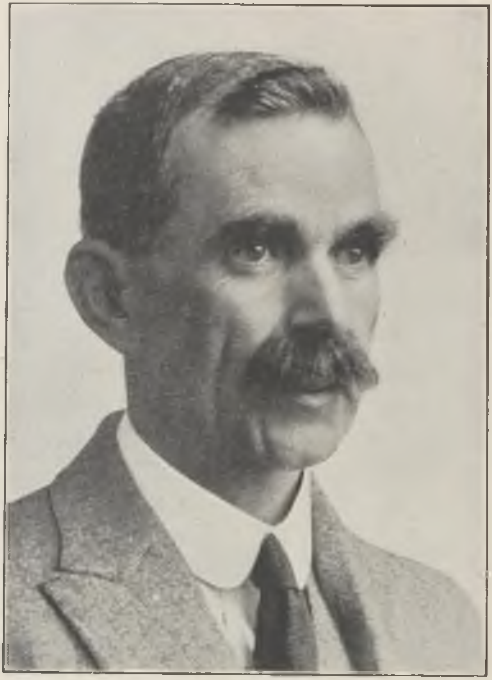

Mr. John Cameron (President).

Mr. John Cameron is managing director of Messrs. Cameron & Roberton, Limited, of Kirkintilloch, and a director of Eastern Light Castings, Limited, of Bengal, India. He is also a member of Council of the British Cast Iron Research Association.

PROCEEDINGS
OF THE . .
INSTITUTE OF
BRITISH FOUNDRYMEN.

1924-1925.

Containing the Report of the Twenty-second Annual Conference, held at Glasgow, June 9th, 10th, 11th and 12th, 1925; and also Papers and Discussions presented at Branch Meetings held during the Session 1924-1925.

Institute of British Foundrymen.
Head Office:
38, Victoria Street, London, S.W.1.

LONDON: Printed by
"THE FOUNDRY TRADE JOURNAL,"
49, Wellington Street, Strand, London, W.C.2.

THE INSTITUTE OF BRITISH FOUNDRYMEN

OFFICERS 1925—1926.

President :

J. Cameron, Cameron & Robertson, Ltd., Kirkintilloch, N.B.

Vice-Presidents :

V. C. Faulkner, 49, Wellington Street, Strand, London, W.C.2.
J. T. Goodwin, Red House, Old Whittington, Chesterfield.

Past-Presidents :

R. Buchanan. (Deceased 1924.) 1904-1905.
H. Pilkington. (Deceased.) 1906-1907.
F. J. Cook, 31, Poplar Avenue, Edgbaston, Birmingham. 1908-1909.
P. Longmuir, D.Met., 2, Queen's Road, Sheffield. 1910-1911.
C. Jones. (Deceased 1923.) 1912.
S. A. Gimson, 20, Glebe Street, Leicester. 1913-1914.
W. Mayer. (Deceased 1923.) 1915.
J. Ellis, 20, Lambourn Road, Clapham, London, S.W.4. 1916-1917.
T. H. Firth. (Deceased 1925.) 1918.
John Little, M.I.Mech.E., 20, St. Ann's Square, Manchester. 1919.
Matt Riddell, Etna Iron Works, Falkirk, N.B. 1920.
Oliver Stubbs, M.I.Mech.E., Openshaw, Manchester. 1921.
H. L. Reason, M.I.Mech.E., M.I.M., 29, Hallewell Road, Edgbaston, Birmingham. 1922.
Oliver Stubbs, M.I.Mech.E., Openshaw, Manchester. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.

