cores compared at all favourably with the making of them in the ordinary way. Further, he was surprised to find that it was possible by the method as described in the lecture to make allowances for machining or grinding to such a narrow margin as $\frac{1}{16}$ in. top and bottom. Candidly, he had difficulty in believing it. Was any trouble experienced by the straining of the oil-sand cores at the joints during the pouring of the metal?

Regarding the making of castings in multiple cores, was it a common trouble to find that the sand had fused on to the castings? What percentage of wasters through blowholes, etc., was usual with this type of casting?

Waster Losses.

Mr. West replied that the great object in the making of cylinders in the manner described was to obtain a casting which would be dimensionally accurate. The mould and cores being made in hard and dry oil sand enabled a closer and more accurate fitting of the various cores together and the cores in the core prints. The fact that production is being obtained of cylinders having only $\frac{1}{16}$ in. to grind off top and bottom was sufficient confirmation that the accuracy sought for was actually possible. The section of the cylinder displayed was undoubtedly suitable for the production of such accuracy, and reflected great credit upon its designer, but in the case of the cylinder head as shown by the half-section the numerous bosses closely connected with the intertwining of the water chambers made this casting not so easy; yet the same narrow margin of allowance is regularly obtained without incurring wasters from undersize of dimensions. He could only eliminate any doubt which might exist in the mind of Mr. Dicken, in spite of the actual cylinder on the table, by giving him a warm invitation on behalf of the Leyland Motors, Limited, to see the production from start to finish.

The percentage of wasters during the little while the process had been passing through the experimental stages was no greater than 15 per cent. from all causes, and the time was confidently looked forward to when the men would become more accustomed to the handling and fitting of the cores to bring the waster figure well below 10 per cent. Cost of production was slightly lower when using the oil-sand mould than by using the dry-sand mould; this initial cost, however, was no index as to the value of the method, because it was necessary to take into consideration any saving of fettling time and machining operations, together with the improved appearance of the casting, in order to arrive at a sound judgment.

had found that an equal mixture of Leighton Buzzard medium coarse with sea sand gave excellent results.

Mould Subsidence.

Mr. Wilkinson gave expression to the value of the lecture, and remarked that he had once tried in a similar way to produce a 7-h.p. four-cylinder block, but had not met with much success. There were particular advantages he could see, insomuch that accuracy was obtained without the use of impracticable methods. One thing occurred to him which might be a cause of certain inaccuracies, and that was the degree to which the oil-sand block subsided during drying, and, too, the possibility of distortion of the mould. He would be obliged to learn what experience had shown on these matters. The excellence of the skin on the castings showed, in that direction that the object had certainly been obtained.

In answer to Mr. Wilkinson, the Lecturers explained that there was little or no subsidence of the mould during drying, the various ingredients, particularly the gum, enabling the sand to maintain its shape to the dried state. Distortion of the moulds so far had not been experienced, but a certain amount of care is essential while the cores are in the green state.

Shrinkage.

Mr. F. C. Edwards commented upon the fact that the lecture was original in its character, and that the film had made it also intensely interesting. He was particularly struck with the idea of having the three spots or projections cast on to one face of the cylinder, as it seemed to him to make the work of the machine shop considerably easier. He had, like others, wondered to what extent shrinkage took place in the casting from the top to the bottom, and first exactly how this had been determined, as it seemed to be a point of particular importance in view of the fact that such a small margin of metal was left on the top and bottom faces to be removed. Did the temperature of pouring the metal cause the allowance made to be insufficient?

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Mould Subsidence.

Mr. **Wilkinson** gave expression to the value of the lecture, and remarked that he had once tried in a similar way to produce a 7-h.p. four-cylinder block, but had not met with much success. There were particular advantages he could see, insomuch that accuracy was obtained without the use of impracticable methods. One thing occurred to him which might be a cause of certain inaccuracies, and that was the degree to which the oil-sand block subsided during drying, and, too, the possibility of distortion of the mould: He would be obliged to learn what experience had shown on these matters. The excellence of the skin on the castings showed, in that direction that the object had certainly been obtained.

In answer to Mr. Wilkinson, **the Lecturers** explained that there was little or no subsidence of the mould during drying, the various ingredients, particularly the gum, enabling the sand to maintain its shape to the dried state. Distortion of the moulds so far had not been experienced, but a certain amount of care is essential while the cores are in the green state.

Shrinkage.

Mr. F. C. **Edwards** commented upon the fact that the lecture was original in its character, and that the film had made it also intensely interesting. He was particularly struck with the idea of having the three spots or projections cast on to one face of the cylinder, as it seemed to him to make the work of the machine shop considerably easier. He had, like others, wondered to what extent shrinkage took place in the casting from the top to the bottom, and first exactly how this had been determined, as it seemed to be a point of particular importance in view of the fact that such a small margin of metal was left on the top and bottom faces to be removed. Did the temperature of pouring the metal cause the allowance made to be insufficient?

Mr. Aston, in reply, pointed out that the degree of shrinkage in the vertical plane was negligible, and if such actually did take place and was not adequately allowed for, the method of grinding which is at present adopted in the machine shop was sufficient even to cover any chance of inaccuracy in this direction. The method employed was to place the casting with the three spots on the table and to take just a grinding cut sufficient to clean the face. A sixteenth was allowed on each side, so that by taking such a small amount off one face a greater amount was on the other side or face.

Mr. McQuin inquired if the actual casting of the metal into the mould caused the mould to be disturbed by the strain which was set up, and was the clamp at either end sufficient to hold the mould together during this period?

In reply Mr. Aston said that the two clamps were sufficient when effectively wedged, but to be certain weights were always put on the top cake core of the mould to prevent any straining or distortion.

Vote of Thanks.

Mr. Lewis, in proposing a vote of thanks to the lecturers, paid compliment to the nature of the lecture which had been given to them. It was, after all, from only the practical application of science and the elucidating of practical methods that the members of the Institute of Foundrymen could derive most benefit. There were one or two queries which had occurred to him while listening to the lecture. In the making of the internal cores for the head casting, was any drier used, such as black sand, to maintain the hanging cores in position during the drying period?

During the casting of the cylinder castings, did the fumes from the oil sand become irritating to the workmen?

He had great pleasure in proposing a vote of thanks to the lecturers for their labours, and also for bringing so many exhibits for them to examine. He would take this opportunity also of thanking the firm of Messrs. Leyland Motors. Limited, for permitting the lecture to be given.

Mr. Edwards seconded.

Mr. West thanked the members for their vote of thanks on behalf of Messrs. Leyland Motors, Limited, and also his colleague—Mr. Aston. Though much labour had been expended by Mr. Aston and himself, they felt it had been worth while. In answer to Mr. Lewis, he would say that it was necessary to use a little black sand as a support to the overhanging parts of the core during drying, and also, owing to the lofty buildings in the Leyland foundry, no trouble was experienced with the oil fumes.

West Riding of Yorkshire Branch.

RUNNERS, RISERS AND GATES.

By J. Butterworth (Associate Member).

Foundrymen do not give the subject of runners, gates and risers as much attention and thought as they should. It is left too much to the abilities and skill of the moulder, without giving him any instruction as to how the particular casting is to be machined or fitted. Although this system has worked fairly well in the past, the subject will have to be a separate study on account of the great increase in machine and plate moulding methods of production.

Foundrymen are simply left to use their own judgment from past experience, and adapt their methods of production to suit the pattern. This is unfair to the foundryman in general, as every other department in connection with engineering sees the drawings and adopts its own methods for producing the finished article.

Runners, Their Economy and Size.

The object of the runner is to introduce molten metal into the mould, and to have more runner and gate than is necessary is a waste of both time and material. Their cost might not seem high when regarded from the point of view of a single casting, but examined in the light of the production of six or twelve months the extra cost becomes apparent.

The selection of the size, shape and position of the channels by which the metal shall enter the mould is a matter of great importance. The shape and weight of the casting must be fully considered, as well as parts which are required to be sound and clean.

The size of the ingates is determined by the weight and the shape of the castings, and also the temperature of the metal necessary at the time of pouring. The openings must be so arranged that they are sufficiently large to allow the mould to fill without the metal becoming stiff, and so producing short-run or seamy castings. They must not be made too large, so that there is but little control over the metal during pouring, in which case dirty castings will result.

Round or Square.—There are numerous methods used, the round and the square types of down runner being most common. The author generally prefers the round type, because when drawing a square runner from the sand the moulder always leaves a ragged corner, or loose pieces of sand in the corners. Especially is this so in greensand work, and the wash of the metal is sure to carry these loose pieces into the mould. When using the round type of a down runner, the safer type of pear-shaped plug can be used. The flat type as used for square runners is dangerous, because it requires holding, whereas the pear-shaped type holds itself.

Gates.

The selection of the size, shape and position of the channels by which the metal shall enter the moulds is also of great importance, and the nature, shape and weight of the casting must be fully considered. The size of the ingates must be determined, as these are also controlled by type of casting, the temperature and composition of the metal.

Light Castings.

Some light flat castings are run on the side; sometimes with one long shallow runner, but in other cases two or more; again, some are run directly on the top with a V or wedge-shaped runner, depending upon the thickness and size of the casting.

Gas Cooker Side.—Gas cooker side castings, 20 in. × 28 in., and 3/16-in. thick, should always be run with wedge-shape runners from the top on account of the contraction. They have been tried by running at the sides with spray runners or gates, but it was found that the contraction pull on the runners warped or even cracked the casting, but after adopting the wedge-shape runner on the top of the casting, and knocking out the sand in the top part directly after the metal was set, this difficulty was overcome, and less metal was required to form the runner.

Flat Plate $\frac{3}{4}$ *in. Thick.*—A similar plate, but, say, $\frac{3}{4}$ in. thick, to be machined all over, would be wasted if run from the top, on account of the tearing by the metal stream on account of the drop. This would make a scab, no matter how well it was vented. The better method would be to run it at the side with as many flat gates or sprues as possible. There should be a down runner at one end and a skimming gate at the other, with a connecting channel cut in the top part from the runner to the skimming gate.

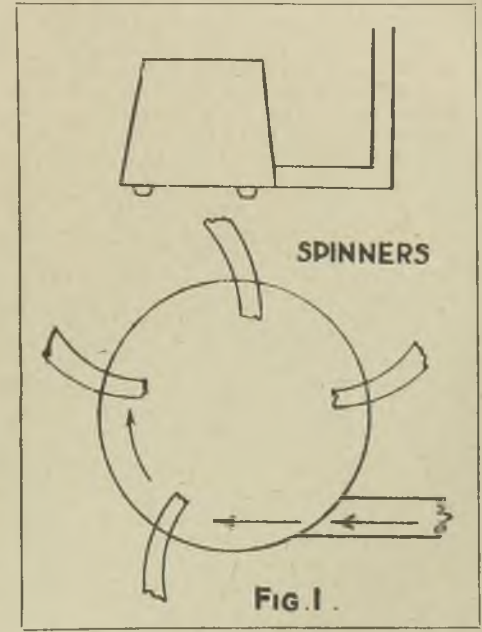


FIG. I.

Small Blank Wheels.

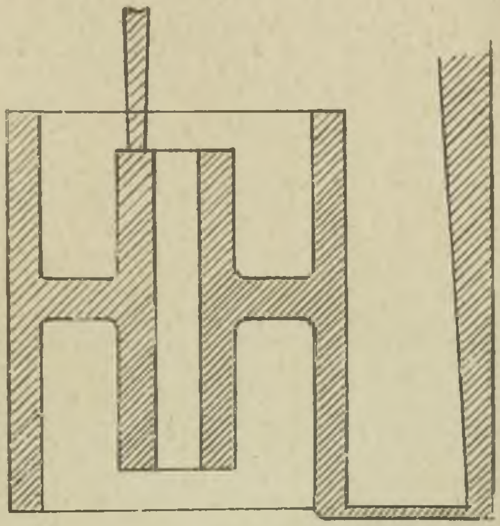
When making small blank wheels on the plate some patternmakers will persist in so placing the runner that the first metal enters the mould at the rim of the wheel, which is inadvisable, because wherever the runner is connected to the casting, that point is the most liable to be spongy or dirty. A blank wheel should always, if possible, be run from the boss with a pencil-like runner. If the boss is a heavy one and requires feeding, then a riser is put on the boss opposite the runner. It is desirable always to have a flow-off riser from the rim, and to run well through. Should there be more than one on the plate, then adopt the spinner method of running so that the first metal enters the spinner. The channel should be cut in the top part and the ingates in the bottom part and cut the opposite way to which the metal is expected to spin. The down runner and channel should be twice as large as the combined openings of the ingates. By this arrangement the spinner is flushed before any metal enters the mould, as shown in Fig. 1.

Plate Pulleys.

In the making of a plate pulley it is generally found that it is run on the boss on account of the ease of making the mould, but from personal experience the author believes it is better to run such a casting, especially when it is made from the loose pattern or a loose rim, from the bottom by cutting a V-shaped runner or ingate under the bottom edge of the rim at the tangent. It is much safer, because instead of having an outward pressure on the sand forming the boss, there is an inward pressure on this part of the mould. This helps to hold the sand by pressing it together from the outside, and in so doing one incurs less risk of having a burst. There is less chance of the plate scabbing, because in running from the bottom all the gases are driven in an upward direction, which gives them a better chance of escaping before the mould is full. When the metal reaches the plate it flows over in a free and easy manner. Otherwise, as soon as the bottom boss is full, the metal rushes over the plate in a tearing sort of manner caused by the pressure from the drop of the metal. This action of dropping into the bottom of the rim causes an explosion of the gases which have accumulated in the vents and rim, thus loosening the sand on the face of the plate and resulting in a scab. By using the method shown in Fig. 2 the casting in some cases does not require feeding, due no doubt to the compression of the metal having to force its way in an upward direction and thereby feeds itself by its own weight.

The Top and Bottom Running of Medium and Heavy Castings.

When dealing with medium and heavy castings one encounters the top and bottom running problem in an intensified form. Some moulders are insistent that bottom running is preferable on account of the drop of the metal and the lift or pressure of the metal as it reaches the top part. It may be, however, that the gases accumulate in a closed mould quicker than they can escape



PULLEY. BOTTOM RUNNING

FIG. 2.

through the vents, and as the mould is filling they are pressed against the top part to such an extent that it is lifted, unless it is securely fastened down. Other moulders prefer top running, insisting that there is no difference between this and bottom running, providing there is no obstruction in the mould which is liable to wash away with the fall of the metal. The metal has to drop to the bottom in both cases, and provision can be made to receive the fall without doing any damage to the casting. A casting should be run in the most convenient place and as far as possible away from all machined or polished parts, but where easy distribution of the metal can be obtained without obstruction, taking into account strains, contraction pulls and density. The advantages in top running are that the gates are more easily made and with care can be immune from dirt; the metal has a shorter drop before entering the mould, and thus is more mobile than would be the case in bottom running under similar gating conditions. In top running the metal is obviously hotter at the top and less metal is required on account of there being less down runner.

Advantages of Bottom Running.

Because the metal drops to the base of the down gate, any tearing or washing away of sand is at this position and not on the casting, and so reducing the liability of scabbing at the bottom of the mould. Moreover, there is probably a denser structure of the metal throughout the casting due to compression. Providing the runners are clean, bottom pouring gives a cleaner casting having an improved skin.

Engine Flywheel.

The author is of opinion that it would be foolish to attempt to run an engine flywheel in any position except on the boss, in spite of the fact that it has to be machined and bored there. Running it on the rim would not assure the same distribution of metal, probably resulting in the flats on the rim being badly scabbed. Running it on the arms would also give a poor distribution of metal, involving contraction stresses on account of the runner solidifying first and pulling against the arms. Obviously, therefore, the boss is the most suitable location.

Engine Bed.

An engine bed or base plate should not be run at the top, although they are moulded with the base of the bed uppermost. The proper method is to ensure that the runner is as near the bottom as is convenient for easy and clean running. The position which suggests itself is up each side of the cylinder core at the cylinder end, because these locations ensure easy distribution of the metal. There is but little fear of any damage from contraction pulls, whilst it gives solid metal at the cylinder end, the important part of the casting. The result is no doubt due to the compression by the metal having to force its way in an upward direction in order to fill the mould. Finally, if any dirt is taken in with the metal at the runner, it has a reasonable chance of being carried forward to the top of the mould away from important parts of the casting.

Sewage Plate.

Sewage plates are made in various sizes, but as an example one about 4 ft. sq. may be cited. It is 2 in. thick on the outside, dome-shaped, fluted on both sides, and is about ⅛ in. deep. On one side there is a lip about 3 in. wide which is from ½ to ¾ in. thick, whilst at the opposite end there is a ¾-in. round core, bottled-necked at each end to ½ in. dia., which runs the whole length of one side, and the body of the core is completely covered with metal. If this type of a casting is run at the thickest part, the metal would be flowing against the run of the flutes, and in all probability a number would be washed away. On the other hand, if they are run contrary to accepted notions, sound castings can be produced, providing the ingates are cut correctly and the area of the down runners is smaller than the combined area of the ingates. It has been found that the ideal place at which to run this type of casting is on the ½-in. lip, so that the flow of the metal is running in line with the flutes. At one time this casting was made with the dome downwards, with two large down runners and four rectangular ingates about 3 in. × $\frac{3}{8}$ in. thick. It resulted, however, in the metal as it ran over the face of the mould driving the air to the far end of the casting, sometimes disturbing the flutes and generally causing a blowing effect on the round core at the top edge. The better way is to mould the casting dome uppermost and to run it by means of two 1-in. round down gates connected to two separate channels, each one having three dome-shaped ingates, approximately 2 in. × $\frac{1}{4}$ in. at the channel end, increasing to about 3 in. × $\frac{1}{4}$ in. at the casting end. This gives a rush of metal in the channel and not over the flutes, and by the time the metal enters the mould it is running freely (Fig. 3). The metal has to climb up the dome, and by the time it reaches the top the gases are driven to the far end where the risers are conveniently situated. By the time the metal reaches the core the mould is almost full, and so the core is covered almost instantaneously, and if the vent is left open at the ends, no blowing effect takes place.

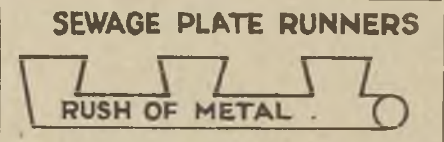


FIG 3

Wheel Ring.

A wheel ring, 14 ft. dia. × 10 in. deep, which is flanged on the bottom side and has metal thickness on the ring of 4 in. and 2 in. on the flange, presents features of interest. There are 165 teeth of 2-in. pitch, and additionally 16 ribs on the inside of the ring. There is also a split rag joint. On the underside of the flange there is a ring 2 in. wide, $\frac{1}{4}$ in. deep, containing 16 washers $\frac{1}{4}$ in. thick, which are also used for bedding the grooved pulley during erection. The weight of the casting is about 35 cwts. It is essential that the castings should be sound, as they are used in pit haulage work, where they carry a rope pulley weighing about 2 tons; there is an 18-ton load on the wire rope, and a number of overhead trucks. The ring is moulded in green sand in the floor, and the teeth are made by the machine. It is difficult to run owing to the design and size. It requires two sets of runners and two ladles of metal casting simultaneously, because of it being split and the liability to contortion.

Now there are three ways of running this casting. Presumably one could start by running straight down the ring side with drop runners, but this is liable to disturb the teeth. Again, running direct on the top of the flange, or by running into the flange at the bottom, suggest themselves. The former method, using six $\frac{3}{4}$-in. dia. round runners, three in each half of the ring placed 12 in. apart, was finally adopted, because it takes care of the contraction. This method necessitated the runners being placed in the cores, which were made in oilsand and well blacked. Thus the cores yield as the ring contracts, and there is no pull caused by the runners setting before the casting (Fig. 4).

Secondly, the runners can be so placed that the metal would drop into the ring-like washer which encircles the bottom side of the flange, acting like a channel connecting two or more ingates, and ensuring easy distribution over the face of the mould. Again, the runners were easier to make. It was a cleaner method (providing plugs were used in running the casting) than would have been the case if run at the flange on the bottom, because the runners would have to be cut into the core print or seating, and the down runners would have had to be rammed up after the ingates were cut and the cores set. Finally, the top-running method was the safer, as there is little fear of the metal tipping or pushing the cores forward into the teeth.

Pipes.

There are no less than five different methods used for running pipes, and every method has produced good castings. Straight lengths, bends, and T pipes are often run on the top of the body with one or more runners. Sometimes they are run in at the side of the body with flat spray gates and V gates. Alternatively they are run on the top and at the side of the flange, and also

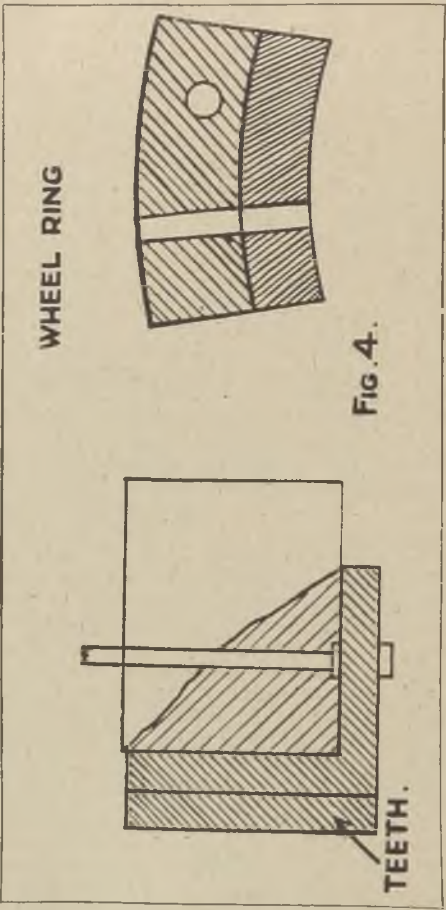


Fig. 4.

up each side of the core at the end of the pipe.

The author's preference is the last method mentioned, because the runners are easily made and kept clean; the metal is always running in the same direction as the vent, and by so doing one is always "chasing" the vent instead of trapping it, and finally there is little fear, especially in the case of a thin sectioned pipe, of doing any harm should a runner break in through carelessness, either in the construction of the runner or in knocking it off. The runners are away from all scotchings and weights.

Risers.

In dealing with the riser problem much depends on the design of the casting. The duty of a riser is to form an opening whereby fresh supplies of metal can be put into a mould to give solidity to the casting. A riser is placed on to a casting to relieve the mould from strain. When a riser is required for feeding purposes it does not mean that it should always be placed at the highest point, but it should be so placed that the fresh metal will reach the point which is acting as a reservoir to the other part of the casting. If this is not done, then a cavity will result. The riser ought to be made as large as possible to allow the metal to get into the casting. However, if there is a boss, say, 6 in. dia., one should not put a 5-in. riser on, but nothing less than a 1½-in. riser should be used if solidity is essential. It should be remembered that a similar action is taking place in the metal of the riser as that in the casting. It is well known that solidification of the metal commences from the outside or outer surface—the part nearest to the sand, and if the riser is not large enough to be kept open by means of feeding it will set before the casting, and in that case it might as well have never been used.

Taper Risers.

On a heavy casting, which requires feeding, there is an advantage in having the riser stick tapered for the reason outlined above, and additionally it allows of a freer escape of the gases as they are being driven forward by the heat of the metal to the outlet, especially if the metal happens to be "dull." A riser having a smooth, round hemispherical surface is caused by the gases in the molten metal being unable to escape on account of the chilling effect the metal receives on contact with the riser. If a tapered stick is used there is a better chance of successful running, because the hotter metal which is under the chilled portion has a better chance of breaking through and lifting the ball of metal containing the trapped gases into the open bush.

Ball Casting. (Fig. 5.)

In the case of a sphere, a solid casting can be made easier and better by cutting a riser at the side, having a large down-gate and keeping the metal working through to the runner by feeding. It is generally found when a riser has been placed directly on the top of a ball casting, although it has been fed, there is a flat sunken place to be found just round by the bottom of the riser, and when the riser is broken off it leaves a flat surface, but if a riser is cut at the side the metal is pressed into the centre of the casting by the continuous motion from riser to runner, and *vice versa*. When the riser and runner are broken off the casting they leave a small lip at the top edge, which can be dressed by very little chipping or grinding and leave the ball perfectly spherical.

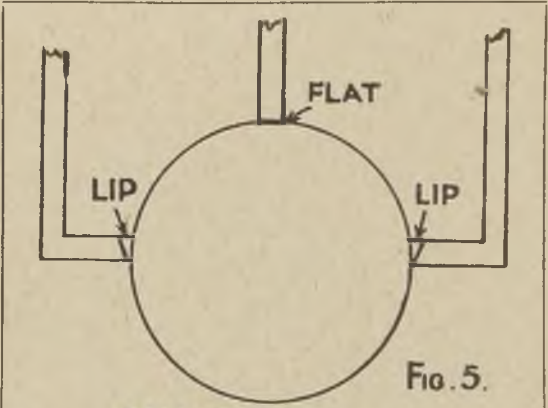


FIG. 5.

BALL CASTING.

Dummy Risers.

The functions of a dummy riser are supposed by some to be the following:—(1) to allow any dirt to be removed from the casting, and (2) to feed the casting. The first suggestion is totally wrong, because if any dirt enters a dummy riser it does so entirely by chance, as such extraneous matter will stick to the first obstruction it happens to touch. This can be seen on any casting having a top riser, where it looks as if the moulder has rubbed his thumb round the bottom in making his riser and then left it, leaving a rough uneven surface. An outstanding example of dirt adherence is plainly seen on the shanks and ladles, otherwise there would be no need to daub and fettle them after each day's melt. In the case of a bad runout, it is found that the first metal, nearest to the sand, has formed a skin or a shell, and apparently if any dirt touches this skin it sticks, otherwise specks of dirt will not be found during machining after this skin has been removed.

Thus dummy risers are useless for cleaning a casting, but they help to give solidity providing they are sufficiently large. If they are too small they set first, and then the riser will rob the casting of metal and a cavity will be found directly underneath. Dummy risers are unnecessary, as it is very seldom one encounters a casting where the vital point cannot be dealt with by means of an ordinary riser, and in any case one can use a densener, which is a more effective and cleaner method.

A case came to the author's notice of two moulders who were making a back barrel casting for a lathe. It was 3 or 4 ins. diameter, and about 18 ins. deep, and solid. This (Fig. 6) casting has to be machined all over and machine-cut teeth have to be provided at the pinion end. Both moulders ran the casting half way down the barrel with a dirt riser attached. But one of them placed a riser about 1 in. diameter on the top and fed it, and although the metal was adequately skimmed, his castings were returned from the machine shop, being both dirty and spongy. The other placed a riser about 2¼ in. diameter on the top, or about 1 in. less than the diameter of the casting. He never fed his castings; as soon as he had cast the mould he used to cover the riser with dry parting or sea sand and leave it, insisting that the riser being almost as large as the diameter of the casting, and the parting sand being dry, the metal would remain fluid as long in the head as it did in the casting, and that being so the casting would draw the metal down from the head and feed itself solid. Additionally the castings were clean.

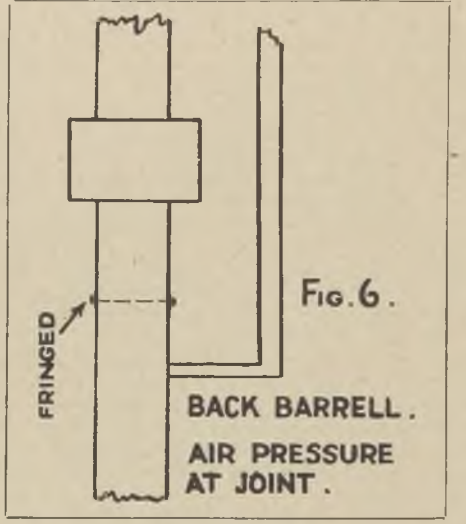


Fig. 6.

Strain and French Risers.

Another type of riser that is commonly used is the French or flow-off riser, which, when placed on the top edge of a casting, is more efficient in relieving strain than one placed directly on the top. The metal in filling a mould does not drive the gases in an entirely upward direction, because the vents are continually sucking the gases to the outer surface of the mould. A good illustration of this movement can be seen when making a deep mould, where it is necessary to make a joint between top and bottom of the mould. It does not matter how hard it is rammed, there will always be found a fringe if not an actual swelling, even if the joint has not been disturbed. This is caused by the gases making their way out at this point. If this happens half-way down the mould, it is obviously more likely to occur at the top joint. Thus the flow-off riser, when placed at the top edge of a mould shows a distinct advantage over one situated directly on the top of a casting, as it allows of easier escape of the gases.