General Council:

*A. R. Bartlett, 1, Lower Park Road, Belvedere, London, S.E.
†A. Campion, 3, Strathview Gardens, Bearsden, by Glasgow.
†W. F. Cheesewright, Col., D.S.O., 5, Duke Street, Adelphi, W.C.2.
†Geo. Edginton, "Silverdale," St. Margaret's Drive, Chesterfield.
*W. T. Evans, Mount Pleasant, Sunny Hill, Normanton, Derby.
*A. Firth, 50, Clarendon Road, Sheffield.
†J. W. Frier, 5, Northumberland Villas, Wallsend-on-Tyne.
*J. Haigh, "Stoneclough," Carr Lane, Wakefield.
*A. Harley, Ashlea, Stoke Park, Coventry.
†J. Hogg, 324, Manchester Road, Burnley.
†J. R. Hyde, 27, Hastings Road, Millhouses, Sheffield.

†J. B. Johnson, 27, Ball Fields, Tipton, Staffs.
†J. F. Kayser, 30, Oakhill Road, Nether Edge, Sheffield.
†A. L. Key, 271, Reddish Road, S. Reddish, Stockport.
*Wesley Lambert, J. Stone & Co., Ltd., Deptford, S.E.14.
†J. Lucas, "Sherwood," Forest Road, Loughborough.
†R. A. Miles, 46, Dean Lane, Newton Heath, Manchester.
*H. Pemberton, 15, Wolfa Street, Derby.
†J. M. Primrose, Mansion House Road, Camelon, Falkirk.
†J. S. Glen Primrose, Richard Johnson & Nephew, Ltd., Metallurgical Laboratory, Bradford Iron Works, Manchester.
*G. E. Roberts, Rosedale, Earlsdon Avenue, Coventry.
*J. Shaw, 39, Montgomery Road, Sheffield.
†R. J. Shaw, 41, Dorset Road, S. Ealing, London, W.5.
†H. Sherburn, Ellesmere, Padgate, Warrington.
†J. N. Simm, 61, Marine Drive, Monkseaton.
†H. O. Slater, Sunny Hill, Lessners Park, Belvedere, London, S.E.
†T. A. Spiers, "Belah," Marston Road, Leicester.
†F. G. Starr, 128, Selwyn Road, Rotten Park, Birmingham.
†W. G. Thornton, 1,081, Grangefield Avenue, Thornbury, Bradford, Yorks.
†T. Vickers, 14, New Street, Birmingham.
*H. Winterton, "Moorlands," Milngavie, Dumbartonshire.
†H. J. Young, 3, Central Buildings, London, S.W.1.

*Elected at Annual Conference. †Branch Delegates.

BRANCH PRESIDENTS AND SECRETARIES.

(Ex-officio on General Council.)

BIRMINGHAM.

D. H. Wood, 7, Augusta Road, Moseley, Birmingham.
F. K. Neath, 16, Sarehole Road, Hall Green, Birmingham.

EAST MIDLANDS.

E. Stevenson, "Charnwood," Albert Avenue, Charlton Hill, Nottingham.
H. Bunting, 17, Marcus Street, Derby.

LANCASHIRE.

J. Masters, The Hollies, Vane Road, Longenden Road, Shrewsbury.
T. Makemson, 21, Beresford Road, Stretford, Manchester.

BURNLEY SECTION OF LANCASHIRE.

G. Barnes, 16, Tremallan Street, Accrington.
J. Pell, 17, Mersey Street, Rose Grove, Burnley.

LONDON.

G. C. Pierce, 11, Athelney Street, Bellingham, Kent.
H. G. Sommerfield, Charterhouse Chambers, Charterhouse Square, E.C.1.

NEWCASTLE-ON-TYNE.

M. B. Herbst, 23, Saltwell View, Gateshead-on-Tyne.
C. Gresty, 101, Queen's Road, Monkseaton, Northumberland.

SCOTTISH.

Jas. Affleck, 21, Overdale Avenue, Langside, Glasgow.
J. Bell, 60, St. Enoch Square, Glasgow.

SCOTTISH—FALKIRK SECTION.

J. M. Primrose, Mansion House Road, Falkirk, N.B.
A. M. Cleverley, 45, Kennard Street, Falkirk.

SCOTTISH—PAISLEY SECTION.

Jas. Galt, Sneddon Foundry, Paisley.
Jas. Y. Anderson, Fullerton, Hodgart & Barclay, Ltd., Vulcan Works, Paisley.

SHEFFIELD.

L. Jackson, Engr.-Lt.-Comm., 2, Richmond Avenue, Park Lane, Sheffield.
R. Village, Bircholme, Dronfield, nr. Sheffield.

WALES AND MONMOUTH.

P. L. Gould, Vulcan Foundry, East Moors, Cardiff.
J. J. McClelland, "Druslyn," Bishops Road, Whitchurch, Glam.

WEST RIDING OF YORKS.

H. Summersgill, Stanacre Foundry, Wapping Road, Bradford.
S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford.

MIDDLESBROUGH.

F. P. Wilson, Parkhurst, Middlesbrough.
N. D. Ridsdale, 3, Wilson Street, Middlesbrough.

J. G. Pearce, British Cast Iron Research Association, 75, New Street, Birmingham.

Hon. Treasurer:

W. Finch, 52, Denmark Road, Gloucester.

General Secretary:

William G. Hollinworth, 38, Victoria Street, London, S.W.1.

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The Institute of British Foundrymen

ANNUAL CONFERENCE HELD AT GLASGOW.

June 9, 10, 11 and 12, 1925.

The twenty-second annual convention of the Institute was held in Glasgow from Tuesday, June 9, to Friday, June 12. The business of the Convention opened on June 10 at the Institute of Engineers and Shipbuilders in Scotland, Elmbank Crescent, Mr. R. O. Patterson, the retiring president, presided, and there were a large number of members and visitors present.

Civic Welcome.

The **President**, in introducing the proceedings, said he was sorry to have to announce that Lord Provost Montgomery, the civic head of the city, had been called away to London in connection with municipal business. In his absence, however, he had pleasure in calling upon Bailie Angus McDougall to extend greetings to the members attending the Convention.

Bailie McDougall, who was cordially received, explained at the outset that the Lord Provost of the city had been summoned to London in connection with the Glasgow Boundaries Bill. As business men, they would, in the circumstances, appreciate the fact that the subordinate ought to do his best in the absence of the chief. That, therefore, was his duty that morning. It was his privilege to extend to them a hearty welcome to the city of Glasgow. At the moment it was not his intention to deliver anything in the nature of a speech, because later in the day he would, he hoped, be speaking to them at the reception in the City Chambers.

Lord Invernairn, on behalf of the Glasgow Reception Committee, extended a formal welcome to the delegates. He explained that the Glasgow

Committee had endeavoured to arrange for those attending the Convention an interesting as well as an instructive programme. The social aspect had not been overlooked, and, indeed, it had been the earnest desire of the Reception Committee to return, in some small measure at least, the hospitality which the Scottish members of the Institute had at all times received when attending similar conferences in England. From the information placed at his disposal he understood that the Institute had met in Glasgow on three previous occasions, namely, 1905, 1911 and 1920. Since the last annual conference was held in Glasgow, the Institute had been incorporated by Royal Charter. While he did not propose to trespass upon their time and patience, he should like to say that meetings of this kind, where an exchange of views was encouraged, had a value both important and far-reaching. In their own industry, as well as others, it seemed to him to be one of the essential roads to success. Members of the Institute—at least so far as Scotland was concerned—were representative of Scottish foundry practice and engineering, and he noticed that visits were to be paid to the works of the Carron Company, the Falkirk Company and the establishments of Messrs. Babcock & Wilcox and Messrs. Weir, of Cathcart. These were firms who were known throughout the world. Proceeding, Lord Invernairn went on to say that the success of the initial annual congresses had been such as to lead to a demand for extended opportunities for the further acquisition of practical and scientific knowledge. It had resulted in the formation of local sections not only in Glasgow, Paisley and Falkirk, but in all large centres of the iron industry in England. At these places branch meetings were regularly held. It was very pleasing to reflect that the Institute of British Foundrymen was taking a forward part in bringing about an international spirit among foundrymen in Great Britain, America, France, Italy, Spain, etc. They of the Reception Committee and the Institute in Glasgow were glad to have the delegates with them, and their one wish was that the visit should prove not only beneficial, but interesting.