It is not the metal which lifts a top part but the pressure of the gases, and thus more weight is necessary at the runner end of a mould. The gases are trapped at the runner end owing to the down runner being kept full of metal.

Open and Closed Risers.

If castings, having a large, flat surface and thin in section are being made, then better results can be obtained by leaving the riser open, because as soon as pouring is commenced the mould is full almost immediately, and the open riser allows a free egress for the air. There is no time for suction or drawing of air, and so the mould is quite safe with the open riser.

For loam and dry sand work the question of whether the risers are to be left open or be closed seems to have been established more from custom than from logic. One shop casts all its moulds by having the risers left open, whilst others would not envisage such a procedure.

When metal is poured into a mould which has all the risers tightly closed, the air is compressed. Iron dropping into compressed air cannot drop with such a dead fall as it would if there was no compression, and additionally cannot rise so quickly as it would otherwise.

These ideas seem to give sufficient reasons for drawing the following conclusions. When iron is poured into a loam mould from the bottom it is very often best in thin castings to have the risers open, this will allow the iron to rise up more freely and faster. Whenever a mould is cast "open" the area of the risers should be large enough to permit the air to pass off freely. It is often best when the iron is dull to leave the risers open. Blow holes in the upper portion of dry sand or loam castings are often due to the dullness of the iron not allowing the collected gases a fair chance to escape. When a mould is burnt badly it is better to keep the risers closed as there will be a compression against its surface.

The open riser, especially when placed on the top of a casting in a green-sand mould, has a tendency to cause a scab on the side of a casting as well as the top, because the gas rushing out of the open riser during casting is not entirely the air that has previously filled the mould, but a mixture with gases that are being drawn through the face of the mould and gases from the metal. The open riser acts as a chimney, or flue, and instead of the gases entering the vents provided, they are drawn from the back of the mould inward through the same channels, and in doing so often enough bring patches of sand with them, causing a scabbed and dirty casting. On the other hand, if the risers are sealed, the gases which accumulate in the mould form a support for the sand in trying to force their way out into the vents. Thus the sand in the top portion of a mould, especially in a large casting, retains its shape, although it is sure to be slightly burnt before the metal reaches it. If it was not for these gases forming this support, the sand would simply crumble away. If the gases cannot get away fast enough through the vents they will force their way through the joint, up the gaggers and up the box bars, as can be seen in any unvented top part.

DISCUSSION.

Mr. J. G. Robinson (Halifax), in opening the discussion, said it was a Paper which raised a good many controversial points. He could not agree entirely with Mr. Butterworth's suggestion that for the plate pulley it was better to run from the bottom edge of the rim. If it was run from the outside and the metal rose up to the rim, when it reached the plate it had to fill the plate and the boss after, and in most cases, in his (Mr. Robinson's) opinion, it would leave a dirty place. Personally, he regarded it as better to run down the boss. To eliminate gases, the vents should be suitable for them to evacuate without a loss of pressure. Mr. Butterworth had declared that he saw little use for dummy risers, but in his (Mr. Robinson's) experience he had known cases in which they were essential, but not always for feeding purposes. In malleable iron and steel work it was often necessary to put on dummy risers because one could not get risers to feed from the outside. When gas—or it may be air in the mould—was heated up to the temperature of the metal it had to escape, and when it left the face of the mould, it reached the damp sand and lost in volume. The pressure of the air was reduced on account of the reduction in the temperature. In the matter of weighting the casting, Mr. Butterworth had mentioned three to one as being not sufficient in some cases. He (Mr. Robinson) hardly thought the question of weight entered into the matter at all. It all depended on the area of the surface of the casting and the head pressure.

Mr. Butterworth, replying, said for plate pulleys it had always been the recognised system in his shop to run from the bottom, and whenever they did have occasion to run one from the top it generally resulted in scabbing. In regard to the three to one weight mentioned, in a jobbing shop the moulder would put three times the weight there was in the casting and it would hold it. He (Mr. Butterworth) thought in many cases that was insufficient.

Mr. S. W. Wise said he thought nobody could lay down hard and fast lines for any particular casting or type of casting. He had been very interested in the comments of Mr. Robinson in regard to the weight required for holding the top part down, and agreed that weight *per se* had really very little to do with the matter. It was rather a question of head pressure. He agreed that risers were not much use in removing dirt, and if there was dirt in a mould it was likely to be found on the casting. When Mr. Butterworth referred to a tapered riser-stick it would be interesting to know exactly the amount of taper he meant. If one used a long yet small diameter riser one was only increasing the cooling surface. If one made a true cone and had a good volume of metal then it was useful, but the majority of risers on most jobs were not used for feeding purposes because they were chilled before they had a chance of feeding. One point on which he could not agree with Mr. Butterworth was in his preference for a pear-shaped stop, because there was a chance of the metal trickling down and forming a cushion. Such metal would set instantly. From this it was carried up not completely melted to parts of the casting where it was not wanted. This matter led one to think of the question of "shotting." There was a tendency on the part of many to confuse shotting on the outside of the casting with the shots found on the internal parts of the casting. Whilst the Paper contained much debatable matter because there was much controversy as to just how a casting should be run, there were, however, to-day certain general rules for the work which most of them were prepared to follow, and he believed the industry had departed from the old "hit and miss" methods.

Mr. Butterworth, replying to Mr. Wise's comment on the pear-shaped plug, said the plug was used so that the metal was just dribbling down the side.

Mr. F. Berry (Halifax) said that on big melts it was his practice to cut a small gate under the plug for the metal to dribble in, and he had never had an accident. Sometimes with a big cast if the metal did not trickle slightly one would get an explosion. A drastic way in which this was sometimes to be seen was if two biggish jobs were being cast near to one another, one might cast one job and wait half an hour or so before doing the other, and when the second one was cast—especially if the coke bed was the same—in either of them one could get an explosion. Mr. Berry suggested that it was the metal that was lifting the top part, and that was where the question of the area entered when one calculated the amount of weight for holding down. Personally, he did not think gases did very much lifting. When one was casting a mould he thought that primarily it was practically all air that was in the mould, but when one had gases from a neighbouring mould, as in the instance he had mentioned previously, it gave a larger explosion. Mr. Berry agreed with Mr. Butterworth's views as to risers, they should always be of generous size, but there was not such a wide range of application as most people imagined. Metal should not be run so very hot, because if in the heavy part it was getting into the pasty condition it did not necessitate a riser.

Mr. Butterworth, replying, maintained that it was the gases that lifted the top part. The gases accumulated in a mould more quickly than they escaped, and that being so they must press against the top part.

Mr. Berry insisted that the pressure was diminished by the vents.

Mr. Butterworth asked as to where the whistling noise came from, whereupon Mr. Berry agreed the question was debatable.

Mr. W. T. Thornton (Bradford) said he would prefer to run a plate pulley down the boss, but if the plate were strong enough it sounded reasonable to run it on the plate. In large work he thought a combination of bottom and top running was satisfactory. The bottom runner filled the mould and then filling the top plugs it relieved the bottom lift. He did not think dummy risers were much use, because the casting remained hotter than the dummy riser. With regard to the matter of the weighting castings, an easy rule which could be calculated by any foundryman was that the area of the top part of the casting in square feet multiplied by the depth from the top of the runner to the bottom of the runner, in feet, divided by five, equalled the tons weight required to hold the top part down. In any case, one had to consider the velocity of the mould.

Mr. J. J. Watson (Huddersfield), referring to this question of pressure on the mould, suggested as a useful general rule that the area of the casting multiplied by the depth of the box gave square inches, and that multiplied by 0.26 lb. gave the pressure.

Mr. L. Farrar (Shipley) said one point mentioned by Mr. Butterworth was as to risers not necessarily being on the highest point. He once made a little casting in which there was a slight defect. It was a friction pulley, having a riser on the boss. He did this by instructions of the foreman. Personally, he had a general conviction that the heaviest part of the mould would feed itself, but the lighter parts needed feeding. It was the case in the instance he mentioned. He knew this was an idea with which some would not agree. An older man who took on the job put two risers on the pulley rim and fed it there and not on the boss at all, and he got a good casting. Another principle to which he (Mr. Farrar) held was that the riser should be practically a part of the casting.

Mr. R. D. Welford (Bradford) said there was no doubt that a proper runner was the first step to a good casting, but he would have liked the author of the Paper to have told them something about the runner box. Moulders often did not think of the differences in size of the down-runner and the combined in-runners. A man may use an inch diameter runner for one job and the next day put in a 2-in. runner, failing to realise that the diameter of the runners varied according to the square of the diameter. Personally, Mr. Welford said he did not see the necessity for the "trickling-in" method under plugs. A little trickling-in would ignite the gases just as much as if the whole plug were lifted, and he did not see any material difference between lifting the plug and trickling in some metal first. In regard to the pulley plate, he agreed with Mr. Robinson that there would be a dirty place on the outside of the rim unless the metal was very hot. On the question of the gases lifting the top part of the mould, that might happen if there was an explosion and the mould was very wet. The lift of a mould was done by hydrostatic pressure, and its natural effect upon metal pressing against the top part, the amount of which could be easily calculated. A cube 12 in. sq. on the top part had no greater lifting power than a square plate 1 in. thick, if the riser and the runner were the same height from the top of the mould. The gases had no effect on that lifting pressure. It was, in his view, a fallacy to put on risers with a view to catching dirt. If there was any dirt it would usually go somewhere other than in the riser. Sometimes risers were a real disadvantage, especially in moulds which had a large number of cores in them. If one fitted a riser in such cases there was a tendency to find the metal coming up through the expansion of the forces. Mr. Welford said he could quite appreciate and understand the experience mentioned by Mr. Farrar. There was, he went on, quite a considerable difference between running a casting with hot metal and with cold metal; also the runner should be large enough to fill the mould reasonably quickly.

Mr. H. Sayers (Leeds) said the first rush of metal was usually that which carried any dirt, and it would carry dirt into the ingates and it would go into the mould. He agreed that the ideal way of running a casting was to run it both top and bottom and get the dull metal into the middle where the freezing was likely to be the last. Suction had been spoken of, but he did not think there could be any suction in a mould that had been filled. The gases in it expanded, and there was enormous pressure in the mould. The cause of the tops giving was pressure coming in from moisture or steam behind the surface. If one trickled metal down there was a chance of drying that moisture and keeping it out.

Mr. H. Summersgill (Bradford) said Mr. Butterworth had mentioned scabbing, and had said in some he would run the mould down the face and some at the side. He referred to gutters for shed roofs, etc., which weighed from a few cwt. to 3 tons. These were run straight down the V-piece with a number of runners in proportion to the size of the casting—sometimes a dozen—and they very seldom had any scabbing, though they ran right down on to the face of the mould.

Reverting to the subject of risers, Mr. Welford said he once had to make about 200 tons of docking wedges. There were 185 pairs, and no risers whatever were used, and they found no shrink on any of them. They were run slowly with metal. They were quite good and level. Judging from the outside, one could cast fairly big castings without any risers.

The Chairman, in voicing the thanks of the meeting to Mr. Butterworth, said the lecturer had certainly gone to a great amount of trouble in the preparation of the Paper.

Lancashire Branch.

SOME ASPECTS OF FOUNDRY WORK.

By E. Longden (Member).

During the last four years there have been advanced certain theories concerning the effect of mould and occluded gases on the soundness of grey iron. In this Paper remarks on such theories will be brief because it is desired to record one or two points worthy of notice which the author was unable to develop in the last Paper he presented on this subject, although most of the examples which will be shown were obtained at that time.

Further evidence of gas effects on grey iron has been excellently dealt with by Mr. Hird, who confined himself mainly to chills and gave some remarkable figures relative to the gas content of grey iron. The volume of gas collected was very evident, but whether all the gas came from the metal is a moot point. However, the author has had cast thousands of tons of important castings, using both external and internal denseners and chills, without experiencing serious trouble. With many types of castings it is only by employing denseners that it is possible to secure the soundness required. There have been occasions when a casting has blown from a chill used for the first time, and then perhaps a hundred castings have been made using the same chill. It is a question of arranging a correct section of densener according to the body of metal to be frozen quickly, keeping denseners clean and free from dampness and pouring them with the correct mixture of metal with low silicon and phosphorus contents. The first example is a densener used only once at the nose of a core under a feeding head weighing one ton. The casting for which it was used is a certain type of hydraulic cylinder. Fig. A is a densener the condition of which was obtained after using twice. The progress of liquation can be clearly seen in an advanced stage. Little streams of metal can be seen running to the outside of the densener. The example is very illuminating and shows the almost complete disintegration of the metal structure due to the use of a comparatively high phosphoric iron in the densener.

There is on record a statement made by an eminent metallurgist to some of his students to the effect that cast iron is such a complex and mysterious material that to-morrow he may have cause to contradict that which he might say to-day. This statement is very true. How very surprising are the contradictions of some of our best-known metallurgists can be proved by reading back through the foundry and metallurgical literature. Surely this is inevitable to some extent with cast iron. It is stated that each investigator can see further by standing, as it were, on the shoulders of the last.

FIG. A.—DENSENER AFTER USING TWICE.

Solidity, Liquid Shrinkage and Mould Pressure.

It is best, therefore, again to state that the author's opinion still is that liquid shrinkage in grey iron as is generally made evident by cavity and porosity is caused, mainly, by mould and occluded gases, but that there is also abundant evidence to prove that the degree of resistance offered by a mould material to grey iron when cooling has an important bearing on the solidity of the metal. It would appear that actual metal shrinkage, except in very strong iron, is practically nil. Mr. Broughall proved very clearly by casting grey iron in metal moulds that not only was there no need for the usual feeders, but that metal was actually exuded from the top of the casting.

Whilst the pouring of grey iron into moulds which would give the conditions governing the statements made previously is not commercially practicable, except in the case of metal moulds, its study has been very helpful in the solution of many foundry problems. Foundry tests are handicapped by so many variables and results are very often masked.

Fig. B shows in no unmistakable way that gas can and does play out from a core or mould into the molten metal without leaving the supposed characteristic globular blowhole formation which is very evident in many cases when a mould or core has been violently blowing off gas. Unfortunately, the photograph does not clearly show the spongy area which proceeded from the small core both upwards and downwards. In places the cavities extended from the small core right through the metal section to the mould surface. The arrows indicate the affected areas. If a spongy area be viewed under the microscope it may be found to contain globular as well as a crystalline formation. If a portion of the spongy area seen in the example was isolated from the core hole most foundrymen would describe it as a clear case of liquid shrinkage. This spongy area does not show clear blowholes, but there is no doubt that gas has been blowing out into the fluid metal and that it has occupied area which might have been otherwise occupied by metal.

Mould Materials and Density of Castings.

Fig. C shows four castings each 3⅞ in. dia. × 4 in. deep and machined from castings 4⅛ in. dia. ×

$4\frac{1}{4}$ in. deep and poured in various mould materials. No. 1, the top right-hand side, was poured in a green sand mould and exhibits the usual cavity, No. 2, the top left-hand side, in dry sand with less cavity, and Nos. 3 and 4, respectively the bottom left-hand and right-hand sides, in plumbago and ganister respectively, giving perfectly sound castings. In each case the blocks were poured through a thin flash-gate about $\frac{1}{32}$ in. in depth running completely round the periphery of the casting at the joint. No riser or feeder of any description was employed.

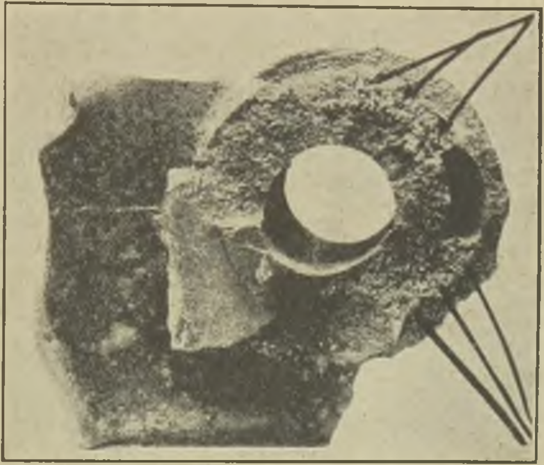


FIG. B.—INDICATING ESCAPE OF GAS THROUGH THE METAL WITHOUT LEAVING GLOBULAR BLOWHOLE FORMATION.

The castings were machined and polished alike to the finest possible limits. The weights of samples were: No. 1, green sand, 11 lbs. $8\frac{3}{8}$ ozs.; dry sand, 12 lbs.; plumbago, 12 lbs. 1 oz., and ganister, 12 lbs. $1\frac{3}{8}$ ozs. The Brinell hardness Nos. were: Casting No. 1, centre, 115; average of four readings from points 1 in. from outside of casting, 145; No. 2, centre, 116; average from four points, 146; No. 3, centre, 118; average at four points, 145.5; and No. 4, centre, 137; average at four points, 155.5.

Fig. D shows the half of a 6-in. sphere casting with the face polished. The casting was poured through a flash runner encircling the periphery at the joint and a small relief riser placed at the top of the casting. The photograph shows the section right through the centre and also through the small pencil riser. This casting was poured in a ganister mould and is perfectly sound with very uniform Brinell hardness through the section, being: Centre, 137; at each of four points 1 in. from outside, 149 in each case.

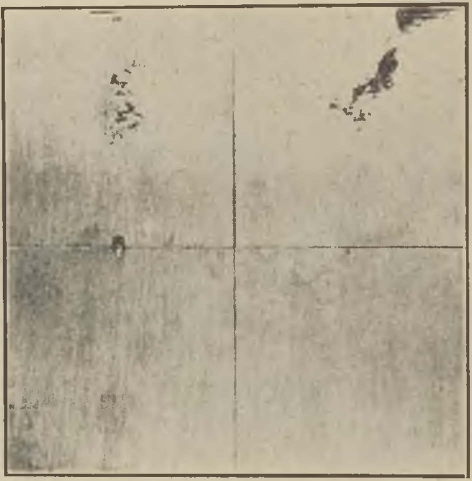


FIG. C.—EFFECT OF POURING INTO GREEN SAND, DRY SAND, PLUMBAGO AND GANISTER RESPECTIVELY.

There is but little chance for these castings to receive a supply of metal from the runners which, whilst being thin, allowed the moulds to be filled at a fairly quick rate. If it were possible for the castings poured in ganister to receive a supply of feeding metal through such a runner, then logically the green and dry sand castings should be sound instead of containing cavity.

The analysis of metal poured in the four first-mentioned castings was: T.C., 3.2; Si, 2.65; Mn, 0.5; P, 0.8, and S, 0.13 per cent.

Spherical Castings.

The initial experiments were, with one or two exceptions, confined to what are termed common irons; the conclusions hold good for special irons with low phosphorus and sulphur content. So long as the metal contains an amount of silicon to act either by catalysis or directly on the carbon present, so that sufficient graphite is precipitated to produce grey iron, then solidity can be obtained if the mould is gas free and resistant to the grey iron expansion at the point of solidification. Gases absorbed by the metal during smelting and melting would appear to be held in solution or dormant if solidification be hastened or the mould resists the grey iron expansions. It does seem that dissolved gases in grey iron are not very harmful if entrained and mould gases are eliminated. It is possible that the action of mould gases can be either catalytic or direct by interaction with occluding gases.

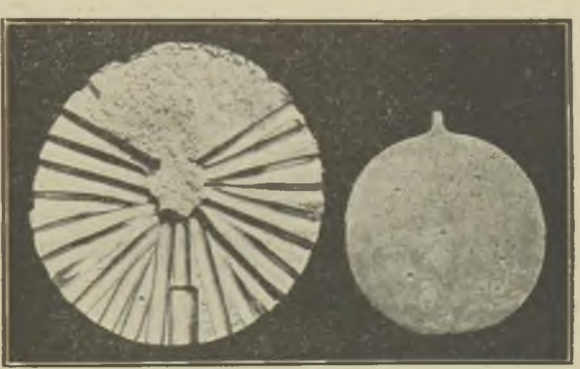


FIG. D.—PERFECTLY SOUND CASTING POURED INTO GANISTER MOULD.

Further experiments seem to indicate that with very low silicon grey iron a plumbago mould was not sufficiently gas free and strong enough to prevent a slight sink on the 9-in. sphere casting used in the experiments. A hot cast-iron mould gave definite fullness and perfect solidity throughout the section. The sample castings exhibited and shown in Fig. D are two of a series of tests taken by pouring 6-in. and 9-in. sphere castings in ganister and iron moulds respectively. The analysis of the 6-in. dia. casting poured in a ganister mould and shown on the right of the photograph was: C.C., 0.5; Gr, 2.65; Si, 2.45; Mn, 0.55; S, 0.12, and P, 0.85 per cent.; and the casting on the left: C.C., 0.6; Gr, 2.43; Si, 1.36; Mn, 0.63; S, 0.104, and P, 0.37. The 9-in. sphere was poured through a $\frac{5}{8}$-in. round top gate.

The runner basin metal used when pouring a metal mould casting does not sink. Metal is actually exuded slightly from the mould, and a convex surface is obtained on the head metal. In green and dry sand moulds the head metal is often seen to sink at some stage after pouring has ceased and is generally understood to be fluid metal shrinkage. To this one could agree as being partly responsible for what is termed fluid shrinkage if it was established that various portions of the outer skin of a casting solidified and expanded outward, leaving metal to be supplied to certain portions of the interior of the metal section. But it would appear that the sinking in the head is mainly caused by mould and occluded gases failing to find an immediate or early passage from the inside of the mould before pouring is complete. Gas can be trapped in various sections of the mould, especially in between cores almost surrounded by metal, and be unable to quickly pass through the pores around the sand grains, artificial vents and risers. In the meantime certain sections above may partly solidify and prevent the flow of metal to the sections which have been overburdened with gases over a longer period.

Cause of Mould Disturbances.

Disturbance in a mould is sometimes made evident two or three minutes after pouring by, in some cases, a gentle rise and fall of the head metal and in other cases a violent blowing will be seen. In the former cases it might be due to gas which has been unable to pass out through the sand and vents due to lack of permeability or inadequate mould and core vents and has found a passage through the fluid interior of the metal section. Violent blowing is associated with either choked core vents by fluid metal or other material or a great excess of moisture in the sand of core or mould. The gases given off the confined core shown in Fig. A did not cause any visible disturbance in the runner and riser heads.

Porosity of Moulding Sand.

Since writing the above notes there has been published the report of a Paper* on the "Advantages of Foundry Control," delivered by Mr. H. J. Young to the Middlesbrough Branch of this Institute. Mr. Young is reported as having stated that: "Draw or shrink holes, together with gas cavities, are the cause of many wasters and of much patching and burning. Proper metal and discreet chilling will eliminate some drawholes, but at times design must be changed. Porosity is associated with drawholes where the walls of the casting form a junction or where a lump of metal is surrounded by sand which gets overheated. Some holes are really sinkings of the molten or semi-molten iron; in a small way these are caused by leaks at joints, and in a large one by gas pockets which disappear too late in the solidifying period. This kind of thing is seen sometimes in a flange, and the phenomenon may go side by side with cold-shuts. Damp moulds, inequalities in the sand and poor venting are common faults. Foundry sand is insufficiently porous to permit of the free passage of mould gases; if it were the mould would collapse. Hence the venting of dry sand moulds is an artificial process to which more attention might be given by the foundry foreman than is often the case. Inequalities in the sand lead to local gas holes, scabbing, and to defects elsewhere in the casting, as well as where it arises."

Mr. Young has on previous occasions stated that

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* FOUNDRY TRADE JOURNAL, April 28, 1927.

foundry sand was not sufficiently permeable to gases. The author is in entire agreement with him in this respect and takes it as further evidence of the conclusions stated earlier and emphasises the importance of venting which he and others have stressed at various times.

Moulding a Large Blowing Engine Bedplate.

Fig. 1 shows the outline of a blowing engine bedplate of the girder type, weighing 22 tons. The production of such a casting is made a little difficult by the restriction of the core outlets. Section B-B shows the size of the holes to be 5½ in.; they were the sole outlets for core gases.

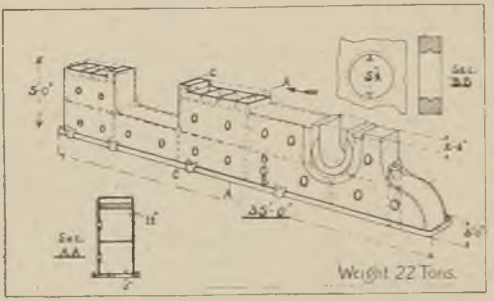

Fig. 1.—Outline of a Blowing-Engine Bedplate of the Girder Type, weighing 22 tons.

Section A-A illustrates still further the interior of the casting.

The pattern was constructed in two portions divided at point C-C. Core prints are indicated by dotted lines. These prints receive the cores which form the pockets and bearing seen on the top side of the casting, the oil well running round the base of the casting and the bolting down core holes as seen in Fig. 1.

Fig. 2 shows the bottom portion of the moulding box with five straightedge boards "A," correctly levelled in the base of the drag without any upward or downward camber. Experience has shown that only a ¼ in. of inward camber was required at the point "B," Fig. 3. The casting is moulded at right-angles to the position when erected with the engine. "B" also points to a solid 3-in. section of metal running the full length of the casting.

Previously much trouble had been experienced in keeping the castings straight. Various forms of camber had been employed without complete success. After a careful examination it was discovered that the metal sections were not as intended. The metal on the bottom side of the casting was found to be thinner than the top section. This variation in metal thickness proved to have been the cause of most of the trouble from distortion. Subsequently the only camber allowed was the $\frac{1}{4}$-in. inward camber at the point "B." Great care was exercised in correctly locating the cores, and holding them in position to obtain as near as possible uniformity of metal section as intended by the design.

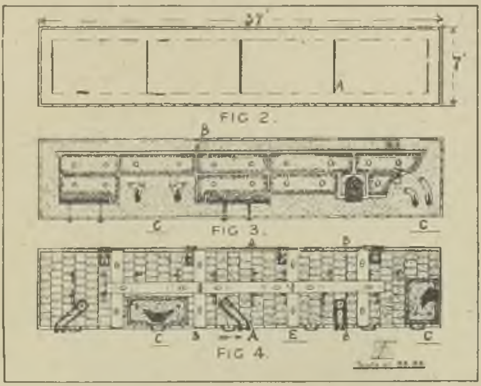

Fig. 2.—Bottom Portion of the Moulding Box; Fig. 3.—Plan of the Mould with Cores Arranged; Fig. 4.—Plan of the Mould Ready for Casting.

Fig. 3 is a plan view of the mould with cores arranged resting on $1\frac{1}{2}$-in. wooden thickness pieces ready to receive the top box-parts for the first time after drying the mould. The mould is rammed up in the usual manner except that greater care is exercised when constructing the top side of the mould, as will be explained later.

Running Arrangements.

It will be noted that the mould is filled with metal by way of two pairs of runner gates located at the points "C" which allows the metal to enter the mould at the lower face and clear below the cores. The cores just in front of the inlet gates are enlarged a little to allow an easy and free flow of metal in all directions, thereby reducing the tendency of both the mould and core

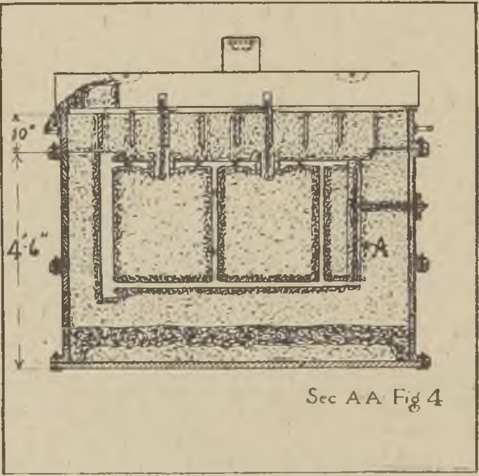

Fig. 5.—Sectional View of the Assembled Mould at the Point A—A.

to scab and erode and reducing the collection of scum about the runner entrance.

Fig. 4 illustrates a plan view of the mould ready for casting. The pouring basins are indicated by the letters "C," two ladles being, of course, employed to fill the mould with metal. There are seven riser gates, four being located on the long flange "B" shown in Fig. 3, which forms the base of the casting, two on the cylinder bearings and one on the large crank bearing. At "E" is sketched a number of weights which are placed to prevent straining of the boxes due to the pressure and momentum of the metal, and additionally gas pressure, at the moment of complete filling of the mould with iron. The boxes are wedged to the underside of the weights along the centre line of the mould. The boxes are bolted together at the joints and stout steel rods placed through further holes and iron packing arranged to prevent lateral pressure straining the mould. The joints between the three top parts are made as seen in the small sketch "B-B." These joints are carefully sealed and weighted to prevent leakage of metal. The drawings do not reveal all the care that must be exercised to make sure of such a type of casting.

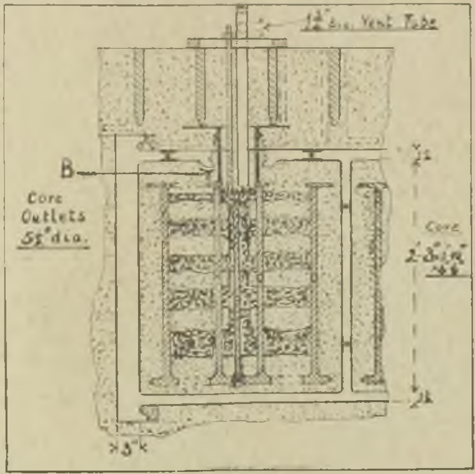

Fig. 6.—Detailed Description of the Construction of the Mould and Suspended Cores.

Fig. 5 represents a complete sectional view of the assembled mould at the point "A-A," Fig. 4. The two cores marked "A" in Fig. 5 are bolted back to the side of the moulding box and the remainder of the cores, with the exception of the one for crank bearing, are suspended from the top side of the mould.

Construction of the Mould.

The next sketch, Fig. 6, gives a clearer and a more detailed description of the construction of the mould and suspended cores to ensure, as near as possible, true safety. The core is required to be soundly made and with good venting. Since much difficulty can be foreseen to extract the core irons after casting through such comparatively small apertures, care must be taken to make the core supports in metal which will allow of easy breaking into pieces no larger than 5 in. to pass through the restricted core outlets. Strength is maintained in the core by ramming up with an outside layer of strong sand and on the inside with alternate layers of medium-bonded sand and cinders for venting. Each layer of cinders communicates with a central column of cinders which leads to the surface of the core just below the neck. The most vulnerable part of the core, the outlet for the gases, is specially cared for. It will be noted that the sketch indicates that a cast iron or steel bush is built into the neck of the core and seated solidly down on the core iron. Around the bush is rammed a strong mixture of stiff loam into which has been worked a little core gum. The top boxes are also carefully made. Metal reinforcements are introduced to correspond with the bushes in the cores and rammed with strong facing mixture.

Arrangements for coring the mould are made by first bolting the side cores into position, locating the crank core and then those to be suspended from the top boxes are placed in the open mould and resting on wooden thickness pieces equal to the desired metal section. Studs are placed between the cores to lend steadiness when bolting up to the top side. Small pieces of clay are placed on the top of the cores to ascertain the metal section and for positioning a number of studs to lend further steadiness to the hanging cores. Around the top of each core outlet is placed soft loam covered with paper. The top boxes are then located for the first time after drying the mould. The soft loam is squeezed between the lower face of the top boxes and the top face of the core outlets, effectively sealing any crevice through which metal might otherwise find ingress to the core. The top boxes are again lifted off and all loam which has been pressed beyond the area of the core outlets and central portion through which gases must pass is trimmed off and well dried with hot irons. Studs are placed in various positions on the top of the cores, the location and section having been previously ascertained by the clay impressions and the top boxes again located. The cores are firmly bolted to the top-part boxes by passing hook bolts through the holes prepared and under staples cast in the core grid. The boxes are again lifted and set on suitable logs; whilst in this position the moulders give a further touch of safety by wet blacking around each of the core outlets, using a small brush on a long handle. More studs are located, and on the top side of the boxes vent tubes are placed alongside the hook bolts and penetrating right through the top boxes and into the cinders below the neck of the core. Sand is then carefully rammed around the vent tubes. The mould is finally closed and poured.

The most skilled attention is needed to ensure that no metal enters the core vents. If cores were simply placed on studs resting on the bottom face of the mould many things might happen to cause this expensive casting to be lost. With cores and mould so constructed very little risk is taken. Even if the top boxes lifted a little during pouring the casting may still be saved because the core vents would still be secure.

Two Grades of Metal in the Same Casting.

An incident during the American foundry tour reminded the author strongly of similar work done by him 11 years ago. During the journey round one of the jobbing foundries he stopped to question the foundry manager concerning the reason for employing two sets of gates and consequently two ladles to pour a lathe-bedplate weighing about 8 tons. The casting was bulky and about 16 ft. long × 8 ft. wide, thereby being quite safe if run from two or three places at one end of the casting. He had also remembered that previously he had seen among other ladles one of 25-ton capacity. The manager's answer was that he poured a strong semi-steel mixture into the lower part of the mould, which constituted the working and wearing surfaces. When enough semi-steel had been poured to fill just above the important parts they ceased pouring; at the same moment a low grade of cast iron was poured from the waiting ladle at the other end of the box at a higher level and the mould completely filled. The ratio of metals was about 25 per cent. semi-steel on the bottom side and 75 per cent. common iron to complete filling.

Making a Lathe Bedplate.

To illustrate this practice a little further, sketches are reproduced of the moulding of a lathe bed which the author described in a recent Press contribution.*

Fig. 7 shows the plan and elevation of a lathe-bedplate 38 ft. 5 in. long. Whilst this casting is much longer and lighter in section than the one referred to, it is a much heavier casting as a whole. The idea, of course, is to fill the faces there marked A and B, which are cast the reverse way up to that in the sketch with a strong, close-grained cast iron obtained by introducing 35 per cent. steel into the cupola mixture.

Fig. 8 shows the arrangement of the in-gates when pouring such a casting. In this instance the author employed four in-gates at each end of the long mould. Until a later stage in the pouring the two sets of in-gates at the higher level were stopped up by placing plugs over the down-gates in the pouring basin. When sufficient metal had been poured through the lower set of in-gates from each end to fill 25 per cent. of the mould, the stoppers or plugs which controlled the flow of metal to the higher level of the mould were lifted, allowing a hotter metal to occupy the top surface of the casting. This arrangement was found to give better control over the camber, or distortion, because it ensured a more uniform temperature of metal over the whole of the mould; also the bottom side of the casting was cleaner, due to less metal passing the lower levels which may cause erosion and scabbing of the mould face; again, the metal in the bottom faces which were the important sections of the casting tends to be of closer grain

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* See THE FOUNDRY TRADE JOURNAL, vol. 25, p. 155.

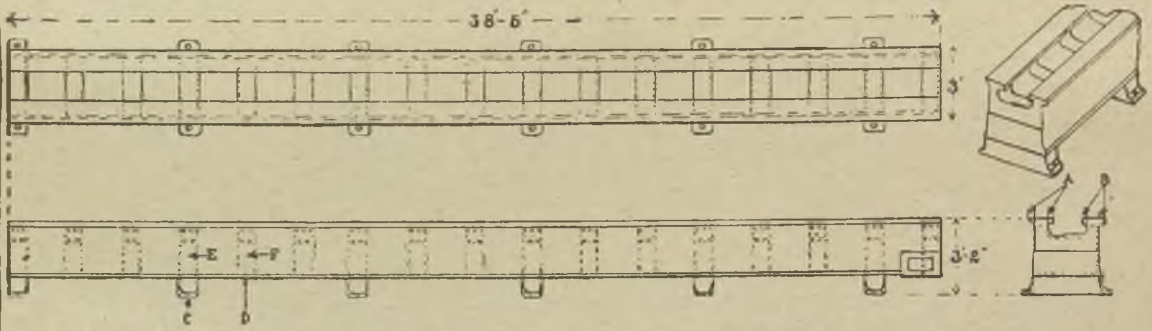


FIG. 7.—PLAN AND ELEVATION OF A LATHE-BEDPLATE, 38 FT. 5 IN. LONG.

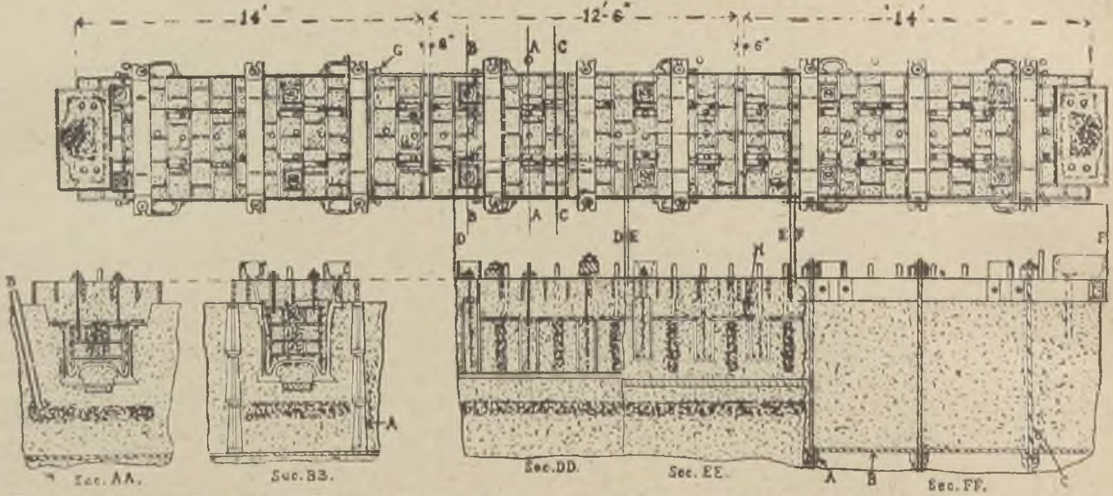
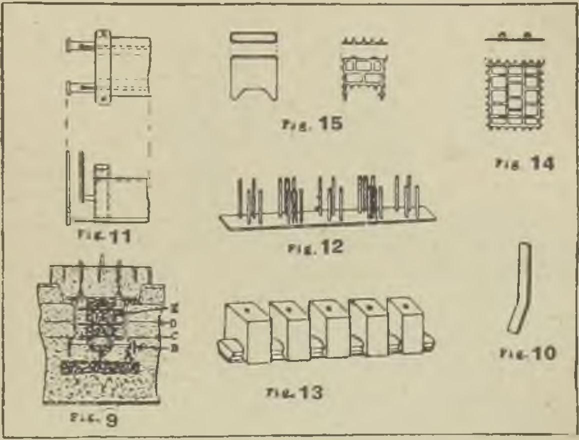


FIG. 8.—CROSS SECTIONAL VIEWS OF THE ASSEMBLED MOULD, AND PLAN SHOWING RUNNER BASINS AND FOUR DOWNGATE ENTRANCES.

and freer from gas cavity due to an earlier freezing than would otherwise obtain if the whole of the metal passed through at the lower level to fill the higher reaches of the mould.

It would be possible to pour even such a long casting with two grades of cast iron, but it means bringing into action four ladles, two to pour semi-steel in through the bottom in-gates from each end and two to pour later at the higher level. However, it is thought preferable to secure economy by using a series of chills along the important faces and pour with a moderately strong iron, which has been done with smaller castings.



Figs. 9—15.

The sketch (Fig. 8) shows a series of cross-sectional views of the assembled mould and a plan view with the runner basins and the four down-gate entrances at each end, whilst Figs. 9, 10, 12, 13, 14 and 15 illustrate respectively cross-sectional view of mould, special sand rammer, core iron for the cores (Fig. 13), grid for lift between feet in top part boxes, and feet core with its accompanying grid.

Stamp Block Castings.

As pointed out earlier in this Paper, the practice of pouring two grades of iron into the same mould reminded the author of the time when he regularly cast stamp blocks and dies with a facing of steel on the working surface and grey iron the remainder of the casting.

Fig. 16 illustrates the procedure. "A" is a sketch of a casting and "B" the mould for same. About 2 in. of steel is poured into the mould at the low level. Almost immediately after the steel is poured the common grey iron is filled in at the higher level. The specific gravity of the steel ensures that it remains settled at the lower level, amalgamation of the two metals only taking place at the contact line. This method was practised because of cheapness. The castings were very satisfactory and had a long life.

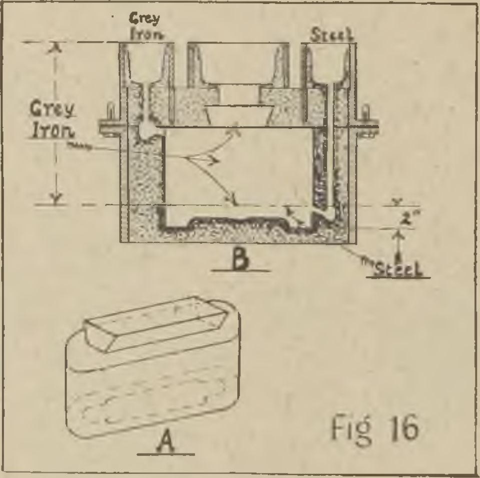


Fig 16

Moulding Hydraulic Cylinders, Rams and Heavy Flywheels with Special Reference to Moulding-box Construction.

In many districts both medium and heavy castings are loam-moulded in strong cast-iron rings or plates with vertical prods cast thereon to hold in the bricks and other material. Such is the practice when using strickles and templates, etc., or building to skeleton of full pattern.

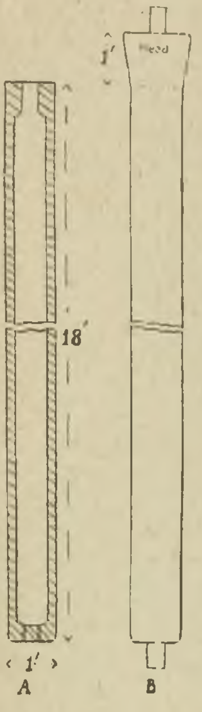


FIG. 17.

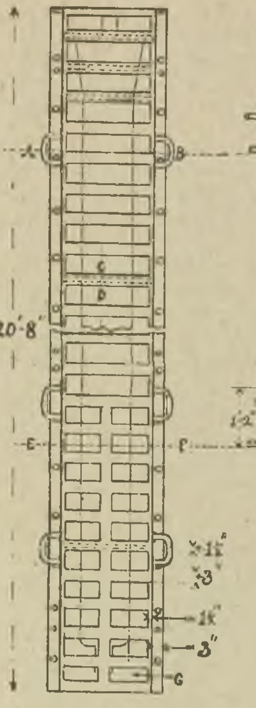


FIG. 18.

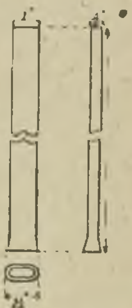


FIG. 19.

There are quite a number of founders who place the finished mould in a pit and ram around the outside with black sand. The author has had cast thousands of tons of large castings made in such a mould without having to incur the expense of ramming and again removing a large body of sand around the mould in the casting pit without the loss of a single casting. There are well-known founders in the Manchester district and elsewhere who are carrying on in the same way with real success.

The production of hydraulic rams and cylinders can be carried out in boxes which will eliminate the need for the extra ramming of sand around the boxes.

Fig. 18 illustrates the boxes and a method of moulding hydraulic rams, whilst cylinders can also be made similarly.

At A, Fig. 17, is shown the section of a medium-sized hydraulic ram with a 12-in. sullage and sink head cut off, and B outlines the necessary pattern. Fig. 18 gives the construction of the strong moulding box suitable for making ram and cylinder castings therein, without having to resort to the ramming around the outside of the box. Each half-box is made in two or more parts, according to the length of the casting required, and bolted together. The joints are then machined. CD shows above Fig. 19 the shape of the bars which form a T head partly boxing in the sand and helping greatly to withstand the outward pressure of the metal whilst pouring. Section AB seen above Fig. 19 shows a cross-sectional view of the upper part of the box which runs about two-thirds of the total length, and EF indicates the construction of the lower portion of the box. In this lower part of the box an additional bar is introduced and runs vertically in the centre for about 6 ft. from the bottom end.

With a box so made and the parts well bolted together at intervals of about 12 in. a burst-out or runaway is very unlikely. The mould is made horizontally and constructed very soundly in strong refractory sand. Stiff loam is worked on the pattern at what will be the bottom end when pouring vertically, and the remainder of the pattern is faced with a strong sand For about half the length of the box (the bottom end) it is advisable to ram in a stronger sand than that from the floor heap. A mixture of half black and half core sand can be recommended. The remainder of the box is rammed with black sand which has been wetted with clay-water.

After extracting the pattern, the mould at the bottom end is studded with flat-headed nails to receive the heavy impact of the first metal poured. The mould is well blackened with a good mineral blacking, and, after drying again, washed over

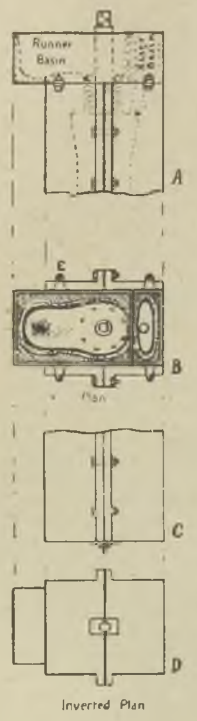


Fig. 20.

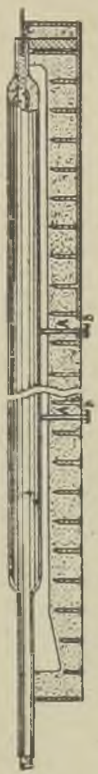


Fig. 21

with a thin solution of good plumbago blacking and gum water. Fig. 19 shows the design of the drop gates, eight in number.

Fig. 20 illustrates with section A and B the construction of the runner and riser basins. The head is helped in its work by feeding for a short time until the runner basin is run dry by tapping into a ladle from below the runner box. Every effort is made to free quickly the top of the core bar, which is lightly tapped with an iron bar to induce it to expand upwards, otherwise the core bar may be found to be much bent when extracted from the casting.

It is the practice in some foundries to prevent lifting of the core by chaining the bar from the top side. In this case they cannot be quick enough in releasing the bar after casting, consequently the core barrel is bent. As a matter of fact, the bar and core is distorted before that stage is reached, and sometimes a waster results. This can also be proved on occasions if rams are inspected after having been scrapped and broken. The section will be found to be thick and thin instead of regular.

Section C and D show the correct way to secure the cores. The core bar is made solid to about 3 in. behind the neck of the core and a stud bolt screwed in to allow the core to be bolted down from the bottom end. Made thus, the core is allowed freely to expand whilst the metal is still being poured. Such a core is so slender that when it is located it will sit on the bottom side of the mould, and when the box is turned up to cast vertically the core is very unlikely to straighten itself. To avoid such risks two wooden pegs are placed to act as temporary chaplets, as shown in Fig. 21. When the mould has been turned up to the vertical casting position the wooden chaplets are withdrawn and the holes vacated plugged with round cores secured by the special plates on which the wooden chaplets had been previously resting.

Heavy Flywheels.

The next example explains the moulding of a 10-ton flywheel. Fig. 22 shows in plan the pattern resting on a plate ready to receive the moulding box. The elevation of the pattern above the plate is shown below. To make a full wheel a half-pattern is made in two pieces, dividing the pattern to represent a quarter wheel, as indicated in the plan at AB. Below the plate is shown the section of the flywheel. This sketch must not be mistaken as to indicate a half-pattern on either side of a plate. The two quarter (half) patterns are located by pins on .. large machined cast-iron plate set permanently on the moulding floor. On the plate are machined lines to give foot squares and are used to set the pattern dowel and moulding-box pin holes for the various sizes and types of flywheels which can be made on this one plate. Much economy in patterns and in moulding is thereby secured. When a flywheel is required in halves only one quarter-

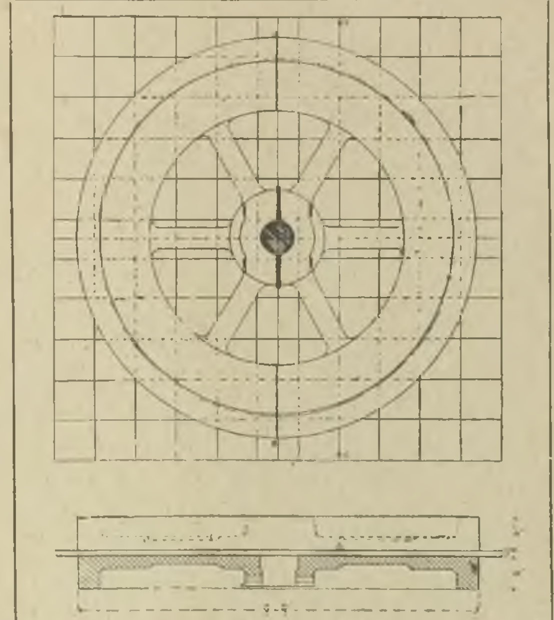


FIG. 22.

pattern is needed, and the moulding box is also disassembled to make a half wheel. When a full wheel is required the two quarters are used.

Fig. 23 illustrates the construction of the moulding boxes. Such heavy flywheels are very exacting on the moulding boxes due to expansion which takes place from the heat radiated from the heavy sectioned casting. The repeated breakages can be minimised by making the boxes in several pieces. In the example shown the moulding box is made from two pieces forming the area about the boss; this, incidentally, allows various sized bosses to be used. Two pieces make up the middle bars and the outside ring is formed again by two pieces. The sections are firmly bolted together and they make together a very durable

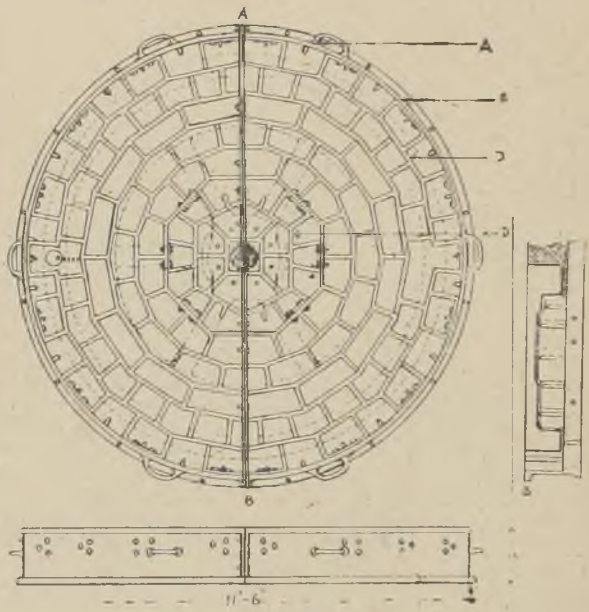


Fig. 23.

box. Little or no casting strains remain in such a construction.

Soon after the flywheel has been poured and the metal is set bolts are released in the various sections and at the joint of the box to allow of free expansion; otherwise the box would be broken, although not so seriously as if cast in one piece as previously.

Semi-Permanent or Long-Life Moulds.

The progress of permanent mould casting is not very substantial. Beyond the centrifugal casting process as practised by the Stanton Ironworks Company, Limited, for making pipes and that by the Centrifugal Castings Company, Limited (Thorncliffe Ironworks), for the manufacture of piston rings, liners and similar castings, and the making of carburettors in metal moulds by the Holley Carburetor Company, Detroit, U.S.A., and various other similar castings by other makers we can say that there is little progress.

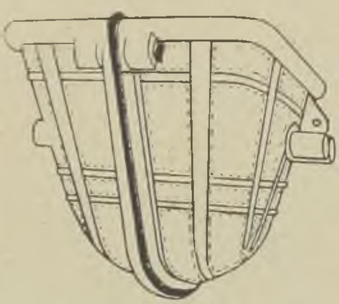


FIG. 24.

There are several foundries in the U.S. making sashweights in permanent moulds with very indifferent success. There is a company in the United States which was installing a system of permanent moulding for making radiators, but it is thought that the company has abandoned the system.

It will be found that the only castings which are made in metal moulds and made to pay are castings which give trouble when poured in sand moulds.

The author well remembers the experiments of Mr. S. G. Smith, to whom the foundry trade is so deeply indebted. It will be 15 or more years ago when he cast small valve castings in metal moulds; but, if memory is correct, the object was to secure sound castings. Mr. Feasey, foundry manager of Ruston & Hornsby, Lincoln, cast a certain small type of valve-shaped casting in metal moulds again to secure a sound casting. The Holley Carburetor Company, Limited, started off with the same object—to secure good castings. Mr. Broughhall's classical work will also be remembered. He employed certain types of cast-iron moulds to produce close-grained sound metal in the form of long sticks to be cut up to make gears, etc. Again, sound castings was the aim. Most progressive foundrymen will, from time to

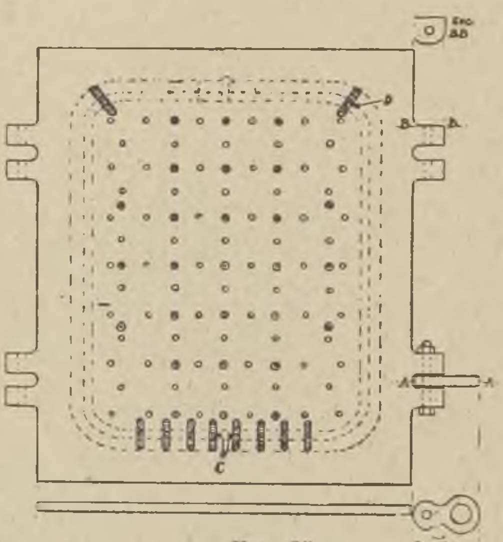


Fig. 25.

time, have made simple types of castings in metal moulds with indifferent success. The author has tried many times, but has come to the conclusion that it is only sensible to make castings in metal moulds when good sound castings cannot be secured by ordinary methods. Therefore, the production of castings made in metal moulds in the great majority of cases has not been finally continued for the sake of direct cheapness, but to secure sound castings which, of course, cheapens the cost of the castings by eliminating wasters.

The cost and upkeep of permanent moulds, etc., is extremely high, and can never compete with the modern quick methods of moulding from various types of hand and power machines, and even with ordinary hand-manipulated plate patterns.

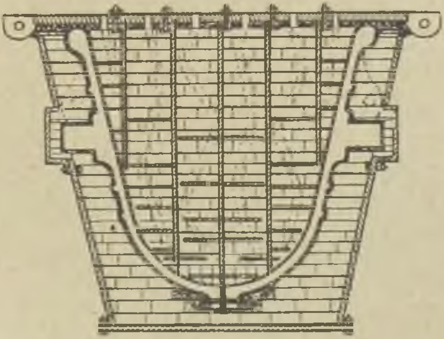


Fig. 26.

In the case of medium and light castings real economy is obtained from some form of semi-permanent mould structure. It is on record that there are founders who have produced a large number of various types of simple unimportant castings with a little preparation each time from the same mould which is made from fire bricks. The author has made similar castings in brick-lined moulds, but finds that the castings must be of thicknesses above $\frac{3}{4}$ in., otherwise blowholes will be encountered. Why this is so he has not yet been able to find out. Probably in the heavier sectioned castings gases have time to bubble through the metal and find a passage through the top face of the mould. This is most likely.

When pouring moulds vertically much greater success can be achieved from the fire-brick-lined moulds. Apart from the blowholes in the thinner castings in both thick and thin moulds, much trouble is experienced with blacking washing. Well burnt bricks should be used. They are more porous with less bonding material, which will give off gas at the higher temperature. The effort of the gas to break through the blacking causes the latter to peel, apart from lack of adhesion and expansion of the blacking face.

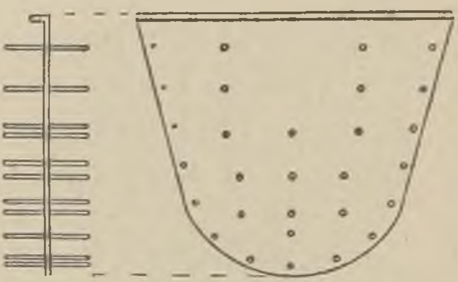


Fig. 27.

Many types of castings are produced in partly metalled moulds to secure either hard-wearing surfaces or soundness. Many loam moulds can be described as semi-permanent. The next series of sketches can be taken as an example of what can be done in this respect.

Slag Ladles.

Fig. 24 shows the outline of the ordinary type of slag ladle, which weighs about 10 tons, although the larger sizes may reach 20 tons. Fig. 25 illustrates the strong top plate to which is soundly bolted a number of plates similar to the sketch Fig. 27. These plates are bound together and strengthened by cast-in wrought iron bars which help to hold the brickwork together. The bricks are firmly built into the metal framework. Fig. 26 gives a sectional view of the closed mould. The bottom side of the mould is constructed by building brickwork soundly into a metal casing. Fig. 24 indicates by dotted lines the kind of pattern used when moulding by this method. The pattern is first used to mould the bottom side of the casting separate from the top and then the top part is dealt with later. In both cases before placing the skeleton pattern the brickwork is well rubbed with very wet loam. The pattern is next located and loam worked behind the skeleton of the pattern and on the face between the struts. When the loam has stiffened various strickles are brought into action to form the face of the mould not produced by the skeleton patternwork. The ladles are split into halves; this is accomplished by using splitting cores, as shown in Fig. 28. Bolt hole cores are threaded through the splitting cores.