Colonel J. A. Roxburgh, on behalf of the Glasgow Chamber of Commerce, joined in the greetings of the members of the Convention. Glasgow, it was well known, seemed to be a magnet that drew conferences of every conceivable kind to its midst, and the Chamber of Commerce in Glasgow, whom he represented, was always delighted to welcome to the city any body of men or women who had anything to do with trades and industries or who were working in any way whatever for the good of the country. He need not remind the members of the Convention that the particular industry in which they were interested had been and still was in a very depressed condition. It did seem to him, however, that the very fact of the industry being so depressed was a justification for the present Convention. It ought to encourage them to pursue the line they were taking in order to get their processes and their organisation more perfect than they had ever been before. Some of them he was afraid when they got into low spirits were apt to take rather a pessimistic view of the future as regards the industries of the country, but he was sure they would agree with him in saying that they did not feel the last days of Great Britain had come as yet. Personally, he was confident they would pull through this trouble as they had got through other troubles. In the meantime, however, it behoved them all to work together, both from the side of the employers and that of the employees. On behalf, therefore, of the Glasgow Chamber of Commerce and the manufacturers of the neighbourhood, he welcomed the delegates to the city. He hoped the meetings would be both pleasant and profitable and that they would go away with a good impression of Glasgow.

Professor A. L. Mellanby, D.Sc., Royal Technical College, Glasgow, humorously remarked that the members had his sympathy in being subject to the disciplinary process of listening to so many speeches. It seemed to be inevitable that before the members could enjoy the delights of Glasgow and district they should be subjected to the particular ordeal known as speech-making. Already a welcome had been extended to them from the business men of Glasgow, but he (Professor Mellanby) was there that day representing the scientific, technical and educational side of the city. That side of Glasgow would prove equally demonstrative, and it would extend as hearty a reception to the members of the Convention as had already come from the more practical business men. If, however, they had the feeling that by coming to the city they were going to derive some additional excitement, he was afraid they would be rather disappointed. On behalf of the body he represented he welcomed the delegates, and he trusted they would all have a happy and prosperous visit.

The Oliver Stubbs Medal.

The PRESIDENT remarked that it was now his pleasant duty to ask Lord Invernairn to present the Oliver Stubbs medal to Mr. A. Campion. The Council on the previous evening had selected Mr. Campion for that distinction.

LORD INVERNAIRN said he had been asked by the Institute to make this presentation, and it was an honour which he personally highly appreciated. It was now well known in the industry that the Oliver Stubbs medal was presented for meritorious service rendered on behalf of the Institute of British Foundrymen, and it was felt that the present recipient (Mr. Campion) was well worthy the distinction.

MR. CAMPION said he was deeply appreciative of the high honour the Institute had conferred upon him. He was now beginning to wonder if the honour was at all deserved. Anything he had been able to do either for the Institute or the foundry trade in general had been work that he really loved. He had always been fascinated by foundry trade problems, and he hoped he would continue to be so for many years to come. Indeed, if he could assist the Institute in any way or could benefit the industry in any particular direction he would be pleased to do so.

THE PRESIDENT at this stage of the proceedings remarked that they were deeply grateful to all the civic and other dignitaries who had joined in the welcome that morning. They had now, however, completed the first part of the programme.

The Year's Bereavements.

The minutes of the last annual meeting having been read by the acting secretary, the President mentioned the names of those who had died during the past twelve months. As a tribute to the memory of those who had gone the delegates stood in their places.

ANNUAL REPORT AND BALANCE SHEET.

For the Session 1924–1925.

The General Council have pleasure in presenting to the members their report of the progress and work of the Institute during the past Session, 1924-25.