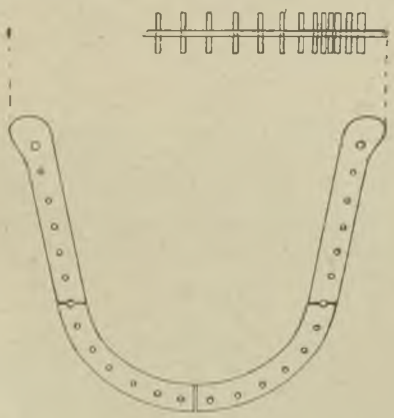


Fig. 28.

The cores at the bottom of the mould are subjected to hematite metal combined with great pressure, which produced, very often, an almost metallised core. This trouble was overcome by arranging a mixture of 25 per cent. red sand, 25 per cent. ganister and 50 per cent. plumbago, or mineral blacking, well milled together, and, of course, well dried.

When the casting is quite set the bolts and clamps are removed and the top plate with its burden lifted about 1 in. This is done to prevent the contracting casting seizing the brickwork and plates on the top side of the mould. The whole of the brickwork, both in the top and bottom, with the exception of that above the trunnions, can be used up to 50 times. Just occasionally bricks here and there are replaced.

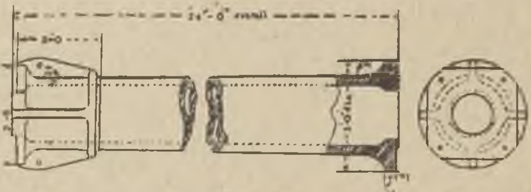


FIG. 29.

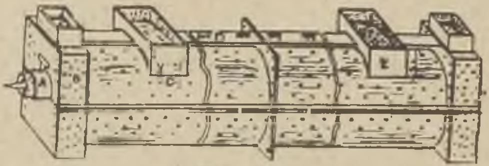


FIG. 30.

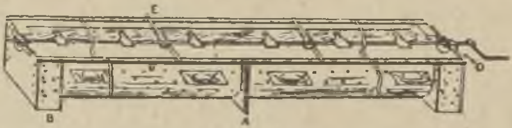


FIG. 31.

Heavy Furnace Column.

The next few sketches describe the moulding in loam, of a heavy furnace column weighing seven tons, and can be described as semi-permanent moulding. Fig. 29 illustrates the casting 24 ft. in length with average metal sections of 3 in.

Fig. 30 gives a view of the bottom half of the mould, with the strickle in position supported by bearers E and the end centres, and resting on a strong cast-iron casing conforming approximately to the contour of the casting. The casing is divided into four pieces, two for the top half and two for the bottom half of the mould. The casing is carefully bricked and jointed with loam. The vertical flanges (as moulded) are faced with loam brick on the inside, so that the casting on cooling will not grip the brickwork too tightly and lift out with the casting when being removed. Except around the brackets, 1 in. of loam is allowed on the face of the brickwork. The top side of the mould is made in much the same way as the bottom, generally, but the brickwork is tied into the casing with suitable strong grids.

Fig. 31 describes the appearance of the assembled mould ready for pouring. A is the round cast-iron barrel core which is made in two lengths, and, when resting in the mould, is supported by strong cast-iron studs, and the side movement arrested by chaplets stretching through the metal section across the joint to the sides of the casing. D indicates pieces of wrought iron cast in the casing to receive the chaplets which hold down the two half cores. C and E are pouring basins which feed four drop runners shown in phantom at C. Two risers áre situated one on each flange.

In such cases, if ordinary care is exercised, quite a considerable number of castings can be made using the same brickwork as first set and facing again with loam as before. Many similar cases could be cited.

Moulding Sash Weights.

The method to be described outclasses any common method of permanent mould production for this simple type of casting or any similar in design with large numbers required.

A, Fig. 32, is a sketch of a sash weight weighing about 16 lbs., and C is one of a number of tubular patterns for making such castings in a box similar to the illustration B, which is a casing with an open top and two outer and inner ends each with about 46 holes corresponding to the diameter of the casting to be made therein and spaced about 2½ in. apart. One end of the box is provided with vertical slots. The inner end can be moved about in the slots to suit different lengths and weights of castings. E and D show respectively a sectional elevation and plan of the mould ready for pouring. F describes the end elevation.

The castings are poured through an inlet gate formed by the end of each of the tubular patterns, as shown at *h* in the sketch C. The horizontal ingates are fed from a series of square vertical runners which are in turn connected with a simple runner basin scooped out of the upper open side of the box. A number of weights are lodged on the top side of the open sand on each side of the pouring basin.

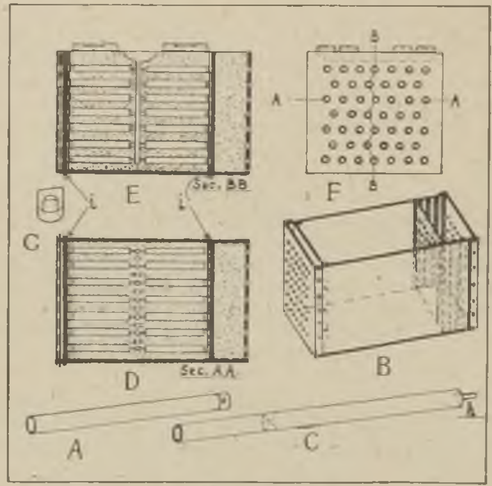


Fig. 32.

To commence moulding the casing B is rammed level with the lower surface of the bottom row of castings, and fourteen of the forty patterns provided are threaded through the holes at each end of the box and lie at a suitable distance from each other at the centre of the box. The first set of vertical gate sticks are then located at the end of the patterns, the ends of which form the inlet gates. Sand is next solidly rammed around and above the pattern to correspond with, again, the lower face of the next row of patterns and the second row of down gates set. After the third row has been rammed up in a similar manner the next and succeeding rows are produced by drawing out the bottom series of patterns in progress and used to fill the box with moulds of sash weights. After the box has been rammed full, the runner basin formed, and the weights bedded down, the patterns and vertical gate sticks are withdrawn. The eye in the casting is formed by an oil sand core similar to the sketch G. This core also serves to blank off the open ends of the moulds. The loose plates in sketches D and E are placed behind the inner ends of the boxes and can be held in position by wedges or ramming sand between the inner and outer end, thus effectively sealing the mould.

With all castings taken from the moulds and sand prepared overnight, a moulder produces between 4½ and 5½ tons of sash-weight castings per day. The moulder receives a price of 60 cents for a flask containing up to 7 cwt. of castings. This moulder made from ten to twelve per day. Small cores which formed the eye in the sash weights were made on an oil sand core blowing machine. From this machine a core-maker made 9,000 complete cores per day.

The very poorest grades of cast-iron scrap were collected together along with thin mild steel scrap and melted for such castings.

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Birmingham Branch.

PATTERNS AND THEIR STORAGE.

By F. J. Cook (Past-President).

During the twenty-five years this Institute has been in existence there have been presented several Papers dealing with various phases of the subject of making and using patterns. The subject, however, is so wide and varied as to make it well-nigh impossible to deal at all thoroughly with all classes of patternmaking, hence the writers have generally dealt with some specialised section of the art.

The present Paper, which is divided into the two parts of patterns and their storage, is not intended to deal with the structure and making of patterns as such, but to enumerate some points which the author, over an extended experience in the use of patterns, has found useful in eliminating misunderstanding between the two departments of foundry and patternshop in conveying the correct information to the moulder, also which assist the patternshop in eliminating many annoying sources of mistakes when fixing up and changing over the handing of large patterns.

Engineers are well versed in the necessity and the usefulness of a tool room as an adjunct to a machine shop, and generally do not begrudge the time, energy and expense incurred in producing elaborate and skilfully devised jigs and tools to enable the machinist efficiently to do his work: but how seldom does one find these same gentlemen consider the patternshop equally as important as a tool room to the foundry, and who rather consider patternmaking as merely a necessary but vexatious evil.

The machine shop tool room and jig designer invariably brings into play, and rightly so, an enormous amount of ingenuity and craftsmanship to produce jigs so devised as to make it well-nigh impossible to misinterpret their proper use and to make them in common jargon " foolproof." But how often is this same helpfulness absent in the patterns which are supplied as tools to the foundry, particularly so when they have to be used by the jobbing founder, who frequently is quite unfamiliar with the use and importance of the various parts of the castings which he has to make from the tool supplied. How often also are there many irritating defects in the nature of crossed joints, bosses and loose pieces either missed off, or misplaced, cores wrongly placed or not put in at all owing to there being no definite indication of a core print, and also from the casting having been moulded the wrong way up to ensure the machined surfaces finishing without blemish. How easily the prevention of many of these more or less serious irritations can be effected is part of the object of the present Paper.

Previous mention has been made as to the diversity and range of the subject of patterns. It therefore becomes necessary to state that the lines of work to which this Paper applies, both as to the patterns themselves and also as to their storage, are those used in the making of high-speed steam and oil engines, compressors, turbines and condensing plants and the like, and embrace those required from the smallest to the largest plants of the various classes enumerated.

It will be understood that these patterns, although somewhat standardised, are frequently only intermittently in use, and some time often elapses between the times they are in commission. Where patterns are standardised and used in mass production, and are in constant use in the foundry, many of the points which will be dealt with in this Paper do not necessarily apply.

With the object in view of the pattern exhibiting the fullest possible information for guiding the moulder to a thorough understanding of what is required, much can be accomplished by a judicious and well-organised system of varnish colours.

Colour Schemes for Patterns.

When patterns have been varnished, it has always been a recognised practice to adopt a different colour for core prints from that of the general body of the pattern which represents metal, although generally one colour only was used for the core box. To a certain extent it is now the custom in some establishments to carry this question of colour to the extent of indicating parts of the casting that have to be subjected to machining by means of a colour distinct from that of the body of the pattern or core print. But when the author of this Paper introduced a scheme of this description about 30 years ago he had not seen or heard of its having been applied elsewhere. The adaptation of a colour to indicate where the finished casting will have to be machined is often of the greatest use to the moulder as indicating at once the part which it will be necessary to mould and cast down to ensure that the product will give a clean face when machined. Much equally instructive and useful information can also be conveyed to him by carrying the colour scheme still further.

Where patterns are made in halves and much coring has to be done, it always well repays, for any time taken in the pattern shop, to indicate, much more than is generally done, on one of the halves of the pattern in varnish, the outline of the section of the metal at this point. As the joint in the pattern coincides with the joint in the mould, indicating the outline of the section of the metal as suggested is generally much more helpful to the moulder as a guide when coring up the mould than the drawing which has been used by the patternmaker can be. For, whether the moulder has a fair knowledge in the reading of a blue print or not, the drawing to which the pattern has been made is generally much less simple to understand than the method now suggested, owing to the necessity, for the guidance of the patternmaker, of views and sections being given when looking in various directions, and which may not give a section coinciding with that of the joint of the pattern.

Indicating by means of a chain of dots or diagonal lines, of a different colour from that of the general body of the pattern, the outline of any loose piece or facing, often prevents their being missed off, as there is thus an indication that they are required, besides which, if the outline has been well scribed round it is a useful guide to the patternmaker, and saves much time in resetting up a pattern. All loose pieces which have to be frequently taken off for handing, etc., should, wherever possible, be dowelled, and where these same pieces or similar have to be used for different hands, a screw should be inserted in the female dowel hole of the hand not required, so that the facings cannot be used in the wrong position when the pattern gets to the foundry.

Position of Chills should be Indicated.

It is often found necessary, to ensure a sound casting, to insert in the mould or core box at one or various places a densener which in some cases may take the form and place of a round core, and how annoying it is when after having gone to a lot of trouble to cure a defect by this means, the same defect has occurred at a later date owing to the fact that the pattern has not been in use for a long time and no one has remembered, or the moulder known, that it had previously been found necessary to apply this remedy. The application of varnish of a well-understood colour to the place where denseners are required would be sufficient indication to a moulder, who had never previously seen the pattern, that a densener was necessary and would thus save a great deal of annoyance, and be an economical gain.

There is really no need to mention that parts to be stopped off, either in the general length of a pattern or in a batten put on to stiffen the pattern, should be indicated as such, as it is invariably the custom to indicate such pieces with diagonal lines of a distinctive colour.

In establishments where patterns are made for use in making castings of various metals, it is good practice to use a separate distinctive colour for the body of the pattern to indicate the metal it represents.

The American Foundrymen's Association, a little time back, formed a committee to frame a standard colour scheme which would cover many of the items suggested. Their recommendation was that surfaces of the casting which had to be left unfinished or not tooled should be indicated on the pattern by black; surfaces which had to be machined should be indicated in red; seats of and for loose pieces should be shown by red stripes on a yellow background; core prints and seats for loose core prints to be painted yellow, and stop-offs to be indicated by diagonal black stripes on a yellow base.

Whilst their suggestion meets many of the views expressed in the Paper, there is no provision for the indication of where it is necessary to apply denseners, nor to indicate the metal of the casting for which the pattern is to be used. The position of denseners could well be indicated with white, and if the general colour of black be used in patterns to produce iron castings, red, with green to indicate machined surfaces, could be used for steel and malleable iron, and yellow with machined faces shown also in green could be used for non-ferrous castings.

In cases where the casting has to be machined all over, the base colour should indicate the metal, and diagonal lines of the colour to indicate machining should be painted over it.

In patterns which are jointed, how often one finds the dowels so placed that when the halves are put together the wrong way round, the contour of the two halves very nearly, but not quite, match; in fact, this so often occurs that one might be excused for believing that it is sometimes purposely done, but in reality it is due to the practical eye of the patternmaker in laying out his job. With patterns so arranged it is not unusual to find that the casting has been produced from the pattern so wrongly jointed, resulting in a cross joint which, if not actually sufficient to scrap it, is sufficient blemish to mar what otherwise is a good job. When discussing the fault afterwards, it is quite easy to lay the blame on to the carelessness of the moulder, but it should be remembered in his favour that when the first half of the pattern has been rammed up in the mould and he has sleaked the joint, and particularly if the pattern is an old one and consequently dirty, that it is difficult to see the outline of the pattern clearly even in well-lighted shops, which unfortunately are not always prevalent. It is, however, quite easy to avoid the possibility of such an error by fitting the joint with one large and one smaller dowel which would make it impossible to put the pattern together the wrong way, and the same method could frequently be applied, with benefit, to core boxes.

Enlarging Patterns.

In patterns of the nature indicated it is often found necessary, to accommodate different sizes of cylinders, etc., to lengthen such parts as crank cases, bedplates, etc. Provision should be made for this when the pattern is first made by making a joint a convenient distance from one end. This joint should be well dowelled and bolted to the general body of the pattern, the dowels ensuring that the whole will be solidly and rigidly held together, and is useful, particularly when the pattern has to be bedded in, as is so often the case with this class of work.

In trunk types of guides, where guide, distance-piece and cylinder bottom-cover are made in one casting, and where there is a constant change of the various parts necessitated by changes in cylinder sizes, length of stroke, type of metallic packing used, etc., if the various sections and flanges are jointed and well dowelled, and held together with a bolt passing through the whole length of each half, a very great saving in time is effected when fixing them up for various jobs. The core boxes should be jointed exactly to match the joints in the pattern, and held together with a bolt each side the full length of the box.

Pattern Storage.

In framing a system for pattern storage, it is first essential to decide on the method of pattern numbering. There are many complicated systems, devised generally, it is feared, by someone who has not to use them in works practice, the object being, by means of numbers, to indicate, very often unsuccessfully, every conceivable kind of information concerning the casting, the order for which it is required and a host of other queries. An explanation of many of these systems often leaves one in the same frame of mind as when asked for the first time the old mathematical gag of "think of a number, etc."

The worst example of this type of system which the author has yet met is used with an American machine being manufactured in this country, and in connection with which the American system of pattern numbering has to be employed. A sample pattern number, which is typical of all those used, is B 29783—56—762—84326 S, making, with the cyphers in between, the various numbers 20 in all. In each type of these machines there are over 100 items for castings, and the humorous part of the business is that there are quite a number of the items the patterns of which are so small as to be impossible to accommodate the number it should carry. Still, each time an order is issued it is made out with the whole of the pattern number in full, and a few days later a subsequent list is issued to the jobbing founder giving an identification number on the patterns which are too small to accommodate the whole gamut, and although these machines have been made by one firm for quite a long time, no one has yet been able to see the necessity or the usefulness of such a complicated form of pattern numbering, whilst the confusion that is frequently arising in trying to use the system often calls forth such expressions as, to say the least, would not look well in cold print.

Simplifying Numbering System.

In the system to be described, the problem to be solved was the numbering, with the smallest possible number of figures so as to be effective and as cheap as possible, and to store in such a way that they could be located, not only by one man as is usually the case, but by anyone connected with the pattern department, a production of 1,000 new patterns every five months. This number of new patterns was kept up for quite a number of years, although of late the number has been considerably less.

The system of numbering employed was to give to each pattern made, irrespective of its size, standard, or type of machine, the next number in numerical order. To keep down the number of figures required no number was allowed to go over 1,000, but to distinguish the pattern each 1,000 numbers had a prefix of a letter of the alphabet till the whole alphabet had been used, and then the letter would be used as an affix. When the whole alphabet has been used twice in this way, the system can be used by using the letter first above and then under the number which will accommodate the numbering, together with the first 1,000 without a letter, of 105,000 patterns, which is a quantity above that usually met with in one's lifetime, for although the system has been in use for 28 years in connection with a pattern-shop employing generally over 70 pattern-makers, the pattern numbering has not nearly exhausted the provision of using the alphabet as a prefix and affix, and with an output up to the full number stated the system would last 50 years.

This system of numbering has many obvious advantages over that previously mentioned. In the first place only one pattern in a thousand has five figures or letters, 10 have two, 90 have three, and the remaining 900 only four figures and letters. This is quite a reasonable saving in the cost of figures and letters and the fixing of same on the pattern. Think also of the time taken to stamp this number, say, on a cylinder pattern and core boxes, the pattern being a four-parted job with steam and exhaust branches to suit both hands and with quite a multitude of core boxes. Besides which, consider the great amount of time saved in the writing of the numbers in the making out of orders, and booking in the various departments which have to deal with the castings.

With the system previously described, each of the 100 items having 20 ciphers calls for the writing of 2,000 figures or letters for each order, against a maximum 400 in the method suggested, and as these numbers have to be written by seven departments, and further owing to the fact that one can visualise a letter and three or four figures and remember them at once if only momentarily, whilst a list of 20 require very careful following, gives some idea of the great amount of time saved throughout a factory by employing the latter system. In practice it becomes quite easy to remember pattern numbers of three or four figures, whilst twenty is impossible.

Pattern Register Details.

The pattern numbers, when given out to the patternmaker, are entered into a pattern register along with all the necessary information regarding them. The register is divided into spaces of the following widths and titles:—

The first division is 1 in. wide, and is headed "pattern number." The next, which is $2\frac{3}{4}$ in. wide, accommodates the name or title of the pattern. The next two divisions are each $\frac{1}{2}$ in. wide, in the first being inserted the piecework contract number under which the pattern was made, and the next the stores in which the pattern is to be kept. The next two are each $\frac{3}{8}$ in. wide; the first contains the letter indicating the bin in the pattern stores, and the other the number of the shelf of the bin on which the pattern has to be kept. The next space is $\frac{3}{4}$ in. wide, and contains particulars of the standard or size of engine the pattern is used for. The next space is also $\frac{3}{4}$ in. wide, in which the engine number the pattern was originally made for is inserted. The next three spaces are also $\frac{3}{4}$ in. wide each; in the first is stated the drawing number the pattern was made to, the next the date on which the pattern was made, and in the last the date on which the pattern was destroyed.

It will be observed that when a pattern is completed a decision is made not only of its distinguishing number but also of the bin and shelf on which it has to be kept when not in use. Each of the bins in the pattern stores is divided in its length into sections defined by bench marks in black varnish; each division is allotted to a particular standard of engine. Both the letter and number indicating the bin and shelf, and also the standard of the engine, is well stamped on the pattern, which indicates to the pattern storekeeper exactly where each pattern has to be kept, and by referring to the register anyone can at once learn the position in which the pattern should be found if not in use in the foundry.

It will also be noted that the patterns are made under piecework, or it should properly be described as a premium bonus plan, the system being the percentage saved is the percentage paid, and as particulars of all the contract numbers are kept, it is an easy matter to turn up particulars of the hours taken to produce any given pattern, which is very useful as a guide when fixing a piecework price or setting out an estimate of patternmaking on any particular job being quoted for.

FIG. 1.—PLAN OF ONE OF THE STORES, SHOWING GENERAL ARRANGEMENT OF THE STORAGE BINS.

Layout of Stores.

It will also be obvious that more than one pattern store is required to hold the many thousands of patterns in existence; a description of one of them is given in Figs. 1, 2 and 3, which are typical of the various stores in which the man-handled patterns are kept. The very large ones are kept under a travelling crane in a covered yard to facilitate handling.

Fig. 1 is a plan of one of the stores, and shows the general arrangement of the storage bins, of shelves, and the gangways. This stores occupies the middle floor of a three-storey building, the

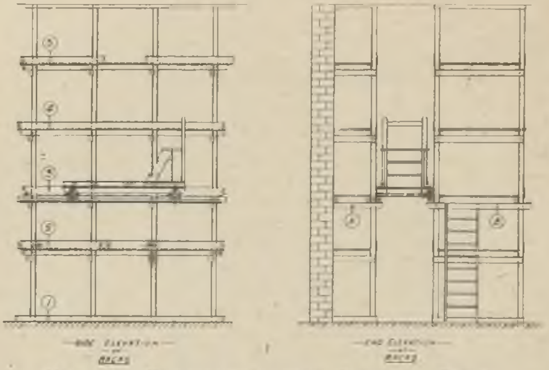

FIG. 2.—DETAILS OF THE STORAGE BINS.

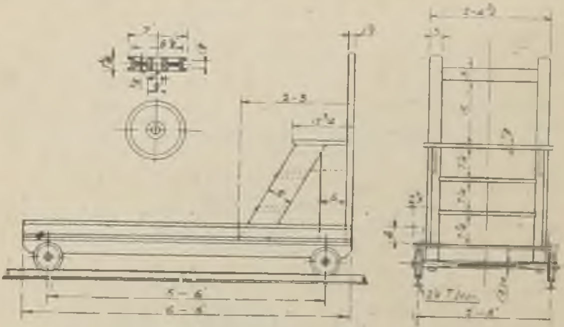

FIG. 3.—SELF-EXPLANATORY DETAILS OF THE TROLLEY.

pattern shop being on the floor above. Each room is as far as possible fireproof, automatic sprinklers being fixed in the roof, and the concrete floor is about 6 in. below the door sills, so that in case of fire the whole floor would be flooded with water to this depth. A telpher indicated, which can be worked from either floor from the projecting platform shown, delivers patterns to either storey. As the patterns arrive from the foundry they are temporarily assembled at X, and are then sorted as to their relative positions. The whole store is worked without the aid of a portable ladder by means of a runway running between each bin as shown in arrangement by Fig. 2, the details of the carriage being given in Fig. 3. After sorting, all patterns which have to be stored above the second shelf are placed on the platform of the carriage, which when full the store attendant mounts by means of the fixed ladder at the end of each bin and propels himself along to the desired position in which the pattern is to be deposited.

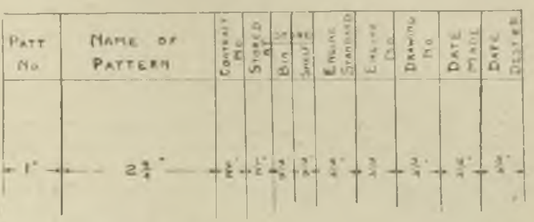

Fig. 4.—An Example Sheet from the Pattern Register.

The stairway at the telpher end of the building is that in regular use; the one at the other end is an emergency one in case of fire.

Storage Bins.

Detail of the storage bins is given in Fig. 2. The frame vertical members are made out of 3-in. by 3-in. timber, the cross-pieces out of 2-in. by 4-in., let ½ in. into the uprights, the cross members supporting the second shelf extend beyond the width of the frame so as to carry the tee iron runway for the carriage. The shelving consists of ¾-in. timber, 5 in. to 7 in. widths, open spaced. The drawing shows them placed across the width of the bin, but subsequently they were placed lengthwise, which obviated the longitudinal member shown, and thereby effected a further economy in an already cheap method of framing. Along each shelf is placed a vertical piece of wood which defines the limits within which the pattern must be kept to avoid its fouling the runway carriage or walking space. This side member is useful to indicate the number of the shelf and the bench mark divisions for the various standards as indicated. The frames are placed at about 3 ft. 9 in. centres. The height of the various shelves will, of course, depend upon the class of patterns to be accommodated; in the drawing is shown the first shelf 3 ft. 6 in. above the floor, and the subsequent ones at 2 ft. 5 in., 3 ft. 2 in., and 3 ft. 2 in. in the clear respectively. Where larger patterns have to be accommodated, the first shelf has been placed at 4 ft. above the floor, and subsequent ones at 2 ft., 3 ft., and 3 ft. in the clear. In the case of the former arrangement of shelves it is necessary to leave out the first shelf between one of the staging frames to provide a passage as indicated by dotted lines in Fig. 1, and also at the end remote from the ladder end. The placing of the ladder at the gangway end only, ensures that the carriage will be always at its most convenient position when not in use.

Fig. 3 gives details of the carriage, which are self-explanatory. It has been designed to give plenty of temporary storage space, to be so arranged as not to tip up; and the steps are so arranged that the whole width of the top shelf of the racks can be reached quite easily.

In conclusion it can be safely said that the system and arrangement of stores has proved easy to work, and quite efficient, and so far has met all requirements expected of a system of pattern storage.

The thanks of the author are due and tendered to Messrs. Belliss & Morcom, Limited, for allowing these particulars to be published.

DISCUSSION.

Mr. F. C. Edwards said that in many pattern shops the machinery was in a very dilapidated condition, especially the lathes. Managements certainly appeared to regard the pattern shop as a sort of necessary evil. The practice of colouring parts to be machined in a distinctive manner was an excellent one. With regard to loose pieces, if they did not clearly distinguish the loose piece from the body of the pattern and show where it had to go there was the possibility of its being left off altogether after several castings had been made. The patternmaker ought to foresee and appreciate the difficulties of the core maker and the moulder. Mr. Cook had spoken of the carelessness of the moulder, but in nine cases out of ten he (Mr. Edwards) did not admit that there was any carelessness on the moulder's part. Unless he deliberately altered the mould, he contended that it was the pattern shop that was to blame in producing a pattern or a core in such a way that the moulder could go wrong. In his view it often paid to make a new pattern rather than to adapt an old one. As to complicated numbering, quite apart from the question of expense, it was impossible to put the numbers on very small castings, and he considered that complicated numbering was a source of loss to any firm foolish enough to adopt it. While Mr. Cook's scheme of numbering was an admirable one for a large concern, it would not suit a small firm. A firm employing two or three hundred men would not wish to go to the expense of putting up bins and providing trolleys.

Mr. Cook having briefly replied, a hearty vote of thanks was accorded to him, on the motion of Mr. F. G. Starr, seconded by Mr. J. B. Johnson.

THE INSTITUTE OF BRITISH FOUNDRYMEN.

LIST OF MEMBERS.

March, 1928.

B.—Birmingham and West Midlands Branch.
E.M.—East Midlands Branch.
Lncs.—Lancashire Branch.
L.—London Branch.
M.—Middlesbrough Branch.
N.—Newcastle-on-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.
Lncs.	1926.	Ackroyd, A. H., White Cottage, Park Road, Timperley, Cheshire.
E.M.	1908.	Aiton, J. A. (Aiton & Company), Derby.
S.	1924.	Alder, A. J., 106, Sincil Bank, 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.
E.M.	1924.	Allin, G. E., Ashleigh Grove, Etwall, near Derby.
Sc.	1927.	Anderson, G. L., Esq., 25, Cluny Drive, Edinburgh.
So.	1920.	Andrew, J. H., D.Sc., Royal Technical College, Glasgow.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1919.	Andrew, J. W., 964, Oldham Road, Thornham, Royton, Oldham.
N.	1925.	Appleyard, K. C., Birtley Springs House, Birtley, Co. Durham.
B.	1925.	Ardern, W. J. A., 23, St. Michaels Hill, Handsworth, Birmingham.
N.	1921.	Armstrong-Whitworth & Co., Ltd., Sir W. G. (Subscribing Firm), Close Works, Gateshead-on-Tyne.
M.	1926.	Armstrong, H., 20, Shaftesbury Street, Stockton-on-Tees.
Lncs.	1924.	Arstall, J., "Kenmarlean," Back, Bowe, Hyde, Cheshire.
M.	1927.	Ashmore, Benson Pease & Co., Ltd., (Subscribing Firm), Parkfield Works, Stockton-on-Tees.
L.	1925.	Ashwell, E. C., "Kenwyn," Stafford Road, Waddon, Croydon.
B.	1924.	Aston, A., "Newlyn," Birches Barn Road, Wolverhampton.
L.	1911.	Aston, W. H., 46, Eagle Wharf Road, London, N.
B.	1921.	Athey (Major), J. W., Fordath Eng. Co., Ltd., Hamblet Works, West Bromwich.
L.	1925.	Bagshawe, A. W. G., Dunstable Works, Dunstable.
B.	1920.	Ball, F. A., c/o Ball Bros., Stratford-on-Avon.
M.	1926.	Barbour, A. R., Bon Lea House, Thornaby-on-Tees.
L.	1923.	Bargellesi, G., Foundry Consulting Engineer, via Tantardini 13, Milano 123, Italy.
B.	1922.	Barnsley, W. G., The Limes, Church Road, Netherton, nr. Dudley.
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.

B'nch.	Year of Election.	MEMBERS.
E.M.	1921.	Bates, W. R., United Steel Companies, Limited, Irthlingboro' Iron Works, Wellingboro'.
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.
L.	1920.	Beech, A. S., 13-15, Wilson Street, London, E.C.2.
Sc.	1910.	Bell, W., 1, George Street, Airdrie.
—	1922.	Bell, Wm. Dixon, 72, Walpole Road, Itchen, Southampton.
L.	1926.	Belling, C. R., 10, Glebe Avenue, Enfield, Middlesex.
Lncs.	1925.	Bennett, A., 57, Lodge Lane, Newton, Hyde.
L.	1926.	Bennett, F. H., "Holyrood," 12, Kilmarton Road, Goodmayes, Essex.
S.	1920.	Benson, E. C., 303, Fulwood Road, Sheffield.
W.R. of Y.	1922.	Bentley, J. N., Plantation House, Hull Road, York.
Lncs.	1922.	Bontley, L. A., Wood End, Bromley Cross, Bolton.
B.	1924.	Bethell, R. P., 51, Sutton Road, Walsall, Staffs.
B.	1925.	Bettinson, C. L.. New Bond Street Ironworks, Bardesley.
E.M.	1915.	Bigg, C. W., Someries, Darley Lane, Allestree, nr. Derby.
S.	1918.	Biggin, Frank, Rye Lodge, Ashland Road, Sheffield.
N.	1921.	Birtley Iron Company (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.

B'nch.	Year of Election.	MEMBERS.
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., 13, Milton Street, Hull Road, York.
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., 4, Etchingham Park Road, Church End, Finchley, N.3.
W.R. of Y.	1922.	Boyle, J., Swann & Davidson, Ltd., Carrick Foundry, Stanningley, Leeds.
N.	1922.	Brailsford, A., 18, Elswick Row, Newcastle-on-Tyne.
L.	1926.	Brendle, T. F., Hospital Road, Insein, Lower Burma.
Lncs.	1914.	Bridge, W., 199, Drake Street, Rochdale, Lancs.
S.	1922.	Brightside Foundry and 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.

B'nch.	Year of Election.	MEMBERS.
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.
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'.
L.	1927.	Bureau of Information on Nickel, Ltd., 2, Metal Exchange Buildings, Leadenhall Avenue, E.C.
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.
M.	1909.	Caddick, A. J., "Eastbrook," 34, The Avenue, Middlesbrough.
Lncs.	1926.	Cadman, E., 69, Manchester Road, Fairfield, Manchester.
L.	1927.	Calder, N. G., 68, Conyers Road, Streatham, London, S.W.16.
Sc.	1917.	Cameron, J. (Cameron & Roberton, Limited), Kirkintilloch.
Sc.	1919.	Cameron, T. P. (Cameron & Roberton, Ltd.), Kirkintilloch.
S.	1922.	Cammell Laird & Co., Ltd., (Subscribing Firm), Cyclops Steel and Iron Works, Sheffield.
Sc.	1927.	Campbell, H. D., Shaw (Glasgow) Ltd., Maryhill Iron Works, Glasgow.
Sc.	1911.	Campion, A. (Honorary Life), 3, Strathview Gardens, Bearsden, Glasgow.
S.	1923.	Cantrill, W. H., 249, Chatsworth Road, Chesterfield.

B'nch.	Year of Election.	MEMBERS.
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.	1927.	Cassidy, G. L., 6, Balham Hill, Balham.
S.	1921.	Castle, Geo. Cyril, 141, Rustlings Road, Endcliffe, Sheffield.
S.	1927.	Cawood, G. R., & Co., Ltd., 1, Cavendish Road, Leeds.
Lncs.	1905.	Chadwick, J. (Life), 12, Nuttall Terrace, Bolton.
Lncs.	1919.	Chadwick, J. N. (Life member), School Hill Ironworks, Bolton.
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.
Gen.	1923.	Clamer, G. H., 129, So. Berkeley Square, Atlantic City, N.Y.
L.	1925.	Clapp, H. B., 25A, Broad Bridge Street, Peterborough, Northamptonshire.
Lncs.	1918.	Clark, A., 133, Denton Road, Audenshaw, Manchester.
S.	1922.	Clark, G., 61, Westbourne Road, Sheffield.
L.	1915.	Clark, H. S., 17, Filey Avenue, Stoke Newington, London, N.16.
M.	1926.	Clark, W. H., 90, Marton Burn Road, Middlesbrough.
E.M.	1927.	Clarke, A. S., "Lyndesfarn," Leicester Road, Loughborough.
B.	1926.	Clarke, W. H., 16, Holly Road, Edgbaston, Birmingham.
L.	1917.	Cleaver, C., 10, Ringcroft Street, Holloway, N.1.
W. & M.	1917.	Clement, W. E., Morfa Foundry, New Dock, Llanelly.

B'nch.	Year of Election.	MEMBERS.
L.	1913.	Coan, R., Aluminium Foundry, 219, Goswell Road, E.C.1.
Sc.	1917.	Cockburn, N., 48, Murrayfield Gardens, Edinburgh.
L.	1925.	Cockram, G. F., 54, Murray Road, Ipswich.
L.	1926.	Coggon, H. F., August's Muffle Furnaces, Ltd., Thorn Tree Works, King Cross, Halifax.
L.	1927.	Coleman, C. W., 99, Clarence Gate Gardens, London, W.1.
N.	1926.	Colls, F. C., Clarendon House, Clayton Street, Newcastle.
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.	1922.	Consett Iron Co., Ltd. (Subscribing Firm), Consett, Co. Durham.
B.	1904.	Cook, F. J., 31, Poplar Avenue, Edgbaston, Birmingham.
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.
W. & M.	1928.	Corbin, F. D., 181, Tyrfran, Llanelly.
L.	1926.	Coupe, J., 9, Delhi Road, Edmonton, London, N.9.
Sc.	1928.	Cowan, H., Foundry Technical Institute, Meeks Road, Falkirk.
Lncs.	1924.	Cowlishaw, S. D., 7, Temple Street, Basford, Stoke-on-Trent.

B'nch.	Year of Election.	MEMBERS.
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.	1919.	Craig, A., Earlsdon House, Earlsdon, Coventry.
B.	1922.	Cramb, F. M., 5, Triangle Villas, Oldfield Park Road, Bath.
L.	1910.	Cree, F. J., Fair View, Huntley Grove, Peterborough.
L.	1911.	Creighton, T. R., The Foundry, Stepney Causeway, E.
Lucs.	1927.	Crewdson, Capt. R. B., 16, Norfolk Crescent, Hyde Park, London, W.
W.R. of Y.	1922.	Croft, Frank, Crofts, Ltd., Bradford.
B.	1920.	Cross, J. K., 152, Yardley Wood Road, Moseley, Birmingham.
L.	1923.	Curtis, A. L., 39, London Road, Chatteris, Cambs.
M.	1926.	Crosthwaite, C., Thornaby Hall, Thornaby-on-Tees.
M.	1926.	Crosthwaite, Ltd., R. W. (Subscribing Firm), Union Foundry, Thornaby on-Tees.
Lncs.	1925.	Daniels, W., 74, Smethurst Lane, Bolton.
N.	1925.	Darlington Railway Plant and Foundry Co., Ltd. (Subscribing Firm), Bank Top, Darlington.
Gen.	1926.	Darnis, I. S., Rampas de Uribitarte 2–1, Bilbao, Spain.
Lncs.	1926.	Davenport, J., Myrtle Bank, Grimsargh, Preston.
L.	1927.	Davis, J. K., Bauville Wood, Harpenden, Herts.
Gen.	1919.	Davies, P. N., 29, Brunswick Road, Brunswick, Melbourne, Victoria, Australia.

B'nch	Year of Election.	MEMBERS.
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.	1924.	Denham, H., "Birchwood," Walsall Road, Aldridge, Staffs.
S.	1917.	Desch, 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.	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.
L.	1914.	Dobson, W. E., "Newlyn," Grand Drive, Raynes Park, S.W.
B.	1926.	Dodd, W., 68, Allport Road, Cannock, Staffs.
Lncs.	1918.	Doughty, E., 54, St. Mary's Road, Moston, Manchester.
Sc.	1911.	Doulton, B. (Life), 3, Berrylands, Surbiton, Surrey.
M.	1927.	Downing, A. G., 2, Oxford Street, Stockton-on-Tees.
Lncs.	1927.	Drake, T., South Bank, Stockport Road, Timperley, Cheshire.
S.	1921.	Duckenfield, W., 47, Dunkeld Road, Ecclesall, Sheffield.

B'nch.	Year of Election.	MEMBERS.
L.	1928.	Duguid, G., 119, High Holborn, W.C.1
L.	1925.	Durnan, F., 43, Grove Road, Millhouses, Sheffield.
Lncs.	1926.	Durrans, J., The Croft, Penistone.
S.	1921.	Edginton, G., Silverdale, St. Margaret's Drive, Chesterfield.
B.	1922.	Edwards, A., "Dunbar," Old Bath Road, Cheltenham.
M.	1927.	Edwards, A., "Wayside," Nunthorpe.
N.	1921.	Eldred, E. J., 8, Ford Street, Gateshead-on-Tyne.
L.	1904.	Ellis, J., 20, Lambourne Road, Clapham Junction, London, S.W.4.
S.	1918.	Elliss, J. A., 217, Middlewood Road, Sheffield.
S.	1913.	Else, L. H., 79, Osborne Road, Sheffield.
Sc.	1925.	English, J., c/o Miss Granger, 9, Prospect Street, Camelon, Falkirk.
L.		Ephraim, V. Rex, 21, Cromwell Road, S.W.7.
L.	1919.	Estep, H. Cole, The Penton Publishing Co., Penton Building, Cleveland, Ohio, U.S.A.
L.	1926.	Evans, S., 9, Bush Lane, Cannon Street, E.C.4.
E.M.	1918.	Evans, W. T., Mount Pleasant. Sunny Hill, Normanton, Derby.
S.	1920.	Fairholme, F. C., Norfolk Works, Sheffield.
Sc.	1928.	Falkirk Iron Co., Ltd., The, Falkirk Ironworks, Falkirk. (Subscribing Firm.)
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.
N.	1918.	Fender, B., 15, Kenilworth Road, Monkseaton, Northumberland.

B'nch.	Year of Election.	MEMBERS.
B.	1914.	Field, H., "Glenora," Richmond Avenue, Wolverhampton.
B.	1904.	Finch, F. W. (Honorary), 52, Denmark Road, Gloucester.
S.	1914.	Firth, A., 50, Clarendon Road, Fulwood, Sheffield.
S.	1914.	Firth, F. W., "Storth Oaks," Ranmoor, Sheffield.
M.	1926.	Fisher, F. E., 2, Albert Terrace, Haverton Hill, Middlesbrough.
Gen.	1907.	Flagg, S. G. (Honorary), 1407, Morris Buildings, Philadelphia, Penn., U.S.A.
B.	1923.	Flavel, P., Bushbury Lodge, Leamington.
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-on-Tyne.
B.	1919.	Fosseprez, G., 3, Rue du Grand Jour, Mons, Belgium.
B.	1920.	Foston, G. H., Ivy Bank, Balsall Common, Berkswell, nr. Coventry.
—	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., "Clay Bank," Pellon, Halifax.

B'nch	Year of Election.	MEMBERS.
Sc.	1920.	Fraser, A. R., Craigard, Bearsden, Glasgow.
N.	1914.	Frier, J. W., 5, Northumberland Villas, Wallsend-on-Tyne.
L.	1919.	Furmston, A. C., Hope Cottage, 211, Neville Road, Letchworth.
W. & M.	1924.	Galletly, J. P., Ben Clench, Pencisely Road, Cardiff.
Sc.	1919.	Gardner, J. A., 24, South Hamilton Street, Kilmarnock.
L.	1922.	Gardom, J. W., 39, St. Peters Road, Dunstable, Beds.
W.R. of Y.	1922.	Garforth, E. P., 48, Haslingden Drive, Toller Lane, Bradford.
Lncs.	1922.	Garner & Sons, Limited (Subscribing Firm), Victoria Street, Openshaw, Manchester.
Lncs.	1919.	Gartside, F., 18, George Street, Chadderton, Lancs.
Gen.	1927.	Geilenkirchen, T., Dusseldorf, Faunastr 37, Germany.
L.	1926.	George, H., "Southdene," High Street, Dunstable.
L.	1922.	Gibbs, A. F., 55, Gordon Road, Wanstead, Essex.
N.	1925.	Gill, C. S., Westbank, Consett, County Durham.
Sc.	1920.	Gillespie, P., "Glenora," Falkirk Road, Bonnybridge.
Sc.	1925.	Gillespie, W. J. S., Ure Allan Park, Bonnybridge, Stirlingshire.
E.M.	1915.	Gimson, H., "Rhoscolyn," Toller Road, Leicester.
E.M.	1906.	Gimson, S. A., 20, Glebe Street, Leicester.
E.M.	1928.	Glover, W., 69, Cardigan Street, Derby.
S.	1905.	Goodwin, J. T., M.B.E., M.I.Mech.E. Red House, Old Whittington, Chesterfield.

B'nch.	Year of Election.	MEMBERS.
M.	1926.	Gore, G. E., "Rosedene," Austin Avenue, Stockton-on-Tees.
W. & M.	1917.	Gould, P. L., Vulcan Foundry, East Moors, Cardiff.
W. & M.	1918.	Gould, W. C., 7, Broad Street, Barry.
Sc.	1921.	Graham, J., 68, Sherbrooke Avenue, Maxwell Park, Glasgow.
Lncs.	1922.	Grandison, W. H., 15, Gordon Road, Clovelly Estate, Worsley Road, Swinton.
L.	1926.	Grange, R., 89, Constantine Road, Hampstead, N.W.3.
Lncs.	1920.	Grant, G. C. (Sir W. G. Armstrong, Whitworth & Company, Limited), Ashton 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.
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., The International Combustion Engineering Co., Derby.
N.	1917.	Gresty, C., 101, Queen's Road, Monkseaton.
W. & M.	1906.	Griffiths, H., 70, Partridge Road, Cardiff.
W. & M.	1927.	Griffin, E. H., 196, Henleage Road, Henleage, Bristol.
Lncs.	1927.	Grundy, H., 20, Thoresway Road, Longsight, Manchester.
S.	1910.	Hadfield, Sir R. A. (Hon.), Hadfields, Limited, Hecla Works, Sheffield.
E.M.	1927.	Hadfield, S., White Lodge, Keyham, near Leicester.

B'nch.	Year of Election.	MEMBERS.
S.	1927.	Hague, A. P., Murray House, Chesterfield.
Lncs.	1906.	Haigh, J., "Stoneclough," Carr Lane, Sandal, Wakefield.
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.
L.	1926.	Hall, S., 57, Eden Grove, Horfield, Bristol.
Lncs.	1927.	Hall, T. W., 67, Edgerton Road South, Chorlton-cum-Hardy, Manchester.
Lncs.	1923.	Hammond, R., 37, Church Road, Smithills, Bolton.
E.M.	1914.	Hammond, Wm., Samson Foundry, Syston, Leicester.
Lncs.	1904.	Hampson, F. R. (J. Evans & Company), Britannia Works, Cross Street, Blackfriars, Manchester.
S.	1926.	Hampton, C. W., 5, Chorley Drive, Fulwood, Sheffield.
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.), 41, High Street, Balby, Doncaster, Yorks.
M.	1926.	Harrod, H., 15, Egglestone Terrace, Stockton-on-Tees.
Lncs.	1918.	Hartley, Wm. Alexr., Stonebridge Foundry Company, Limited, Colne.
Gen.	1922.	Harvey, André, 118, Spring Road, Kempston, Bedford.
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-on-Tyne.
L.	1926.	Hearn, J. E., Craig-y-don, West Hill, Luton.

B'nch.	Year of Election.	MEMBERS.
S.	1928.	Hearnshaw, L., "Gleneagles," Manor Road, Brimington, near Chesterfield.
Lncs.	1925.	Heatley, J., 146, Redlam, Blackburn.
Lncs.	1918.	Helm, R. W., c/o Francis Helm, Ltd., Victoria Foundry, Padiham, Lancs.
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.
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.
B.	1926.	Hieatt, H. J., South Bank, Brierley Hill, Staffs.
L.	1927.	Hickman, G. E., Greensteps, Park Chase, Guildford.
L.	1926.	Hider, G. E., Upton Foundry, Torquay.
W. & M.	1912.	Hird, B., "Woodcot," Upper Cwmbran, nr. Newport, Mon.
L.	1923.	Hobbs, F. W. G., Standard Brass Foundry, P.O. Box 229, Benoni, Transvaal, S.A.
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'nch	Year of Election.	MEMBERS.
B.	1927.	Hole, S. B., "Bourne House," Franchise Street, Wednesbury.
Lncs.	1927.	Hollindrake H. (H. Hollindrake & Sons, Ltd.), Princes Street, Stockport.
L.	1928.	Holmes, W. E., 1, Coronation Road, Plaistow, London, E.13.
B.	1924.	Homer, W. A., 87, Frederick Street, Walsall, Staffs.
Sc.	1914.	Hood, John McLay (Life), 54, Maxwell Drive, Pollokshields, Glasgow.
Lncs.	1919.	Horrocks, B., 1, Jersey Street, Ashton-under-Lyne.
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.
L.	1924.	Hunt, N. H., 1, Albemarle Street, Piccadilly, W.1.
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.	1919.	Hunter, Summers, C.B.E., J.P., 1, Manor Terrace, Tynemouth.
B.	1907.	Hurren, F. H. (The Rover Company, Limited), Meteor Works, Coventry,
S.	1920.	Hurst, F. A., Woofindin Avenue, Ranmoor, Sheffield.
Sc.	1927.	Hurst, H., 35, Alice Street, Paisley.
S.	1914.	Hurst, J. E., Newton Chambers and Co., Ltd., Chapeltown, Sheffield.
L.	1925.	Hutton, R. S., D.Sc., The Greenway, High Wycombe, Bucks.
S.	1911.	Hyde, J. R., A.M.I.Mech.E., 27, Hastings Road, Millhouses, Sheffield.

B'nch.	Year of Election.	MEMBERS.
S.	1922.	Hyde, Robert & Son, Ltd. (Subscribing Firm), Abbeydale Foundry, Woodseats, Sheffield.
Sc.	1925.	Hyman, H., Ph.D., 55, Dixon Avenue, Crosshill, Glasgow.
L.	1927.	Ingrams, S., 77, Wellesley Road, Croydon.
S.	1915.	Jackson, L., Engineer Lieut.-Commander, R.N., Antrim Avenue, Park Lane, Sheffield.
Lncs.	1925.	Jadoul, J. E., 28, Daisy Bank Road, Longsight, 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.
Gen.	1927.	Jenkins, A., 5c, Strada Molins, Cospicua, Malta.
W. & M.	1924.	Jenkins, T., 51, Tydvil Street, Barry.
S.	1917.	Jenkinson, S. D., Cromwell House, Wincobank, Sheffield.
L.	1904.	Jewson, H., Norwich Road, East Dereham, Norfolk.
L.	1921.	Jewson, K. S., 4, Coopers Terrace, Gearing Road, Dereham, Norfolk.
E.M.	1909.	Jobson, V., The Derwent Foundry Company, Derby.
Lncs.	1920.	Jolley, W., Breeze Hill, Urmston Lane, Stretford, Manchester.
W. & M.	1928.	Jones, C. E., 65, Cathedral Road, Cardiff.
Lncs.	1922.	Jones, G. A., 54, Fox Street, Edgeley, Stockport.
B.	1925.	Jones, O. P., 25, Rathbone Road, Bearwood, Birmingham.
Lncs.	1927.	Jones, R. A., 36, Wolseley Street, Pendlebury, Manchester.
L.	1927.	Kain, C. H., 189, Raynes Road, Braintree, Essex.

B'nch.	Year of Election.	MEMBERS.
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.
S.	1927.	Kessell, C. E. (Vickers, Ltd.), River Don Works, Sheffield.
Lncs.	1907.	Key, A. L., 271, Reddish Road, S. Reddish, Stockport.
Sc.	1927.	Kidston, R., Springbank, Falkirk.
Sc.	1914.	King, D., Keppoch Ironworks, Possil Park, Glasgow.
L.	1927.	King, E. G., Manor Croft, The Ridgway, Horsell, Surrey.
Sc.	1904.	King, J., 100, Wellington Street, Glasgow.
W. & M.	1924.	Kinsman, W. S., 116, Miskin Street, Cardiff.
Sc.	1919.	Kinnaird, George, 21, St. Ann's Drive, Giffnock, Glasgow.
S.	1925.	Kitching, W. T., c/o John Fowler, Don Foundry, Sheffield.
L.	1922.	Lake, W. B., Mount Place, Braintree, Essex.
L.	1921.	Lambert, Wesley, "Whitefriars," 41, Bromley Road, S.E.6.
Sc.	1907.	Landale, D. (Life), 36, Great King Street, Edinburgh.
B.	1919.	Lane, F. H. N., 46, Holyhead Road, Coventry.
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," Campton Road, Wolverhampton.
L.	1921.	Lawrence, Geo. D., 5, Clare Road, Leytonstone, E.11.
Lncs.	1918.	Layfield, R. P., "Mossfield," Codsall Road, Wolverhampton.
B.	1927.	Lee, C. P., Trelawny, 81, Court Road, Barry, South Wales.
B.	1909.	Lee, Howl & Company, Engineers, Tipton.
S.	1920.	Leetch, S., 126, Pitt Street, Rotherham.
B.	1926.	Lench, S. C., "The Beeches," Blackheath, Birmingham.
—	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, Durham.
S.	1913.	Little, J., 20, St. Ann's Square, Manchester.
L.	1922.	Littleton, W. H., 29A, Worbeck Road, Anerley, S.E.20.
S.	1926.	Liversidge, B., 6, Nelson Street, Rotherham.
B.	1927.	Lloyd, D. C., Stockwell End, Tettenhall, near Wolverhampton.
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.
Lncs.	1921.	Longden, Ed., 158, Manley Road, Manley Park, Manchester.
S.	1904.	Longmuir, P., D.Met., 2, Queens 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.	1922.	Luke, C. H., "Roslyn," Lyonsdown, New Barnet, Herts.
L.	1921.	Lum, Harry, 54, Park Road, Dartford,
Sc.	1925.	McArthur, J., "Hawthorn," Shields Road, Motherwell.
W. & M.	1922.	McClelland, J. J., "Druslyn," 81, Bishops Road, Whitchurch, Glam.
Sc.	1919.	McFedries, T., 17, Kirktonholm Street, Kilmarnock.
S.	1916.	McGrah, F. E., 19, Lonsdale Road, Wolverhampton.
L.	1919.	McIntosh, A. E., 1, Ecclesbourne Avenue, Duffield, Derbyshire.
Lncs.	1924.	MacKay, M., 109, Edmund Street, Rochdale.
Sc.	1914.	MacKenzie, Alex. D., 35, Braid Road, Edinburgh.
Sc.	1910.	Mackenzie, L. P., 5, Polwarth Terrace, Balcarres Street, Edinburgh.
Sc.	1922.	McKinnon, Gavin, 1477, Dumbarton Road, Scotstoun, Glasgow.
Sc.	1923.	McKinty, J. (The Thomson-Litchtner Co.), 8, Federal Street, Boston, Mass., U.S.A.
Lncs.	1921.	McLachlan, Jas., 2, Broadoaks Road, Washway Road, Sale, nr. Manchester.
Gen.	1922.	McLain, D. (Hon.), 710, Goldsmith's Buildings, Milwaukee, Wis., U.S.A.

B'nch.	Year of Election.	MEMBERS.
N.	1923.	Mackley, J. R., 20, Beaconsfield Avenue, Low Fell, Gateshead-on-Tyne.
Sc.	1928.	McFarlane, P., Leicester Avenue, Kelvinside, Glasgow.
Lncs.	1923.	McLean, C. G., 14, Jemmett Street, Preston.
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.
Lncs.	1922.	Marsden & Son, J. (Subscribing Firm), 188, Regent Road, Liverpool.
S.	1922.	Marshall, J., "The Willows," Barrow Hill, Chesterfield.
L.	1924.	Mason, W. C., Richardson & Cruddas, Byculla Iron Works, Bombay, India.
B.	1927.	Mason, W. H., 32, Lord Street, Bradley, Bilston.
L.	1911.	Mather, D. G. (Mather & Smith), Ashford Foundry, Godinton Road, Ashford.
S.	1915.	Mather, T., South View, Carholme Road, Lincoln.
N.	1912.	Mathews, W., 82, St. Peters Road, Holy Cross, Willington Quay-on Tyne.

B'nch.	Year of Election.	MEMBERS.
L.	1926.	Matthieson, R., 37, Closeside, Enfield, Middlesex.
L.	1921.	Mayhew, C. M., 60, Ewesley Road, Sunderland.
Lncs.	1917.	Meadowcroft, Wm. H., 10, Hamblodon View, Habergham, Burnley.
Lncs.	1919.	Medcalf, W., 265, Manchester Road, Burnley, Lancs.
B.	1927.	Mees, J. H., 129, King William Street, Amblecote, Stourbridge.
S.	1922.	Melmoth, F. A., "Lyndhurst," Aughton Road, Swallownest, Sheffield.
M.	1926.	Mercer, J. E., Windsor House, Cromwell Terrace, Thornaby-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, Rd. A., 46, Dean Lane, Newton Heath, Manchester.
Sc.	1927.	Miller, J., 7, Eildon Villas, Mount Florida, Glasgow.
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., 470, Victoria Avenue, Montreal, Canada.
Sc.	1920.	Mitchell, W. W., Darroch, Falkirk.
Lncs.	1921.	Moffat, Wm., Linden House, Chapel-en-le-Frith.
Gen.	1910.	Moldenke, Dr. R. (Hon. Member), Watchung, New York.
N.	1919.	Molineux, W. J., 1, Laburnum Gardens, Low Fell, Gateshead.
L.	1925.	Moore, A. H., Standard Brass Foundry, Benoni, S. Africa.
E.M.	1914.	Moore, H. H., Holmwood, Leicester Road, Loughborough.

B'nch	Year of Election.	MEMBERS.
L.	1926.	Moorwood, H. S., Onslow House, Sheffield.
W. &	1928.	Morgan, A. J., 48, New King Street, Bath.
W. & M.	1928.	Morgan, C. F., 1, Cynthia Villas, Cynthia Road, Bath.
B.	1927.	Moran, G., 18, Bridge Street, West Bromwich.
M.	1927.	Morley, S. H., 13, Peel Street, Thornaby-on-Tees.
N.	1912.	Morris, A., Pallion Foundry, Sunderland.
B.	1925.	Morris, D., c/o Morris (Engineers) Ltd., Greatbridge, Birmingham.
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.
S.	1918.	Newell, Ernest, M.I.Mech.E., The Thorne, Misterton, *via* Doncaster.
Lncs.	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.
L.	1927.	Nicholson, F. W., 139, Sydney Street, Chelsea, London, S.W.3.
L.	1924.	Nikaido, Y. (Lieut.-Com.), Kiro Naval Works, Kure, Japan.
N.	1913.	Noble, H., "The Cedars," Low Fell, Co. Durham.
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.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1918.	Oakden, E., A.M.I.C.E., Further Hey, Woodley, nr. Stockport.
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.
B.	1918.	Oubridge, W. A., M.I.M.E. (British Piston Ring Company, Limited), Holbrook Lane, Coventry.
S.	1921.	Oxley, G. H., Norton Grange, nr. Sheffield.
S.	1915.	Oxley, G. L., Vulcan Foundry, Attercliffe, Sheffield.
S.	1910.	Oxley, W., Vulcan Foundry, Attercliffe, Sheffield.
N.	1921.	Palmer's Shipbuilding & Iron Company Ltd. (Subscribing Firm), Hebburn-on-Tyne.
W.R. of Y.	1922.	Parker, W., 271, Meadow Head, Woodseats, Sheffield.
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.	1923.	Parsons, F. H., "Avondale," Heaton Park View, Heaton, Newcastle.
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.

B'nch.	Year of Election.	MEMBERS.
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., B.Sc., Director, British Cast Iron Research Assn., 24, St. Paul's Square, Birmingham.
E.M.	1913.	Pearson, N. G. (Lieut-Col.), Beeston Foundry Company, Limited, 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.
L.	1918.	Perkins, J. E. S., "Hilmorton," The Park, Peterborough.
B.	1920.	Perks, C., Phœnix Castings, Ltd., Coventry.
Lncs.	1919.	Perryman, W., 17, Hurst Street, Bury.
L.	1926.	Pisek, Dr. Mont. Fr. Technical High School, Brno, Czechoslovakia.
L.	1926.	Petters, Ltd. (Subscribing Firm), Westland Works, Yeovil.
—	1927.	Phillips, E. A., Laceby, near Grimsby.
Lncs.	1922.	Place, J. H., Station Road, Simonstone, nr. Padiham, Lancs.
—	1919.	Player, E., Cow Lees, Astley, Nr. Nuneaton.
E.M.	1922.	Pochin, R. E., 246, Fosse Road, South, Leicester.
Lncs.	1922.	Pollard, J. T., 7, Powell Street, Burnley.
W.R. of Y.	1912.	Pollitt, E. E. (Pollitt & Wigzell), Sowerby Bridge.
Lncs.	1924.	Pollock & Macnab (Subsidiary), Ltd. (Subscribing Firm), Bredbury, nr. Stockport.
Lncs.	1926.	Poole, J., "Clevelands," Bury New Road, Whitefield Manor.

B'nch.	Year of Election.	MEMBERS.
W.R. of Y.	1922.	Poole, W. H., Kings Grove, Villa Road, Bingley, Bradford.
S.	1923.	Porter, H. W., 78, Ringinglow Road, Sheffield.
B.	1919.	Pott, L. C., 38b, Baron's Court Road, London, W.14.
E.M.	1924.	Potter, W. C., "Kenwalyn," Sykefield Avenue, Leicester.
S.	1926.	Presswood, B.A., C., "Crowgate," South Anston, nr. Sheffield.
S.	1908.	Prestwich, W. C., "The Hallowes," Dronfield, Sheffield.
L.	1926.	Prior, W. H., 62, Andalus Road, London, S.W.9.
L.	1927.	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.	1924.	Pritchard, P., "Eastcote," St. Agnes Road, Moseley, Birmingham.
E.M.	1904.	Pulsford, F. C., "Kenmore," Sandown Road, Leicester.
L.	1928.	Quicke, J. H., c'o Leocock, 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 d Constantinople, Place de l'Europe, Paris.
N.	1912.	Rang, H. A. J., 2, St. Nicholas Buildings, Newcastle-on-Tyne.
Lncs.	1919.	Ranicar, W., 1, Parr Street, Tyldesley, Lancs.
Sc.	1923.	Rattray, W. J., c/o Burns & Co., Ltd., Howrah, Bengal, India.
S.	1921.	Rawlings, Geo., 23, Banner Cross Road, Sheffield.
W. & M.	1927.	Rees, J., 27, Allington Road, Southville, Bristol.
Sc.	1920.	Rennie, A., "Kilnside," Falkirk.

B'nch.	Year of Election.	MEMBERS.
Sc.	1927.	Rennie, W., "Ardenlea," Cumbernauld, Dumbartonshire.
Lncs.	1919.	Rhead, E. L., Prof. (Honorary), College of Technology, Manchester.
Gen.	1923.	Rhydderch, A., Lenton Sands, Robertson Place, Vancluse, Sydney, Australia.
W. & M.	1925.	Richards, C. E., 53, Merches Gardens, Grange, Cardiff.
W. &	1924.	Richardson, R. J., Llanblethian House, near Cowbridge.
Lncs.	1919.	Richardson, W. B., Hope Foundry, Farnworth, nr. Bolton.
Sc.	1911.	Riddell, M., Dungoyne, 35, Aytoun Road, Pollokshields, Glasgow.
M.	1926.	Ridsdale, N. D., 3, Wilson Street, Middlesbrough.
M.	1926.	Ritchie, R. J. H., Cambridge House, Linthorpe, Middlesbrough.
M.	1926.	Robbins, A. G., 19, Newcomer Terrace, Redcar.
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., "Kinfanns," High Station Road, Falkirk.
Lncs.	1927.	Robinson, F. O. "Braemar," Birchfield Road, Widnes.
W.R. of Y.	1908.	Robinson J. G., 17, Gibraltar Road, Halifax.
Lncs.	1912.	Roe, S., 23,Grantham Street, Oldham.
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.

B'nch.	Year of Election.	MEMBERS.
B.	1923.	Roxburgh, W., 29, Clifton Road, Rugbv.
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., 10, Westgate Road, Newcastle-on-Tyne.
S.	1921.	Sandford, J., 46, Clifford Road, Sheffield.
N.	1915.	Saunders, J., Borough Road Foundry, Sunderland.
W.R. of Y.	1922.	Sayers, H., 53, Acre Road, Middleton, Leeds.
B.	1921.	Scampton, Chas., South Avenue, Stoke Park, Coventry.
M.	1927.	Scholes, A., Alma House, Junction Road, Norton-on-Tees.
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.	1920.	Sharpe, Daniel, 100, Wellington St., Glasgow.
Lncs.	1927.	Shaw, A., 52, King Street, Oldham.
L.	1906.	Shaw, J., "Cartref," Parkstone Avenue, Southsea.
L.	1907.	Shaw, R. J. (Life), 26, Queens Road, Monkseaton, Northumberland.
M.	1922.	Shaw, W. (Subscribing Firm), Wellington Cast Steel Foundry, Middlesbrough.
S.	1908.	Sheepbridge C. & I. Company, Limited (Subscribing Firm), Sheepbridge Works, Chesterfield.
L.	1927.	Shepherd, H. H., c/o Crane Bennett, Ltd., Nacton Works Ipswich, Suffolk.
Lncs.	1907.	Sherburn, H. (Life), "Ellesmere," Padgate, Warrington.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1905.	Sherburn, W. H. (Life), Rotherwood, Stockton Heath, Warrington.
L.	1912.	Shillitoe, H., "Westward," Potter's Bar, N.
N.	1920.	Shipley, H. J., East Cottage, Delacour Road, Blaydon-on-Tyne.
S.	1927.	Shirt, F. A., 317, Psalter Lane, Sheffield.
Lncs.	1907.	Simkiss, J., Abington House, Hyde Road, Gorton, Manchester.
N.	1913.	Simm, J. N., 61, Marine Avenue, Monkseaton.
Lncs.	1924.	Simpson, H., 102, Edmund Street, Rochdale.
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.
N.	1921.	Smalley, O., Park Villa, Thrybergh, Rotherham.
Sc.	1927.	Smart, G., Rowallan Stepps, Glasgow.
S.	1922.	Smith, A., "Oakroyd," Dodworth Road, Barnsley.
B.	1928.	Smith, A. B., "Bramber," Histone Hill, Bodsall, Staffs.
S.	1922.	Smith, A. Qualter, "Lynwood," Dodworth Road, Barnsley.
B.	1925.	Smith, B. W., Heath Farm, Marston Green, Birmingham.
B.	1919.	Smith, C. R. (Messrs, C. & B. Smith), Stewart Street, Wolverhampton.
N.	1908.	Smith, E., Belle Vue, Harton, South Shields.
S.	1921.	Smith, Fredk., Devonshire Villas, Barrow Hill, nr. Chesterfield.

B'nch.	Year of Election.	MEMBERS.
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, nr. Stockton-on-Tees.
N.	1922.	Smith Patterson & Company, Limited (Subscribing Firm), Pioneer Works, Blaydon-on-Tyne.
N.	1913.	Smith, R. H., 16, Whitburn Road, East, Cleadon, nr. Sunderland.
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.
Lncs.	1927.	Stanworth, J., "The Woodlands,', Rimington, Clitheroe.
Lncs.	1922.	Staveley Coal & Iron Company (Subscribing Firm), Staveley Works, nr. Chesterfield.
S.	1927.	Steele, F. E., 66, Hatfield House Lane, Firth Park, Sheffield.
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.

B'nch.	Year of Election.	MEMBERS.
L.	1915.	Stone, E. G., 20, Cautley 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.
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., 34, Wood Road North, Old Trafford, Manchester.
N.	1921.	Stothard, A., 32, Grainger Street, West, Newcastle.
M.	1927.	Styles, W. E., 9, Cromwell Terrace, Thornaby-on-Tees.
W.R. of Y.	1922.	Summerscales, W. H. G., Rockfield, Keighley.
E.M.	1927.	Summersgill, E., (Senior) 47, Station Road, Long Eaton, Notts.
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, Kamarhatty, 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 (near) Knutsford, Cheshire.

B'nch.	Year of Election.	MEMBERS.
L.	1925.	Tarrant, W. J., Eiffeldale, Longfleet, Poole, Dorset.
N.	1927.	Tate, C. B., 17, The Crescent, Whitley Bay.
Lncs.	1924.	Taylor, A., 84, Hornby Road, Blackpool.
N.	1919.	Taylor, C. R. R., Manor House, South Shields.
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., 1,081, Grangefield Avenue, Thornbury, Bradford.
L.	1924.	Thornycroft and Co., Ltd., John I. (Subscribing Firm), Iron Foundry, Woolston Works, Southampton.
M.	1926.	Thorpe, S. P., 14, Park Terrace, Stockton-on-Tees.
L.	1925.	Tibbenham, L. J., The Limes, Stowmarket.
W. & M.	1928.	Timmins, D., 1, Westbourne Road, Caston, Bristol.
M.	1926.	Todd, H., 175, Southfield Road, Middlesbrough.
L.	1927.	Tompkins, S. J., Sefton, Birmingham Road, Wylde Green, Birmingham.
S.	1927.	Tonge, J., Bovey Court, Vereeniging, S. Africa.
—	1922.	Touceda, E. (Hon.), 943, Broadway, Albany, N.Y., U.S.A.
Lncs.	1921.	Town End Foundry Ltd. (Subscribing Firm), Chapel-en-le-Frith, Derbyshire.
Lncs.	1928.	Toy, H., 4, Westmorland Road, Urmston, Manchester.
M.	1924.	Toy, S. V., The Ridge, Saltburn-by-the-Sea.

B'nch.	Year of Election.	MEMBERS.
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., 10, Holmdene Avenue, Dulwich, S.E.24.
B.	1927.	Turner, H. L., 23, Mellish Road, Walsall.
B.	1910.	Turner, Prof. T. (Hon. Member), Netheridge Elm Drive, Leatherhead, Surrey.
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.
B.	1918.	Tyson, E. H., 269, Gillatt Road, Edgbaston, Birmingham.
S.	1916.	Underwood, G. H., Cottage Hill, Bircholm, Chesterfield.
Sc.	1913.	Ure, G. A. (Smith & Wellstood, Ltd.) Bonnybridge, Scotland.
Gen.	1927.	Vanzetti, Comm. Img. Carlo, C.B.E., General Manager, Fonderia Milanese di Acciaio, Milan, Italy.
Gen.	1922.	Varlet, J. (Hon.), Esperance Longdoz Works, Liege, Belgium.
S.	1924.	Varma, J. P., 3, Bingham Park Crescent, Sheffield.
S.	1922.	Vickers, Limited (Subscribing Firm), River Don Works, Sheffield.
Lncs.	1922.	Vickers, Limited (Subscribing Firm), Barrow-in-Furness.
B.	1917.	Vickers, T., 14, New Street, Birmingham.
S.	1917.	Village, R., Bircholme, Dronfield, nr. Sheffield.
Sc.	1911.	Waddell, R. C., 2, Percy Street, Ibrox, Glasgow.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1924.	Wainwright, T. G., The Mount, 195, Huddersfield Road, Stalybridge.
L.	1911.	Walker, C. F., 42, Windsor Street, Wolverton, Bucks.
S.	1907.	Walker, E., Effingham Mills, Rotherham.
Lncs.	1924.	Walker, J. S. A., Major, Walker Bros., Ltd., Wigan.
M.	1926.	Walker, T., Hazebronch, Old Sporaby, Stockton-on-Tees.
S.	1918.	Walker, T. R., B.A., 26, Castlewood Road, Fulwood, Sheffield.
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 Eng. Company, Limited, Love Lane, Mazagon, Bombay, India.
N.	1927.	Walton, S. H., 73, Highbury, Jesmond, Newcastle-on-Tyne.
S.	1908.	Ward, A. J. (T. W. Ward, Limited), Albion Works, Saville Street, Sheffield.
S.	1914.	Ward, J. C., Oak Park, Manchester Road, Sheffield.
L.	1919.	Wares, F. J., 216, Cromwell Road, Peterborough.
E.M.	1910.	Wassell, A., Kilburn Hall, nr. Derby.
S.	1915.	Watson, J., 31, Hornton Court, Kensington, W.8.
N.	1919.	Watson, J. H., 6, Sidney Grove, Newcastle-on-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'nch.	Year of Election.	MEMBERS.
Sc.	1920.	Weir, Rt. Hon. Lord, The, P.C., D.L., LL.D. (Life Member), G. and 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, S. G., Da Dng. Dusseldof, Lindernannstr 18, Germany.
Lncs.	1926.	West, Walter, 12, The Crescent, Leyland, Lancs.
S.	1921.	Wharton, E., Rosemont, Station Road, Brimington, Chesterfield.
N.	1913.	Wharton, J., Maryport, Cumberland.
B.	1925.	Whitehouse, E. J., "The Knoll," Penn, Wolverhampton.
S.	1916.	Whiteley, A., 7, Glen Road, Nether Edge, Sheffield.
Lncs.	1910.	Whittaker, C., & Company, Limited, Dowry Street Ironworks, Accrington.
B.	1919.	Wild, M., 29, Beauchamp Avenue, Leamington.
B.	1921.	Wilkinson, D., 1,114, 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.
W. & M.	1924.	Williams, R. G., 179, Crogan Hill, Barry Dock.
W. & M.	1916.	Williams, W., Alexandra Brass Foundry, East Dock, Cardiff.

B'nch.	Year of Election.	MEMBERS.
L.	1927.	Williams, W. L., 61, Grenville Road, Braintree, Essex.
N.	1913.	Willott, F. J., 17, Park Road, Clydach-on-Tawe, Swansea Valley.
M.	1912.	Wilson, F. P., "Parkhurst," Middlesbrough.
L.	1927.	Windsor, W. T., "Pax," Coggershall Road, Braintree, Essex.
Sc.	1906.	Winterton, H., "Moorlands," Milngavie, Dumbartonshire.
S.	1924.	Winterton, H. T., The Knole, Old Whittington, 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., "Kenwyn," Waddon, Croydon, Surrey.
B.	1919.	Wood, D. Howard (Capt.), Kingswood Park Road, Moseley, Birmingham.
B.	1909.	Wood, E. J. (Patent Axlebox and Foundry Company, Limited), Wednesfield Foundry, Wolverhampton.
Lncs.	1926.	Woodcock, A., 163, Hartington Street, Moss Side, Manchester.
W.R.	1914.	Worcester, A. S., Toria House, 162, Victoria Street, Lockwood, Huddersfield.
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.	1927.	Wyborn, S., 93, Valley Road, Sherwood, Notts.
Sc.	1919.	Wyllie, W., 20, Loanhead Street, Kilmarnock.
L.	1925.	Yar Khan, M. M., 102, Beulah Hill, Upper Norwood, London, S.E.
Lncs.	1911.	Yates & Thom, Limited, Canal Engineering Works, Blackburn.
L.	1914.	Young, H. J., F.I.C., 3, Central Buildings, Westminster, S.W.1.

ASSOCIATE MEMBERS.

B'nch.	Year of Election.	
W.R. of Y.	1928.	Ablard, A., 231, Folkstone Street, Bradford Moor, Bradford.
M.	1926.	Adcock, F. H., 7, Beech Grove, Middlesbrough.
Sc.	1919.	Affleck, J., B.Sc., 21, Overdale Avenue, Langside, Glasgow.
W.R.	1927.	Ackeroyd, H., 40, Devonshire Street, Keighley.
B.	1915.	Aldridge, S., 91, Dale Street, Walsall.
B.	1925.	Allen, Wm., Chuckery Foundry, Walsall, Staffs.
S.	1927.	Alford, A. L., 408, Windmill Lane, Shiregreen, Sheffield.
Sc.	1926.	Anderson, J. Y., 35, Alice Street, Paisley.
Lncs.	1907.	Andrew, F., 120, Gas Street, Failsworth, Manchester.
L.	1925.	Armishaw, W. J., 44, Common View, Letchworth, Herts.
M.	1926.	Armstrong, G., 23, Chipchase Street, Middlesbrough.
L.	1925.	Armstrong, L. R., 39, Nessinden Mansions, N.W.15.
Sc.	1920.	Arnott, J., A.I.C., G. & J. Weir, Ltd., Cathcart, Glasgow.
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, Norwich, near Bolton.
Lncs.	1923.	Astall D., 380, Oldham Road, Limehurst, Ashton-under-Lyne.
L.	1905.	Aston, D. A., 36, Bastwick Street, Goswell Road, London, E.C.1.
Lncs.	1922.	Atkinson, Albert, 11, Guy Street, Padiham, Lancs.
S.	1916.	Atkinson, F., "Woodlands," Richmond Road, Handsworth, Sheffield.
N.	1925.	Atkinson, G., 10, Queen's Drive, Whitley Bay.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1922.	Askew, J., 20, Mount Road, West Sunderland.
S.	1920.	Avill, Wm., 44, Albion Road, Rotherham.
S.	1912.	Ayres, J. A., "Aldbourne," Ecclesfield, Sheffield.
Sc.	1918.	Bacon, A. H., 228, Saracen Street, Possilpark, Glasgow.
S.	1924.	Bacon, P., 86, Bridge Street, Swinton, nr. Rotherham.
Lncs.	1926.	Bagley, J., 34, Guest Street, Leigh, Lancs.
S.	1909.	Bailey, P. T., 17, Hallowes Lane, Dronfield, nr. 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.
N.	1925.	Balderston, R. A., 21, Wentworth Place, Newcastle-on-Tyne.
W.R. of Y.	1927.	Balme, H., 33, Grange Avenue, Marsden, nr. Huddersfield.
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.	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.	1915.	Baron, E., 24, Grimshaw Lane, Newton Heath, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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 Road, West Hagley, Stourbridge.
B.	1904.	Bather, H. K. (Chamberlain & Hill), Chuckery Foundry, Walsall.
S.	1920.	Batty, F., 52, Hampton Road, Pitsmoor, Sheffield.
E.M.	1926.	Baxter, J., 108, Stene Hill Road, Derby.
L.	1921.	Baxter, Percy L., 131, Ampthill Avenue, Benoni, Transvaal, S. Africa.
W.R. of Y.	1924.	Bean, E., 8, The Hollies, Sidmouth Street, Hull.
L.	1925.	Beardshaw, A., 50, Jackmans Place, Letchworth, Herts.
W.R. of Y.	1923.	Beaumont, G., 25, Oxley Street, Pontefract Lane, Leeds.
E.M.	1919.	Beck, H. J., Barton House, Littleover Lane, Derby.
L.	1925.	Becker, M. L., National Physical Laboratory, Teddington.
Lncs.	1927.	Beech, T. L., 86, Cyprus Street, Stretford, Manchester.
S.	1920.	Beeley, W. H., Clarence Lane Works, off Eccleshall Road, Sheffield.
W.R. of Y.	1927.	Beilby, A. R., 233, Melrose Gate, Tang Hall, York.
Sc.	1917.	Bell, J., 60, St. Enoch Square, Glasgow.
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. & N.	1928.	Bennett, S. L., Esq., 2, Lily Street, Roath Park, Cardiff.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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., Cole Bank, Hall Green, 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, Streetley, Birmingham.
B.	1922.	Bird, J. B., "Corallyn," Hardwick Road, Streetley, nr. Birmingham.
Sc.	1919.	Black, A., 10, Prince Edward Street, Crosshill, Glasgow.
Sc.	1928.	Blackadder, T., 5, Orchard Street, Falkirk.
Sc.	1928.	Blackadder, W., Linton Vale, Meeks Road, Falkirk.
E.M.	1921.	Blackham, E. L., 460, Uttoxeter Road, Derby.
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.
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.
B.	1925.	Bode, C., 87, Main Street, Sparkbrook, Birmingham.
W.R. of Y.	1922.	Booth, G. E., 80, Institute Road, Eccleshill, Bradford, Yorks.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1915.	Borthwick, T., Crookhall House, Consett, Co. Durham.
M.	1920.	Bound, W. H., Wh. Ex. A.M.I. Mech.E., 12, Dufton Road, Linthorpe, Middlesbrough.
S.	1927.	Boulton, D. C., 4, Littlemoor Crescent, Newbold, Chesterfield.
Lncs.	1921.	Bowden, J., 72, Grange Road, Chorlton-cum-Hardy, Manchester.
L.	1906.	Bowman, A., 48, Lathom Road, East Ham, E.6.
W. & M.	1926.	Boxall, H. A., 33, Gellydeg Street, Maesycummer-via-Cardiff.
S.	1926.	Bradbury, J., 14, Littlemor Crescent, Newbold, Chesterfield.
S.	1916.	Bradley, H., "Cotswold," Bocking Lane, Woodseats, Sheffield.
B.	1925.	Bradshaw, J. H. D., 4, Foley Street, Wednesbury, Staffs.
Lncs.	1922.	Brandrett, T., 35, Ryall Street, Regent Road, Salford, Manchester.
N.	1921.	Brass, A., 44, Haydn Terrace, Gateshead-on-Tyne.
Lncs.	1923.	Brereton, C. F., c/o Mrs. Oldham, 25, Manchester Road, Chorlton-cum-Hardy, Manchester.
Lncs.	1917.	Brierley, A., 76, Ash Road; Gorton, Manchester.
Lncs.	1923.	Brockbank, A. H., 3, Hawkens Street, Old Trafford, Manchester.
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.
L.	1917.	Brown, E. H., 91, Devonshire Road, Forest Hill, S.E. 23.
Lncs.	1923.	Brown, G. H., 17, Derbyshire Avenue, Stretford, Manchester.
Lncs.	1917.	Brown, J., 227, Milnrow Road, Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1909.	Brown, T. W., 21, Burngreave Street. Sheffield.
Sc.	1914.	Bruce, A., 52, Ashley Terrace, Edinburgh.
Sc.	1928.	Bruce, W., 38, Watson Street, Falkirk.
Sc.	1926.	Bruce, W. T., 52, Ashley Terrace, Edinburgh.
Sc.	1927.	Bryden, Walter Myreton, Bonnybridge, Stirlingshire.
Lncs.	1926.	Buck, A., 9, St. Paul's Road, Blackpool, N.S.
N.	1920.	Buckham, G. H.. "Harewood," Grange Road, Newcastle-on-Tyne.
L.	1926.	Buckingham, F. A. T., 114, Richmond Road, Gillingham, Kent.
E.M.	1928.	Buckland, R. H., 20, Dairyhouse Road, Derby.
B.	1925.	Bullows, W. D., c/o Castings, Ltd., Selbourne Street, Walsall, Staffs.
E.M.	1928.	Bulmer, G. N. B., 11, Station Road, Chillaston, Derby.
N.	1920.	Burcham, J., 35, Alverthorpe Street, South Shields.
E.M.	1928.	Burgess, F., 21, Foundry Cottages, Syston, nr. Leicester.
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.	1923.	Butterworth, A. W., 214, Frederick Street, Werneth, Oldham.
Lncs.	1919.	Butterworth, J., 24, East View, Mitchell Street, Bury Road, Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1921.	Butterworth, John, 19, Neville Street, Clare Mount, Halifax.
Lncs.	1920.	Buxton, J., 68, Luke Lane, Hurst, Ashton-u.-Lyne.
Lncs.	1926.	Cairns, F., 59, Blodwell Street, Seedley, Manchester.
B.	1924.	Callaghan, G. M., 6, Foxgrove, Acocks Green, Birmingham.
S.	1920.	Cameron, N., Cavendish Villas, Devonshire Road, Totley Rise, Nr. Sheffield.
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.
Lncs.	1925.	Carr, H., 7, Lord Street, Stalybridge.
L.	1921.	Carrell, Hy. Alfred, 6J, Peabody Buildings, Farringdon Road, E.C.1.
W.R. of Y.	1927.	Carter, S., Cowley Lane, Lepton, nr. Huddersfield.
W.R. of Y.	1923.	Carver, W., 112, Valley Road, Pudsey, near Leeds.
Sc.	1928.	Chambers, H., c/o Mutton, 18, Lorne Street, Leith.
S.	1925.	Chambers, J. F., 31, Duke Street, Staveley, Chesterfield.
W.R. of Y.	1922.	Chappelow, Thos., 181, Taylor Street, Batley, Yorks.
Sc.	1921.	Charters, J., 12, Walworth Terrace, Glasgow.
Lncs.	1925.	Cheetham, E., 5, Eldon Road, Edgeley, Stockport.
W. & N.	1928.	Chilvers, W., High Street, Crowmarth, nr. Wallingford.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1911.	Chope, H. F., 38, Church Street, Sheffield.
Lncs.	1927.	Clark, J. J., 39, Disconson Street, Ormskirk, Lancs.
N.	1920.	Clark, J. W., 133, St. Thomas' Terrace, Blaydon-on-Tyne.
Sc.	1928.	Clark, R. F., c/o Robertson, 12, Clarence Street, Paisley.
L.	1923.	Clark, W., 9, Jubilee Road, Basingstoke.
E.M.	1919.	Clarke, A. S., Leicester Road, Loughborough.
N.	1912.	Clarke, J., Albert Street, Tayport, Fife.
L.	1925.	Clarke, J. W., 17, Major Walk, Peterborough.
Sc.	1928.	Clarkson, A., c/o Mr. Boyd, 39, Seedhill Road, Paisley.
N.	1920.	Clements, H. F., c/o Wm. Jacks & Co., Ltd., Ocean Buildings, Prince Street, Singapore, Straits Settlements.
Sc.	1922.	Cleverley, A.M., B.Sc., 24, York Street, Falkirk, Scotland.
Lncs.	1922.	Cleworth, Alf., 25, Walnut Street, Bolton.
Lncs.	1921.	Coleman, J. I., West Dene, Brooklyn Road, Wilpshire, Blackburn.
W. & M.	1926.	Coles, F. L., 46, Burnaby Street, Cardiff.
S.	1920.	Coles, W. H., 2, Gordon Avenue, Woodseats, Sheffield.
S.	1916.	Collins, B. L., Folds Crescent, Abbey Lane, Sheffield.
W.R. of Y.	1926.	Collinson, K. H., 11, Grandmere Place, Halifax.
S.	1907.	Cook, A. H., W. Cook & Sons, Ltd., Washford Road, Sheffield.
E.M.	1916.	Cook, F., 168, Woods Lane, Derby.
S.	1914.	Cook, W. G., Washford Road, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Cooke, J., 116, Derbyshire Avenue, Stretford, Manchester.
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.
N.	1919.	Corbett, W. A., "Dinguardi," Bungalow 19, High Farm Estate, Wallsend-on-Tyne.
Lncs.	1926.	Coupe, Wm., junr., 36, Kittlingborne, High Walton, nr. Preston.
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.
S.	1912.	Critchley, T., 52, Limpsfield Road, Brightside, Sheffield.
Lncs.	1928.	Cross, J., 80, Elmfield Street, Church.
Lncs.	1927.	Cullinmore, G., 15, Lincoln Square, Farnworth, Widnes.
B.	1906.	Curnow, M. H., 41, Cemetery Lane, West Bromwich.
Sc.	1926.	Currie, J., 1, Sutherland Crescent, Bathgate.
B.	1907.	Dalrymple, D., 20, Beeches Road, West Bromwich.
S.	1920.	Darby, A., 5, Dobbin Hill, Greystones, Sheffield.
S	1909.	Darley, F., 187, Burngreave Road, Pitsmoor, Sheffield.
E.M.	1923.	Darrington, L. G., 27, Kingston Avenue, Hallam Fields, Ilkeston.
Sc.	1922.	Davidson, W. B., (Jas. Keith & Blackman Co., Ltd.), Arbroath.
W. & M.	1924.	Davies, E. H., 224, Cardiff Road, Aberaman.
B.	1925.	Davis, A., 3/247, Gt. Russell Street, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1923.	Davis, J., 50, Old Road, Dukinfield, Cheshire.
Sc.	1926.	Davis, Thos., 633, Dumbarton Road, Partick, Glasgow.
L.	1914.	Davis, W. H., 8, Pye Street, Portsmouth.
S.	1922.	Day, A. B., 19, Scarsdale Road, Dronfield, near Sheffield.
Lncs.	1925.	Dean, J., 48, Northgate Road, Stockport.
Lncs.	1924.	Deeley, F., 52, Bewsey Street, Warrington.
Lncs.	1918.	Demaine, F. C., 9, Rising Sun Lane, Garden Suburb, Oldham.
Lncs.	1922.	Demaine (jun.), F. C., 9, Rising Sun Lane, Garden Suburb, Oldham.
Lncs.	1926.	Denison, H., 20, Second Avenue, Kidsgrove, Stoke-on-Trent.
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.
B.	1925.	Dexter, B. J., 80, New Rowley Street, Walsall.
Sc.	1928.	Dickie, W., 19, Glasgow Road, Paisley, Scotland.
N.	1916.	Dickinson, S., 103, Bede Street, Roker, Sunderland.
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-on-Tyne.
Lncs.	1921.	Dolphin, J. H., 47, Heaton Avenue, Bolton.
W. & M.	1924.	Domville, S., 301, Railway Street, Cardiff.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1919.	Donaldson, J. W., B.Sc., Scott's Shipbuilding and Engineering Company, Limited, Greenock.
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.
Sc.	1917.	Duncan, J., 78, Jellicoe Street, Dalmuir.
L.	1920.	Dunn, J. W., 50, Marlow Road, East Ham, E.7.
W. & N.	1928.	Durrant, G. A., 11, West Park Road, Newport.
Lncs.	1913.	Eastwood, J. H., 83, Princess Street, Castleton, nr. Manchester.
L.	1912.	Eccott, A. E., The Elms, 68, Smithies Road, Plumstead, S.E.18.
S.	1925.	Edginton, J., 3, Coupe Road, Burngreave, Sheffield.
Sc.	1911.	Edmiston, M., Rose Vale, Windsor Road, Renfrew.
W.R. of Y.	1922.	Edmondson, J., 107, Woodroyd Road, West Bowling, Bradford.
B.	1922.	Edwards, F. C., 32, Queen's Head Road, Handsworth, Birmingham.
E.M.	1925.	Elder, A., 90, Stenson Road, Derby.
Sc.	1927.	Elder, P., 10, Napier Crescent, Bainsford, Falkirk.
E.M.	1909.	Ellson, J., 19, Derby Road, Ripley, Derby.
S.	1924.	Emmott, J., 33, Bowood Road. Sheffield.
Sc.	1920.	Erskine, N. A. W., Morton Cottage, Camelon.
Lncs.	1924.	Evans, H., 93, Second Avenue, Trafford Park, Manchester.
B.	1927.	Everest, A. B., B.Sc., Ph.D., Chad Hill, Harborne Road, Edgbaston, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.	1924.	Fenn, J. H., 25, Francemary Street, Brockley, S.E.4.
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, Herts.
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., 108, Upper Conduit 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.
	1923.	Fox, F. S., 6333, Tuxeda Avenue, Detroit, Michigan, U.S.A.
B.	1909.	Fraser, A.,
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., 15, Ridgway Street, Nottingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1904.	Galt, J., Henry & Galt, Sneddon Foundry, Paisley.
B.	1920.	Gaunt, J. W., 101, Beeches Road, West Bromwich.
L.	1927.	Gerrard, J. Norbreck, Alexandra Road, Peterborough.
Lncs.	1927.	Gibson, T., 11, Lincoln Street, Blackburn.
E.M.	1926.	Gill, F., 31, Serlby Rise, Gordon Road, Nottingham.
Sc.	1927.	Gillepsie, H. Mc. K., "Stenhouse," Carron, Falkirk.
Sc.	1928.	Gillespie, C., 67, Commercial Road, Barrhead.
Lncs.	1923.	Gilpin, W., "Sunnyside," Birch Grove, Rusholme, Manchester.
E.M.	1924.	Gilson, A. J., 12, Hanifden 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., 64, Roseneath Road, Urmston, Manchester.
E.M.	1919.	Goodwin, T., Brae House, New Bedford Street, Derby.
B.	1922.	Gospel, W., Gutta Percha Co., c/o The Staffordshire Stainless Iron Co., Ltd., Baldwin Street, Bilston, Staffs.
Sc.	1919.	Graham, R., 116, Stratford Street, Maryhill, Glasgow.
E.M.	1917.	Grant, George, 62, Leicester Road, Quorn, nr. Loughborough.
Sc.	1912.	Gray, J., 2, Station Road, Dumbarton.
S.	1925.	Greaves, H. A., 25, Raven Road, Nether Edge, Sheffield.
S.	1924.	Greaves, J., 3, New Houses, Piccadily, Chesterfield.
S.	1919.	Greaves, J. B., 128, Upperthorpe, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1924.	Green, A., 201, Doncaster Road, Rotherham.
Lncs.	1924.	Green, A. E., 66, Wolseley Road, Preston.
S.	1926.	Green, J. W., 16, Littlemoor Crescent, Newbold, Chesterfield.
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.
M.	1926.	Greenwell, O., 12, Angle Street, Grove Hill, 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, Runnymeade Road, Hall Green, Birmingham.
E.M.	1924.	Griffiths, S., 94, Stenson Road, Derby.
M.	1926.	Griffiths, W., Valley View, Station Road, Amersham, Bucks.
Lncs.	1925.	Grieve, J. E., 24, Tindall Street, Reddish, Stockport.
Lncs.	1919.	Grimwood, E. E. G., 129, Glebelands Road, Ashton-on-Mersey.
Lncs.	1912.	Grundy, H. V., Pentrich, Campbell Road, Brooklands, Cheshire.
L.	1920.	Gurney, S. J., 24, Burns Road, Battersea, S.W.
M.	1926.	Hackwood, J., 52, Byelands Street, Middlesbrough.
Sc.	1920.	Haig, T., 23, Livingston Terrace, Larbert, N.B.
S.	1909.	Hall, E. D., 50, Napier Street, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1921.	Hall, Geo., "Glenthorne," Swan Hill, Oxton, Birkenhead.
N.	1914.	Hall, J. J., Clyde Vale, Rowlands Gill, Co. Durham.
E.M.	1925.	Hallamore, J. C., Oak Farm, Burton Road, Littleover, nr. Derby.
E.M.	1925.	Halloran, J., 152, Brook Street, Derby.
Sc.	1925.	Hamil, W., 50, Woodhead Avenue, Kirkintilloch.
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.	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, S.E.4.
E.M.	1924.	Hanson, C. H., 285, Abbey Street, Derby.
W. & M.	1924.	Harding, J. W., 14, Welford Street, Barry.
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 and Mansergh, Ltd.), Wheathill Street, Salford, Manchester.
M.	1927.	Harper, F. A., 17, Brankingham Terrace, Stockton-on-Tees.
Lncs.	1911.	Harper, H., 28, Alexandra Street, Castleton, nr. Manchester.
B.	1927.	Harper, J., 113, Mansfield Road, Aston, Birmingham.
L.	1925.	Harrington, W. T., 21, Vernon Road, Stratford, London, E.15.
Lncs.	1922.	Harris, F., 18, Holland Street, Padiham, Lancs.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1926.	Harris, R. S., Callywhite Lane, Dronfield, Sheffield.
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.
Lncs.	1924.	Hartley, R., 15, Oxford Road, Bootle, Liverpool.
Sc.	1914.	Hartley, R. F., London Road Foundry, Edinburgh.
M.	1926.	Harvey, D., 4, Rydal Road, Stockton-on-Tees.
S.	1926.	Hatton, W. H., Broomhall Lane, Sheepbridge, Chesterfield.
W. & M.	1928.	Hawes, W., "Ben Trovato," Whittecks, Road, Hanham, Bristol.
E.M.	1925.	Hawley, T. H., 53, Willow Brook Road, Leicester.
Sc.	1928.	Hawthorne, S., 10, Clarence Street, Paisley.
Sc.	1910.	Hay, J., 120, Brownside Road, Cambuslang, Glasgow.
B.	1910.	Hayward, G. T., 8, The Laurels, Marroway Street, Birmingham.
Lncs.	1923.	Hayward, R., 39, Belgrave Road, New Moston, Manchester.
E.M.	1922.	Hayward, Wm., Fairhaven, Pastures Road, Stapleford, nr. Nottingham.
Lncs.	1925.	Heatley, H., 146, Redlam, 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.
L.	1910.	Henderson, G. B., 28, College Road, Woolston, Southampton.
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.
Sc.	1921.	Henry, John, 75, Alma Street, Grahamston, Falkirk.
Lncs.	1922.	Henshaw, J. E., "Trefechan," Hyde Road, Woodley.
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.
L.	1927.	Hider, A. S., Lauriston Villa, Parkfield Road, Torquay.
Lncs.	1915.	Hill, A., 114, Middleton Road, Heywood, Lancs.
Lncs.	1925.	Hill, H. G., 495, Stretford Road, Old Trafford, Manchester.
E.M.	1917.	Hilton, H. J. S., 29, West Avenue, Derby.
Lncs.	1909.	Hilton, T. G., 171, Rose Hill Road, Burnley.
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., Costock, nr. Loughborough.
S.	1920.	Holland, G. A., Red House, Clay Cross, near Chesterfield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1922.	Holland, W., 1151, Chester Road, Stretford, Manchester.
Lncs.	1924.	Holt, A., 41, Carmen Street, Ardwick, Manchester.
Lncs.	1925.	Hopwood, A., 154, Chestergate, Stockport.
L.	1921.	Hotchkis, J. D., 29, Romberg Road, London, S.W.17.
Lncs.	1924.	Howard, E. J. L., 8, Queens Terrace, Clarence Road, Longsight, Manchester.
Lncs.	1921.	Howcroft, J., 5, St. James' Street, New Bury, Farnworth, nr. Bolton.
W. & M.	1922.	Howe, C. A., G. I. P. Loco Works, Parel, Bombay, India.
L.	1927.	Howell, L. H., 67, Foyle Road, Blackheath, London, S.E.3.
W.R. of Y.	1917.	Hoy, R. E., 33, Brunswick Avenue, Beverley Road, Hull.
Sc.	1923.	Hudson, F.,
Lncs.	1926.	Hudson, R., 39, St. Andrew Avenue, Droylesden, Lancashire.
B.	1924.	Hulse, J. C., 51, Westbourne Street, Walsall.
S.	1925.	Hunt, A., 18, Hollingwood Common, Barrow Hill, nr. Chesterfield.
Sc.	1926.	Hunter, J. M., 77, Prestwick Road, Ayr.
L.	1923.	Hunter, R. L., "Kirkmailing," East Cote Road, Ruislip, Middlesex.
L.	1922.	Husselbury, E., Rosemead, Winifred Road, Bedford.
L.	1924.	Hutchings, T. C., 10, Lopen Road, Silver Street, Edmonton, London, N.18.
S.	1927.	Hyde, F. E., 22, Volta Road, Swindon.
B.	1925.	Hyde, Sidney, 25, Inhedge, Gornal, near Dudley.
Lncs.	1928.	Ingham, T., 225, Manchester Road, Denton.
Lncs.	1917.	Inskip, A., 992, Ashton Old Road, Openshaw, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1920.	Irvine, A., The Point, King Street, Larbert, N.B.
W.R. of Y.	1925.	Jackson, A., 73, First Street, Low Moor, Bradford.
Lncs.	1925.	Jackson, A., 27, Marlboro' Street, Accrington.
Lncs.	1923.	Jacques, T., The Cottage, Hill Top, Romiley, nr. 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-on-Tyne.
Sc.	1927.	Jeffrey, R. S. M., Lithgow Avenue, Kirkintilloch.
L.	1927.	Johnson, A. C., 48, Gooch Street, Swindon, Wilts.
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, nr. Bilston, Staffs.
Lncs.	1916.	Jones, J. H., "Elleray," Temple Drive, Swinton, Manchester.
Lncs.	1928.	Jones, W., 112, St. Mark's Road, Saltney, Chester.
Lncs.	1919.	Jowett, H., 53, Turf Hill Road, Rochdale.
Lncs.	1922.	Kay, Wm., 9, Eastbank Street, Bolton, Lancs.
W.R. of Y.	1922.	Kaye, H., 6, Fryergate Terrace, New Scarboro', Wakefield.
Lncs.	1907.	Kemlo, R. W., "Dunottar," Campbell Road, Brooklands, Cheshire.
Sc.	1927.	Kennedy, D., c/o Mundey, 117, Riley Street, Blackburn, Lancs.
Sc.	1912.	Kennedy, J., "Dunard," Howieshill, Cambuslang.
E.M.	1918.	Kerfoot, John, 23, Cumberland Road, Loughborough.
Sc.	1914.	Kerr, W., 101, Ardgowan Street, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1925.	Kershaw, J., 31, Birkdale Street, Cheetham Hill, Manchester.
E.M.	1927.	Kershaw, T. F., 15, Sandford Road, Syston, nr. Leicester.
Lncs.	1927.	Kidd, S. (Junior), 4, St. Stephen's Street, Oldham.
Sc.	1928.	Kidston, W., The Bengal Iron Co., Kulti, E.I.R., India.
Sc.	1927.	Kilpatrick, A., Block 8, Foundry Street, Carron Road, Falkirk.
N.	1925.	Kirby, A. D., 6, Falshaw Street, Washington Station, Co. Durham.
Lncs.	1924.	Kirkham, J., 13, Gt. James Street, W. Gorton, Manchester.
W.R. of Y.	1922.	Kirkbride, A. D., 24, Springswood Avenue, Shipley, Bradford, Yorks.
Sc.	1920.	Kirkwood, J., 102, Balgrayhill Road, Springburn, Glasgow.
B.	1922.	Kitchen, B., 1, Hughes Avenue, Birches Barn Road, Wolverhampton.
Lncs.	1927.	Knight, J., 138, Winwick Road, Warrington.
S.	1908.	Knowles, J. (c/o. Walkers), Manchester Road, Stocksbridge, Sheffield.
B.	1927.	Lafford, T. W., 8, Pensnett Road, Brierley Hill.
L.	1922.	Laidlow, Wm., 9, Griffin Road, Plumstead, S.E.
Lncs.	1923.	Laing, J., 59, Victoria Road, Bedford,
Lncs.	1927.	Lally, W., 60, Clovelly Road, Worsley Road, Swinton.
Sc.	1922.	Lang, Wm., 64, Second Avenue, Radnor Park, Clydebank.
Sc.	1907.	Lawrie, Alex., 20, McKinlay Place, Kilmarnock.
Sc.	1919.	Lawrie, R. D., 49, Thorncliffe Lane, Chapeltown, Sheffield.
S.	1920.	Laycock, E., 213, Grimesthorpe Road, Sheffield.
Lncs.	1914.	Leaf, J. W., District Bank House, Castleton, nr. Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.	Lovesley, Wm., 32, Westbourne Road, Broomhill, Sheffield.
S.	1920.	Lewin, H., "Westbrook," St. John's Road, Newbold, Chesterfield.
B.	1919.	Lewis, D. (John Harper & Company, Limited), Albion Works, Willenhall, Staffs.
B.	1925.	Lewis, E. J., 61, Grafnant, Church Vale, West Bromwich.
B.	1910.	Lewis, G., Strathmore, Paget Road, Wolverhampton.
E.M.	1928.	Lewis, S., 103, Abbey Street, Derby.
W.R. of Y.	1926.	Liddemore, A. E., 4, Park Avenue, Long Park, Keighley.
Sc.	1925.	Liddle, R., 117, Roseberry Street, Oatlands, Glasgow.
Lncs.	1927.	Liley, M., 64, Buxton Crescent, Turf Hill Estate, Rochdale.
E.M.	1923.	Limbert, H., 15B, Factory Street, Loughborough.
Lncs.	1925.	Lineker, A. W., Ruddington House, Beaconsfield, C.P., South Africa.
L.	1919.	Lisby, T., 7, Meanley Road, Manor Park, E.
N.	1919.	Little, J. E. O., 1, Gibson Terrace, Maryhill, Dundee.
Sc.	1910.	Littlejohn, A., 39, Rupert Street, Glasgow, N.W.
Lncs.	1925.	Lockett, E., 38, Jackson Street, Gorton, Manchester.
Sc.	1922.	Longden, J., 11, Drumry Road, Clydebank.
W.R. of Y.	1922.	Lowe, E., 35, Foster Road, Ingrow, Keighley, Yorks.
E.M.	1927.	Lowe, H., "Rose Cottage," Queenborough, nr. Leicester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Lowe, J., 175a, Dill Hall Lane, Church, near Accrington.
Lncs.	1910.	Lupton & Sons, H. E., Scaithcliffe Works, Accrington.
W.R. of Y.	1927.	Loxton, C. R., 26, Elmet Avenue, Roundhay, Leeds.
Sc.	1928.	Lumsden, G., 76, Camp Street, Motherwell.
B.	1908.	Mace, C., 64, Port Street, Manchester.
Lncs.	1927.	Martin, W., 34, St. George's Road, Withington, Manchester.
Sc.	1926.	McArthur, J. N., 12, Hamilton Drive, Hillhead, Glasgow, W.2.
Sc.	1928.	McArthur, W., Block 9, Union Road, 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.	1919.	McConnell, W., 136, Carsaig Drive, Craigton, Glasgow.
Sc.	1925.	McCulloch, W., 174, Newlands Road, Cathcart, Glasgow.
M.	1927.	McCusker, C. B., 32, Lanehouse Road, Thornaby-on-Tees.
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., 219, Ringinglow Road, Ecclesall, Sheffield.
E.M.	1924.	McDonald, D. M., 45, Stenson Road, Derby.
Sc.	1913.	McDonald, W. F., 5, Hutchinson Place, Cambuslang.
Sc.	1917.	MacDougall, Miss E., 22, Clarendon Street, St. George's Cross, Glasgow.
Sc.	1911.	McEachen, J., Regent Street, Kirkintilloch.
Sc.	1910.	Macfarlane, J., 51, Kings Park Avenue, Cathcart, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1904.	McFarlane, T., Farm Road, Horsehay, Salop.
Sc.	1914.	McGavin, R., 5, McKenzie Avenue, Clydebank.
Sc.	1920.	McGovan, A., 69, Battlefield Avenue, Langside, Glasgow.
Sc.	1910.	McGowan, R. R., Colliston-by-Arbroath.
Sc.	1927.	McIntyre, R., 102, Thistle Street, Camelon, Falkirk.
Sc.	1910.	Mackay, G., 103, Glasgow Road, Paisley.
Lncs.	1923.	McKenzie, Wm., c/o J. Hodgkinson, Ltd., Ford Lane Works, Pendleton, Manchester.
Sc.	1922.	McKinnon, J. C., Leaside Cottage, Cogan Street, Barrhead.
Lncs.	1922.	Maclachlan, J. R., 7, Newall Mount, Otley, Yorks.
Sc.	1910.	McLachlan, W., 5, Dawson Terrace, Carron, Falkirk.
W. & M.	1925.	McLean, J., Donella, 12, Dinas Street Grange, Cardiff.
Sc.	1915.	McNab, J., Bells Wynd, Falkirk.
Sc.	1924.	McNab, R., 13, Walker Street, Paisley.
Sc.	1910.	McPhie, H., 40, Philip Street, Falkirk.
Sc.	1927.	McGhie, D. C., 24, Morley Street, Langside, Glasgow.
Lncs.	1927.	McVie, J., 73, Lynwood Road, Blackburn.
Sc.	1926.	McWhirter, A., 74, Ochil Street. Tollcross, Glasgow.
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.
B.	1909.	Marks, J., Sunbury House, 40, Titford Road, Langley, Birmingham.
Lncs.	1923.	Marlow, E., Brownoak, Western Road, nr. Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
Gen.	1924.	Mason, A., 2, Lindsey Street, Frodingham, Scunthorpe, Lincs.
W.R. of Y.	1922.	Martin, F., 67, Nowell Terrace, Harehills Lane, Leeds.
Lncs.	1927.	Martin, W., 34, St. George Street, Withington, Manchester.
B.	1925.	Massey, J. S., 49, Hawkes Lane, Hill Top, West Bromwich.
Lncs.	1917.	Masters, J., "The Hollins," Vane Road, Longden Road, Shrewsbury.
B.	1922.	Masters, T. J., 12, Glover Street, West Bromwich.
B.	1909.	Mathews, J., 20, Earl Street, Walsall.
B.	1921.	Mauby, R. A., Hopstone, Bridgnorth, Salop.
Lncs.	1926.	Mazarachi, A. C., 42, Ullet Road, Liverpool.
Lncs.	1925.	Meadowcroft, H., 14, Worcester Street, Rochdale.
Sc.	1914.	Mearns, A., Bengal Iron Co., Kulti, E. I. R., India.
E.M.	1928.	Measures, J. F., 4, Paton Street, Leicester.
Sc.	1924.	Meikle, A. S., 207, Kent Road, Glasgow.
Sc.	1928.	Meikle, J. R., 20a, Church Place, Grahamston, Falkirk.
S.	1927.	Meldrum, W. K., "Overton," Hatherrage, Derbyshire.
Lncs.	1926.	Mellors, W., 166, West Street, Oldham.
M.	1926.	Menzies, A., 31, Cambridge Road, Thornaby-on-Tees.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1926.	Merigold, J. J., 67, Swans Lane, Bolton.
S.	1913.	Miller, A., 90, Bawtry Road, Tinsley, Sheffield.
W.R. of Y.	1923.	Milner, J. W., 29, Welbeck Street, Sandal, Wakefield.
Sc.	1927.	Mitchell, W. C. 2, Lang Street, 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, N.B.
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.
Sc.	1909.	Morehead, J. S., 98, Wilton Street, Kelvinside, Glasgow.
B.	1919.	Morewood, J. L., 37, Paignton Road, Rotton Park, Birmingham.
B.	1926.	Morgan, E. S., Dalkeith, Stechford Lane, Ward End, Birmingham.
W. & M.	1922.	Morgan, W., Bryn Derwen, Bryn Terrace, Porth, Glam., So. Wales.
N.	1924.	Mudie, T., 34, Beech Grove. Monkseaton.
Sc.	1927.	Muir, W., "Bellevue," Carronshore, Falkirk.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1913.	Murray, J., 5, Elmwood Avenue, Willington. Quay-on-Tyne.
Sc.	1927.	Murray, T., 35, McLelland Drive, Kilmarnock.
S.	1914.	Naylor, A., 239, Abbeyfield Road, Pitsmoor, Sheffield.
Lncs.	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., 14, Broughton Road, South Shields.
Gen.	1921.	Newland, J. E., 37, Provost Street, Holbeck, Leeds.
Lncs.	1912.	Nicholls, J., 146, Hulton Street, Trafford Road, Salford.
N.	1921.	Nicholson, J. D., 13, Taylor Street, South Shields.
Sc.	1918.	Nisbet, H. L., Lilyburn, 91, Hillend Road, Lambhill, Glasgow.
Lncs.	1920.	Noble, A., 42, Central Road, Gorton, Manchester.
Lncs.	1924.	Noble, J., 53, Reddish Lane, Gorton, Manchester.
B.	1924.	Northcott, L., 9, Kirk Lane, Plumstead Common, London, S.E.18.
S.	1921.	Offiler, G., 9, Ward Place, Highfields, Sheffield.
Lncs.	1920.	Oldham, R., 191, Dill Hall Lane, Church, Lancs.
Lncs.	1923.	Ollier, A. L., 53, Gorse Street, Stretford, 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, Leicester, Forest East.
E.M.	1928.	Oswin, H. A., 37, The Banks, Sileby, nr. Leicester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1922.	Owen, A. C., Gladstone House, Ketley Bank, near Wellington, 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.
Lncs.	1923.	Palmer, T., 5, Marmaduke Street, Oldham.
Sc.	1928.	Parker, A. P., Williamlea, Morningside, Newmains.
B.	1925.	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., 33, King Street, Dunstable, Beds.
E.M.	1928.	C. S. Pearn, Warnham, Gibson's Lane, Berstall, Leicester.
N.	1925.	Pearson, C. E., 2, Pearl Street, Saltburn-by-Sea.
E.M.	1927.	Pedge, F., 23, Foundry Cottages, Syston, nr. Leicester.
E.M.	1906.	Pemberton, H., 15, Wolfa Street, Derby.
Lncs.	1919.	Perkins, F. S., 2, Stubbs Terrace, Occupation Street, Newcastle, Staffs.
L.	1927.	Perry, A. E., 122, Tufnell Park Road, London, N.7.
Lncs.	1922.	Phillips, A., 38, Gorse Crescent, Stretford, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1927.	Phillips, H., "Fairholme," Parkvale Avenue, Wednesbury, Staffs.
B.	1918.	Picken, J., Lilac Cottage, Doseley, Dawley, Salop.
L.	1920.	Pierce, G. C., 11, Athelney Street, Bellingham, S.E.6.
S.	1926.	Pollard, C. D., 392, Firth Park Road, Sheffield.
Lncs.	1918.	Potts, W., 1, Far Lane, Hyde Road, Gorton, Manchester.
N.	1928.	Pratt, W., 23, Dene Street, Pallion, Sunderland.
Lncs.	1922.	Prescott, J., 3, Louisa Street, Bolton, Lancs.
Lncs.	1928.	Preston, G. W., 46, Edward Street, nr. Openshaw, Manchester.
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., Ramsey House, Bescot, Walsall.
S.	1917.	Pugsley, T. M., 45, Leslie Street, Vereeniging, Transvaal, South Africa.
M.	1926.	Ramsey, J. E., 95, Princes Road, Middlesbrough.
M.	1926.	Rand, T., 11, Pearl Street, Saltburn-by-Sea.
L.	1926.	Randle, L. A., 45, Nichols Street, Coventry.
Sc.	1904.	Rankin, R. L. (Sharp & Company), Lennox Foundry, Alexandria, Scotland.
Gen.	1928.	Rao, J. S. Gangadhar, Mysore Ironworks, Bhadravati, S. India.
L.	1920.	Rasbridge, W. J., 160, Evelyn Street, Deptford, S.E.
Lncs.	1910.	Rawlinson, W., "Fairhaven," Portland Road, Ellesmere Park, Eccles, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W. & M.	1928.	Rea, H., 176, Caerleon Road, Newport.
S.	1907.	Redmayne, L., Little London Road, Sheffield.
Lncs.	1927.	Reynolds, J. A., "Nirvana," Eccleston Park, near Prescot.
Lncs.	1907.	Reynolds, W., 13, Park View Terrace, Oldham.
W.R.	1922.	Rhodes, W., 20, Hope View, Carr Lane, Windhill, Yorks.
S.	1922.	Rhodes, Wm., Beech Holme, Ecclesfield, nr. Sheffield.
W. & M.	1928.	Richards, T. D., 23, Keppoch Street, Cardiff.
L.	1925.	Richards, W. S., 68, Beatrice Avenue, Keyham Barton, Devonport.
N.	1912.	Richardson, W., 204, South Frederick Street, South Shields.
M.	1926.	Richardson, J. W., 424, Linthorpe Road, Middlesbrough.
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., 42, Smith Street, Hillhead, Glasgow.
Lncs.	1920.	Robinson, F., 369, Wigan Road, Deane, Bolton.
B.	1925.	Robinson, J., 8, Esplanade East, Calcutta, India.
M.	1917.	Robinson, J. H., c/o. R. W. Crosthwaite, Ltd., Union Foundry Thornaby-on-Tees.

ASSOCIATE MEMBERS.

B'nch.	Year of Election.	
L.	1927.	Robson, N. E., 10, Railway Street, Braintree, Essex.
N.	1919.	Robson, F., 44, Stannington Place, Heaton, Newcastle-on-Tyne.
W. & M.	1928.	Rogers, D., 3, Caronation Road, Llanelly, S. Wales.
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.
E.M.	1913.	Roe, J., Globe Foundry, Stores Road, Derby.
Gen.	1920.	Rogers, C. F., 28, Maycock Road, Coventry.
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.
Sc.	1928.	Russell, M., 29, Laurel Street, Partick.
M.	1926.	Rutherford, C., "Inglefield," Egglescliffe, near Yarm., S.O.
N.	1925.	Rutledge, W. B., 61, North View, Heaton, Newcastle-on-Tyne.
Lncs.	1924.	Ryding, F., 52, Barnsley Street, Wigan, Lancs.
W.R. of Y.	1927.	Rymer, A. S., West Bank, Heworth, York.
L.	1923.	Sanders, H. H., 21, Etherley Road, Harringay, N.15.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
S.	1927.	Scholes, A., 35, Bromwich Road, Woodseats, Sheffield.
Sc.	1928.	Scott, A., Wallace Street, Falkirk.
Sc.	1923.	Scott, C., 7, La France Avenue, Bloomfield, New Jersey, U.S.A.
N.	1916.	Scott, G. W., 1, Northumberland Villas, Wallsend-on-Tyne.
N.	1918.	Scott, W., 7, Lynwood Avenue, Blaydon-on-Tyne.
M.	1926.	Seaman, A., 1, Cowper Bewley Road, Haverton Hill, Middlesbrough.
Lncs.	1925.	Self, D.,
S.	1921.	Senior, George, 305, Upperthorpe, Sheffield.
Lncs.	1925.	Service, J., 78, Highfield Road, Seedley, Manchester.
W.R. of Y.	1913.	Shackleton. H. R., Upper Pear Tree Farm, Hainsworth Shay, Keighley.
W.R. of Y.	1922.	Shaw, A., 28, Marlboro' Road, Shipley, Bradford.
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, Birmingham.
Lncs.	1926.	Shepherd, F. L., 215, Tottington Road, Bury.
S.	1923.	Sherratt, W., 39, Horndean Road, Pitsmoor, Sheffield.
E.M.	1925.	Sherriff, C., 62, Herbert Street, Loughborough.
B.	1925.	Shore, A. J., "Bradda," Quinton Hill, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1920.	Shorthouse, W. H., Haybridge Ironworks, Wellington, Salop.
B.	1927.	Shwalbe, S., 62, Milverton Road, Erdington, Birmingham.
W. & M.	1925.	Silverwood, H. Wm., 320, Newport Road, Cardiff.
Lncs.	1922.	Simkiss, H., 28, Energy Street, Bradford Road, Manchester.
S.	1917.	Simpson, C. D., 17, Willis Road, Hillsbro', Sheffield.
S.	1925.	Simpson, F. A., 110, Edward Street, Sheffield.
B.	1914.	Simpson, H., Greenhurst, Doseley, Dawley, Salop.
W.R. of Y.	1925.	Simpson, J. A., 3, Jesmond Place, Hunslet Hall Road, Leeds.
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.
E.M.	1925.	Slade, R. H., 254, St. Thomas Road, Derby.
L.	1911.	Slater, H. O., "Sunny Hill," Lessners Park, Belvedere, Kent.
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., 152, St. Thomas' Road, Derby.
Sc.	1927.	Smith, B. D., 27, Corsewall Street, Coatbridge.
Lncs.	1925.	Smith, F., 85, Greenbank Road, Rochdale.
Gen.	1919.	Smith, F. G., 15, Cherry Street, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1913.	Smith, J., Abney House, Gleadless Road, Sheffield.
Sc.	1921.	Smith, J., 6, Kennard Street, Falkirk.
B.	1917.	Smith, S., 114, Tetley Road, Hall, Green. Birmingham.
Lncs.	1909.	Smith, S. G., 121, Davyhulme Road, Stretford, Manchester.
Lncs.	1924.	Smith, W., 358, Halifax Road, Todmorden.
E.M.	1925.	Smith, W. F., 152, St. Thomas Road, Derby.
E.M.	1926.	Smith, W. H., 9, Leopold Street, Derby.
W.R. of Y.	1924.	Smith, Wm., Main Road, Kesgrave, Ipswich.
Sc.	1924.	Sneddon, F. M., 28, Forest Street, Mile End, Glasgow.
S.	1924.	Somerfield, H., 146, Sandygate Road, Sheffield.
Sc.	1920.	Spittal, J., 82, Norham Street, Shawlands, Glasgow.
Lncs.	1926.	Stacey, C. W., 5, Harcourt Street, Gorse Hill, Stretford, Manchester.
B.	1927.	Stanton, L., 8, Low-wood Road, Erdington, Birmingham.
Sc.	1918.	Stark, W. C.,
B.	1917.	Starr, F. G. O., 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 Rd., Rodbourne, Cheney, Swindon.
Lncs.	1921.	Stevenson, M., 9, Fountains Avenue, Firwood, Bolton.
Sc.	1925.	Stirling, E., York Place, Kirkintilloch,
N.	1914.	Stobbs, R., 199, Stanhope Road, South Shields.
S.	1919.	Stocker, W. E., 109, Ellesmere Road, Pitsmoor, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1920.	Storer, W. H., 255, Settle Street, Great Lever, Bolton.
W.R. of Y.	1926.	Stott, E., 4, Orchard Street, Otley, Yorks.
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.
W.R. of Y.	1922.	Sutcliffe, A., "Thorncliffe," Wellington Road, Todmorden, Yorks.
Lncs.	1919.	Sutcliffe, W., 3, Birkdale Road, Turf Hill, Rochdale.
Lncs.	1923.	Swann, H., 31, Alexandra Road, Patricroft, Manchester.
Sc.	1927.	Syme, T. R., 90, Rolland Street, Maryhill, Glasgow.
N.	1922.	Tait, A. H., Armagh House, Wallsend-on-Tyne.
Lncs.	1922.	Tate, C. M., Brook Royd, Todmorden Road, Burnley.
Gen.	1906.	Taylor, A. (Fielding & Platt, Limited), Atlas Ironworks, Gloucester.
M.	1926.	Taylor, D., 35, Langley Avenue, Thonaby-on-Tees.
B.	1925.	Taylor, E. R., 148, South Road, Handsworth, Birmingham.
W. & M.	1905.	Taylor, F. J., J.P. (Taylor & Sons, Limited), Britonferry, South Wales.
B.	1926.	Taylor, F., J.P., "The Willows," Gipsy Lane, Willenhall, Staffs.
Lncs.	1921.	Taylor, James, 3, Tremellen Street, Accrington.
S.	1926.	Taylor, R. J. S., Hill Crest, Broomhall Lane, Old Whittington, Chesterfield.
W.R. of Y.	1927.	Taylor, W., 77, Dorchester Road, North Shore, Blackpool.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1925.	Teasdale, I., Homeland, Norton Village, Letchworth.
N.	1921.	Temple, G. T., 35, Grosvenor Drive, Whitley Bay.
Sc.	1926.	Tennant, A. McA., 2, Union Road, Bathgate, Scotland.
Lncs.	1922.	Thatcher, E. H., The Newport Foundry Co., Mill Parade, Newport.
N.	1924.	Thom, J., 11, Moorland Crescent, Walker, Newcastle-on-Tyne.
L.	1909.	Thomas, E., 41, Kingshill Road, Swindon.
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.,
S.	1923.	Thornton, A. E., 34, Hampton Road, Pitsmoor, Sheffield.
L.	1927.	Tichelly, L. J., 46, Shern Hall Street, London, E.17.
Lncs.	1911.	Timmins, A. E., 133, Roose Road, Barrow-in-Furness.
Lncs.	1924.	Timperley, T., 30, Ventnor Road, Heaton Moor, Stockport.
E.M.	1928.	Tompkin, A., 54, Harelock Street, Leicester.
E.M.	1927.	Tompkin, S. E., 332, East Park Road, Leicester.
Sc.	1925.	Tonagh, Chas., 70, Stevenson Street, Calton, Glasgow.
B.	1919.	Toplis, H., Brookdene, Hatchford Brook, Sheldon, Birmingham.
Lncs.	1914.	Topping, G., 17, Bebbington Street, Clayton, Manchester.
B.	1909.	Toy, J. H., 12, Rathbone Road, Warley, Birmingham.
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.
W.R. of Y.	1927.	Turner, L., 14, Whitwell Green, Dewsbury Road, Elland.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1918.	Turner, W., 90, Edgedale Road, Sheffield.
B.	1923.	Twigger, T. R., Post Office, Bubbenhall, nr. 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.
E.M.	1921.	Vaughan, Benj. H., 25, Holmes Street, Derby.
B.	1917.	Vaughan, G. A., Pen Glen, Tivedale Road, Burnt Tree, Tipton.
Lncs.	1921.	Vernon, G. W., 11, Ashfield Road, Burnley.
N.	1914.	Wainford, E. H., High Row, Gainford, Darlington.
Lncs.	1925.	Walker, A., 117, Robert Street, Newton Heath, Manchester.
Lncs.	1928.	Walker, A., 45, Highfield Road, Levenshulme, Manchester.
Lncs.	1921.	Walker, Alex. W., 113, Dalton Green Lane, Huddersfield.
Sc.	1920.	Walker, D., 5, New Houses, Anderson Street, Bonnybridge.
L.	1922.	Walker, F. D., 153, Greenvale Road, Eltham, S.E.
Sc.	1920.	Walker, G., 21, Napier Place, Bainsford, Falkirk.
E.M.	1920.	Walker, Geo. H., 2, Camp Street, Derby.
Sc.	1920.	Walker, Wm., 10, Larbert Road, Bonnybridge, Falkirk.
B.	1916.	Wall, J., 15, Flavell Street, Woodsetton, nr. Dudley.
Lncs.	1915.	Walwork, R. N., Western Road, Wilmslow, Cheshire.
S.	1927.	Walmsley, T., 2, Calder Way, Firth Park, Sheffield.
E.M.	1924.	Ward, J. C., Wilncrith, Collingham Road, Leicester.
E.M.	1925.	Warner, Amos, 252, St. Thomas Road, Derby.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1928.	Wass, E., 1, Oliver Road, Balby, Doncaster.
S.	1911.	Wasteney, J., Vulcan Foundry, Eckington, nr. Chesterfield.
Gen.	1914.	Watson, R., Saxilley House, 49, York Street, Rugby.
Sc.	1919.	Watt, R., Etna Ironworks, Falkirk.
L.	1927.	Watts, W., 23, Rolt Street, Deptford, London, S.E.8.
Sc.	1920.	Waugh, Wm., 21, Dundas Crescent, Laurieston, Falkirk.
B.	1923.	Webb, A. W. J., 1, Sidney Street, Gloucester.
B.	1927.	Webb, A. E., 45, Brettel Street, Dudley, Worcester.
E.M.	1921.	Webb, Ernest Alfred, 109, Warwick Street, Leicester.
S.	1909.	Webster, C., 34, Milton Road, Rotherham.
Sc.	1927.	Webster, D. M., 15, Garden Terrace, Falkirk.
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.
W.R. of Y.	1928.	Whitaker, G. H., 20, Sandy Wood Street, Keighley.
W.R. of Y.	1913.	Whitaker, E., 145, St. Enoch Road, Wibsey, Bradford.
M.	1926.	Whitehead, A., "Avondale," St. Luke's Avenue, Thornaby-on-Tees.
M.	1926.	Whitfield, C. S., Bengal Ironworks, Kulti, E.I.R., Bengal, India.
L.	1911.	Whiting, A., Brynhella, Pembroke Road, Erith, Kent.
L.	1924.	Whiting, A. F., 56, Battle Road, Erith, Kent.
S.	1925.	Wild, A. J., Midland Brass Foundry, Attercliffe, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1926.	Wild, H., 14, Albert Promenade, Loughborough, Leicestershire.
M.	1926.	Wilkes, R., 39, Pearl Street, Haverton Hill, Middlesbrough.
B.	1920.	Wilkins, A. J. R.,
M.	1910.	Wilkinson, T., Stockton Street, Middlesbrough.
S.	1919.	Williams, A., 31, Burngreave Bank, Sheffield.
Lncs.	1925.	Williams, O., 25, Thirlmere Avenue, Stretford, Manchester.
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.
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.	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.
—	—	Wise, S. F., 110, Pullan Avenue, Eccleshill, Bradford.
B.	1924.	Wiseman, A. A., 149, Toll End Road, Tipton, Staffs.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1912.	Wolstenholme, J., 111, Carlton Terrace, Bury, and Bolton Road, Radcliffe, Manchester.
B.	1922.	Wood, A., 30, Toll End Road, Toll End, Tipton.
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.
S.	1927.	Woolen, R., Cowley, Dronfield, nr. Sheffield.
M.	1926.	Woolley, H. E., 5, Albion Terrace, Saltburn-by-Sea.
B.	1927.	Worley, S. C., "Ashmore," 153, Bearwood Road, Smethwick, Birmingham.
Lncs.	1917.	Worrall, J. N.,
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.,
Lncs.	1928.	Yates, S., Hayfield Road, Chapel-en-le-Frith,
Lncs.	1926.	Yates, W., 38, Clifford Street, Leigh, Lancashire.
Lncs.	1924.	Yeoman, Robert, 49, Wellington Road, North, Stockport.
Lncs.	1926.	Yeoman, S., 18, Lord Street, Stockport.
Sc.	1919.	Young, J., 45, Cochrane Street, Paisley.
N.	1921.	Young, James, 72, Carlisle Street, Felling-on-Tyne.

ASSOCIATES.

B'nch.	Year of Election.	
N.	1925.	Adams, F., 98, Avondale Road, Byker, Newcastle.
N.	1926.	Ainsworth, L. H., 3, Albert Avenue, Wallsend-on-Tyne.
B.	1925.	Andrews, E., 51, Lansdown Road, West Didsbury, nr. Manchester.
S.	1920.	Ayres, Sidney, 299, Bellhouse Road, Shiregreen, Sheffield.
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-on-Tyne.
Sc.	1927.	Bell, W. M., 2, Bellfield Street, Barrhead.
N.	1924.	Betham, W. S., 9, South Frederick Street, South Shields.
N.	1925.	Blackwell, J., 131, George Street, Willington-Quay-on-Tyne.
Sc.	1926.	Blackwood, W. S., 12, Napier Street, Linwood, N.B.
Sc.	1927.	Blythe, N. C., 11, Danes Drive, Scotstoun, Glasgow.
B.	1922.	Boudry, C., 46, Holly Lane, Smethwick.
B.	1914.	Boyne, W., 157, Wood End Road, Erdington, Birmingham.
N.	1928.	Buckley, B. A., 3, Monk Street, Sunderland.
L.	1928.	Burgess, F. G., 13, Saxon Road, Luton, Beds.
M.	1926.	Cannon, W. R., 9, South View, Billingham, Stockton-on-Tees.
N.	1917.	Carr, S., 44, Stanley Street, Rosehill, Wallsend-on-Tyne.
L.	1924.	Chamberlain, E. E., 70, Albert Street, Slough, Bucks.

B'nch.	Year of Election.	ASSOCIATES.
N.	1923.	Chapman, L. B., 39, Front Street, Tynemouth.
Sc.	1926.	Clark, J., 28, King Street, Paisley.
S.	1920.	Coates, L., Boston Villa, Boston Castle Grove, Rotherham.
W. & M.	1925.	Coles, H., 101, Woodlands Road, Barry Dock.
Lncs.	1927.	Connell, C. H., 9, Muriel Street, Great Glower Street, Lr. Broughton.
Sc.	1925.	Coubrough, W. J., 68, Guthrie Street, Maryhill, Glasgow.
L.	1926.	Cummings, F. C., 3, Waller Road, New Cross, London, S.E.16.
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, Langley Street, Newcastle.
N.	1923.	Davison, R., 79, Second Avenue, Heaton, Newcastle-on-Tyne.
N.	1924.	Dickinson, B., 9, South Frederick Street, South Shields.
N.	1924.	Dodd, C., 6, Relton Terrace, Monkseaton.
B.	1925.	Dubberley, W., 27, Lewisham Road, Smethwick, Birmingham.
N.	1926.	Dunbar, J., 16, Burn Terrace, Willington Quay-on-Tyne.
N.	1918.	Eglen, T., 22, Morley Street, Heaton, Newcastle-on-Tyne.
L.	1922.	Ellis, J. P., 20, Lambourne Road, Clapham, S.W.4.
B.	1925.	Evans, E. H., 100, Brunswick Road, Handsworth, Birmingham.
Sc.	1927.	Ewen, G., 29, Oakbank Terrace Glasgow.

B'nch.	Year of Election.	ASSOCIATES.
N.	1917.	Ferguson, J., 62, South Palmerston Street, South Shields.
S.	1927.	Firth, L. G., 41, Slayleigh Lane, Fulwood, Sheffield.
S.	1922.	Firth. Tom L.. 191, Fox Street, Sheffield.
N.	1925.	Fleck, J., 75, Lamb Street, Walker-on-Tyne.
N.	1913.	Ford, A., 43, Moore Street, Gateshead.
S.	1926.	Fretwell, J., 153, Sheffield Road, Stonegravels, Chesterfield.
B.	1924.	Frost, C., 55, Waverley Road, Small Heath, Birmingham.
Sc.	1924.	Graham, T., 25, William Street, Dumbarton.
Sc.	1928.	Graham, W., 94, Waverly Drive, Wishaw.
S.	1926.	Gray, H., 337, Sheffield Road, Whittington Moor, Chesterfield.
E.M.	1928.	Greatorex, H., 149, Brook Street, Derby.
L.	1924.	Greaves, J. H., 38, Solway Road, Wood Green, N.22.
N.	1925.	Green, S., 67, Cottenham Street, Newcastle-on-Tyne.
B.	1925.	Greenway, J. F., 43, Douglas Road, Handsworth, Birmingham.
N.	1925.	Grigor, R., 38, Grey Street, Wallsend-on-Tyne.
B.	1925.	Hadley, E. T., 207, Horsley Heath, Tipton, Staffs.
B.	1909.	Hamilton, G., 13, Anderson Road, Tipton.
W. & M.	1925.	Harding, W. L., 14, Welford Street, Barry.
N.	1923.	Harle, J. E., 162, South Palmerston Street, South Shields.
M.	1926.	Harvey, E. J., 4, Rydal Road, Stockton-on-Tees.

B'nch.	Year of Election.	ASSOCIATES.
Sc.	1927.	Harvie, R., 21, Campbell Street, Maryhill, Glasgow.
S.	1926.	Hatton, A., 15, Littlemoor Crescent, Newbold, Chesterfield.
S.	1921.	Heeley, John Jas., 36, Gertrude Street, Owlerton, Sheffield.
Sc.	1924.	Higgins, N., 7, Portland Rows, Hurlford, Ayrshire.
Sc.	1920.	Hill, T., 146, Kippen Street, Airdrie.
Lncs.	1925.	Hindley, W., 13, Charles Street, Farnworth, near Bolton.
B.	1926.	Hird, J., 165, Showell Green Lane, Sparkhill, Birmingham.
N.	1925.	Hodgkinson, H. D., 5, Leopold Street, Jarrow-on-Tyne.
E.M.	1917.	Holmes, A,, 87, Albert Promenade, Loughborough.
Lncs.	1926.	Holt, Samuel (Junior), 83, Ridgway Street, Bradford Road, Manchester.
Lncs.	1923.	Hopkins, W., 70, Tootal Drive, Weaste, Manchester.
N.	1928.	Horse, R., 1, Jersey Street, West Hartlepool.
N.	1927.	Hunter, R. W., 104, Shrewsbury Crescent, Humbledon Hill, Sunderland.
M.	1926.	Jameson, J. R., 9, Olive Street, Hartlepool.
Sc.	1927.	Jardine, W., 98, Bank Street, Alexandria, Dumbartonshire.
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.
L.	1924.	Jones, T. H., 40, Glengall Road, Cubitt Town, E.14.

B'nch.	Year of Election.	ASSOCIATES.
N.	1922.	Kelly, F. J., 1545, Walker Road, Newcastle-on-Tyne.
Sc.	1928.	Laird, T., 3a, Buccleuch Terrace, Cambusnethian, Wishaw.
Sc.	1924.	Laughland, H., 15, Burnside Street, Kilmarnock.
N.	1925.	Laven, J., 140, Richardson Street, Wallsend-on-Tyne.
S.	1928.	Law, H. O., 43, Carlisle Road, Grimesthorpe, Sheffield.
N.	1920.	Lindsay, A. W., 36, Bryon Avenue, Willington Quay.
N.	1924.	Lowes, W., 1, Baden Street, Chester-le-Street.
Lncs.	1914.	Lucas, G. W., 36, Langford Street, Leek, Staffs.
Sc.	1926.	McAllister, W. C., 144, Drumoyne Road, South Govan, Glasgow.
N.	1925.	McDougal, T. D., 3, Westmoreland Street, Wallsend-on-Tyne.
Sc.	1924.	McGowan, V. M., 1, Albert Street, Paisley.
Sc.	1926.	McGurnaghan, M., 206, Gallowgate, Glasgow.
Sc.	1913.	McLeish, J., 7, Buchanan Terrace, Paisley.
Sc.	1926.	McPhee, J. McA., 70, High Street, Paisley.
N.	1926.	McQuillan, J., 1, Lodge Terrace, Wallsend-on-Tyne.
Sc.	1925.	Magee, J., 83, Lounsdale Drive, Paisley.
Sc.	1927.	Main, J. W., 175, Holm Street, Glasgow, C.2.
Sc.	1924.	Martin, A. L., 31, George Street, City, Glasgow.
M.	1926.	Martin, J. H., 29, Marton Grove Road, Middlesbrough.
L.	1925.	Mata, C. H., 51, Grosvenor Road, Canonbury, N.5.

B'nch.	Year of Election.	ASSOCIATES.
Lncs.	1923.	Meadowcroft, H., 10, Hambledon, View, Habergham, Burnley.
B.	1925.	Meredith, C., 4, Thomas Street, Smethwick, Birmingham.
N.	1922.	Miller, J. G., 79, Clarence Street, Newcastle-on-Tyne.
N.	1928.	Mitchinson, T. S., Bank Top House, Walbottle, Newburn-on-Tyne.
N.	1925.	Morland, R. H., 106, Clifford Street, Byker, Newcastle-on-Tyne.
Lncs.	1927.	Naidu, D. D., 219, Residency Bazaaro, Hyderabad, Deccan, India.
N.	1925.	Nesbit, G. L., 4, Cobden 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.	1925.	Nuttall, G., 88, High Street East, Wallsend-on-Tyne.
N.	1925.	Osborne, G. F., 39, Franklin Street, Sunderland.
N.	1923.	Peacock, J. E., 40, Bolam Street, Newcastle-on-Tyne.
N.	1923.	Peacock, S., 12, John Street, South Shields.
N.	1922.	Picken, A. D., 87, Cuthbert Street, Hebburn-on-Tyne.
L.	1922.	Pittuck, M. D. (Miss), c/o H. J. Young, 3, Central Buildings, Westminster. S.W.1.
Lncs.	1926.	Pollard, Wm., 7, Powell Street, Burnley, Lancs.
W.R. of Y.	1926.	Poole, F. T. L., 85, Starr Hill, Wyke, Bradford.
N.	1926.	Pratt, S., 29, Randolph Street, Jarrow-on-Tyne.
E.M.	1916.	Radford, H. P., 151, Barclay Street, Fosse Road South, Leicester.

B'nch.	Year of Election.	ASSOCIATES.
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.
W. & M.	1925.	Rees, L. W., 158, Holton Road, Barry Dock.
Sc.	1927.	Reid, A., 12, Anderson Street, Burnbank, Hamilton.
Sc.	1923.	Reid, J. N. (junr.), Elmbank, Larbert.
Sc.	1923.	Riddell, J., 113, Coventry Drive, Glasgow.
M.	1926.	Robinson, J., 172, Abingdon Road, Middlesbrough.
N.	1924.	Robson, J., 15, Hawthorne Grove, Wallsend-on-Tyne.
N.	1925.	Robson, J., 20, Frederick Street, Gateshead-on-Tyne.
N.	1923.	Rollin, C. N., Stanhope House, Westhoe Village, South Shields.
Sc.	1927.	Rose, D., 12, Victoria Street, Alexandria, Dumbartonshire.
Sc.	1927.	Ross, W. (Junior), 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, Queens Road, North Ormesby, Middlesbrough.
N.	1925.	Scott, R. J., 5, Dene Auenue, High Farm Estate, Wallsend-on-Tyne.
L	1926.	Sherman, W. T., "Woodlands" Avery Hill Road, New Eltham.
S.	1925.	Smedley, C. C., 41, Abbey Lane, Woodseats, Sheffield.
B.	1925.	Smith, W. H., 21, Horsely Road, Tipton, Staffs.
N.	1925.	Soulsby, W. A., 14, Armstrong Street, Gosforth.
N.	1912.	Spence, W. D., 124, Heaton Park Road, Newcastle-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
N.	1922.	Spencer, F. C., "Donsfell," New Horsley, Ovingham-on-Tyne.
B.	1910.	Spiers, F., 32, Kenilworth Road, Handsworth, Birmingham.
N.	1925.	Spowart, D., 9, St. Nicholas Road, Hexham-on-Tyne.
N.	1926.	Stafford, J., 143, Harriet Street, Byker, Newcastle-on-Tyne.
Lncs.	1927.	Stanworth, S., The Woodlands, Rimington, Clitheroe.
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.	1910.	Sutton, W. H., 147, Anthony Road, Saltley, Birmingham.
Sc.	1913.	Sword, J., 13, Paisley Road, Barrhead.
N.	1926.	Symon, J. A., 10, Mayfair Road, West Jesmond, Newcastle-on-Tyne
Lncs.	1926.	Tate, W. G., Brook Royd, Todmorden Road, Burnley.
N.	1926.	Thompson, J. T., 42, Monk Street, Gateshead-on-Tyne.
Sc.	1924.	Turnbull, J., Primrose Cottage, Bonnybridge.
N.	1921.	Turnbull, R. G., S.S. "Cairnross," Edinburgh Docks, Leith.
N.	1922.	Van-der-Ben, C. R., 169, Dunsmuir Grove, Gateshead-on-Tyne.
M.	1926.	Vause, W., 33, Hannah Street, Thornaby-on-Tees.
L.	1927.	Ward, E., 56, Park Street, Stoke Newington, London, N.16.
N.	1928.	Watts, N., 8, Hawthorn Street, Millfield, Sunderland.
L.	1911.	Wells, G. E., 89, Larcom Street, Walworth, S.E.
W.R. of Y.	1926.	Wilks, W., 40, Balfour Street, East Bowling, Bradford.

B'nch.	Year of Election.	ASSOCIATES.
Sc.	1927.	Wilson, J. R., 4, Killermont Street, Glasgow.
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.
S.	1927.	Wordsworth, F. S., 11, Coverdale Road, Sheffield.
S.	1920.	Wordsworth, W. A., 11, Coverdale Road, Millhouses, Sheffield.
Sc.	1927.	Wright, J., 198, James Road, Townhead, Glasgow.
Sc.	1928.	Wright, S., "Fernlea," Portland Park, Hamilton.
Sc.	1926.	Young, H., 4, Glasgow Road, Paisley.

Members changing their addresses are requested to notify the same immediately to the General Secretary or to the Branch Secretary of the District.

Members should inform the Branch or General Secretary of any incorrect entries in the Membership List.

NAME INDEX.

SUBJECT INDEX.

TO BE FILLED IN BY GENERAL SECRETARY:

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

INSTITUTE OF BRITISH FOUNDRYMEN.

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

Registered Office - - - - - - - - - - 49, WELLINGTON STREET, STRAND, LONDON, W.C.2.

General Secretary:
T. MAKEMSON.

General Office:
St. JOHN'S STREET CHAMBERS, DEANSGATE, MANCHESTER.

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

* Please cross out the words not required.

Name in full ....

Designation or Occupation ....

Qualification ....

Business Address ....

Private Address ....

being desirous of admission into the Institute of British Foundrymen, we, the undersigned, Proposer and Seconder, propose and recommend him as a proper person to belong to the Institute. To the best of our knowledge and belief he is not of enemy alien birth or interests.

Witness our hands, this ....day of ....192......

Two Members' or Associate Members' Signatures are required.

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

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

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

Signature of Candidate ....

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

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

Branch President ....

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

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

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

TO BE FILLED IN BY GENERAL SECRETARY:

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

INSTITUTE OF BRITISH FOUNDRYMEN.

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General Secretary:
T. MAKEMSON.

General Office:
St. JOHN'S STREET CHAMBERS, DEANSGATE, MANCHESTER.

PROPOSAL AS A SUBSCRIBING FIRM.

Name in full ....

Designation or Occupation ....

Qualification ....

Business Address ....

being desirous of admission into the Institute of British Foundrymen, we, the undersigned, Proposer and Seconder, propose and recommend them as proper persons to belong to the Institute. To the best of our knowledge and belief they are not of enemy alien birth or interests.

Witness our hands, this ....day of ....192......

Two Members' or Associate Members' Signatures are required.

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

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

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

Signature of Firm ....

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

Branch President ....

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

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

Any firm engaged in the Foundry or Allied Industries shall be eligible for enrolment as a Subscribing Firm at an annual Fee of £5 5s., and in respect of such enrolment shall be entitled to receive the printed literature and volume of "Proceedings" of the Institute, and to representation at any of the meetings of the Institute, but such representation shall not confer any voting power on the representative or Subscribing Firm.