Three General Council meetings have been held during the Session at York, York and Sheffield respectively. Representatives of the Branches from all parts of the country have attended the meetings, and there has been an average attendance of twenty-two.

The respective branches have the following members attached:—

	Members.	Associate Members.	Associates.	Total.
Birmingham	48 (56)	81 (85)	14 (14)	143 (155)
East Midlands	32 (31)	44 (46)	8 (7)	85 (85)
Lancashire	105 (99)	197 (174)	9 (6)	311 (279)
London	75 (80)	68 (64)	12 (11)	155 (155)
Newcastle	80 (84)	86 (100)	76 (67)	242 (251)
Scottish	54 (65)	114 (150)	26 (21)	194 (240)
Sheffield	85 (86)	88 (89)	12 (12)	185 (187)
West Riding of Yorks.	34 (36)	50 (46)	— —	84 (82)
Wales and Monmouth	19 (16)	12 (11)	— —	31 (27)
General	47 (31)	44 (4)	4	95 (25)
	579 (604)	785 (810)	161 (142)	1525 (1556)

The figures in brackets are for the Session, 1923-1924.

The total number of members on the roll of the Institute on April 30, 1925, was 1,525. As the Coventry Branch has been disbanded for the present, members belonging to that Branch have been transferred to the general list. The Council regret to have to report that eight deaths have taken place during the year.

The members would learn with regret of the death in August last of Mr. Buchanan, who was the first President of this Institute in 1904 and 1905. Mr. Buchanan was also a trustee, and took a very keen interest in everything appertaining to the welfare of the Institute.

The Institute has also lost a valued member in the death of Mr. E. H. Broughall. It will be remembered that Mr. Broughall was junior Vice-President last year, but had to resign owing to ill-health.

Mr. Oliver Stubbs, a Past-President of the Institute, has been elected an Hon. Life Member in recognition of his valuable services.

Annual Conference, 1925.

This will be held on June 10, 11 and 12 in the Lecture Hall of the Institution of Engineers and Shipbuilders in Scotland, Elmbank Crescent, Glasgow, by the kind permission of the authorities.

"Oliver Stubbs" Gold Medal.

The third medal was awarded to Mr. John Shaw, of the Sheffield Branch, for his work in connection with the Test Bars Committee and meritorious services rendered to the Institute over a period of many years.

General Council.

The members who retire in accordance with the rules are:—Messrs. W. T. Evans, A. Firth, J. Haigh, E. Carey Hill and J. G. Robinson. Messrs. Evans, Firth, Haigh and Robinson offer themselves for re-election.

Standardisation of Test Bars.

Good progress has been made during the year, and a working arrangement has been arrived at between your Committee and the B.C.I.R.A. Three joint meetings have been held and the general outline of the I.B.F. Specification accepted. From further tests it is probable the loads specified on the transverse bars will be lowered to come into line with the usual 28 cwts. now specified on the 2 in. × 1 in. + 36 in. bar. Two full meetings have also been held with the B.E.S.A., Dr. Moore, of the War Office, being elected chairman. All the great public departments and chief technical societies were represented at those meetings. Five other members of the I.B.F. were co-opted to serve on this Committee in their capacity as makers of heavy castings. While good and favourable progress has been made, no general statement can be made, as the proceedings are confidential.

No further progress has been made with the International Bar. The home question must be settled first.

Diplomas.

These have been awarded to the following for Papers read at meetings:—E. M. Currie, Coventry; F. W. Rowe, for Paper read before East Midlands Branch; J. A. Gardner, Scottish; A. L. Key, Lancashire; A. Sutcliffe, Burnley; J. W. Gardom, London; A. Rhydderch, for Paper read before London Branch; J. F. Kayser, Sheffield; J. D. Nicholson, Newcastle; C. Gresty, Newcastle; H. B. Beeny, Coventry; O. Smalley, Newcastle; E. Longden, Birmingham; S. G. Smith, Lancashire; A. R. Bartlett, London.

British Cast Iron Research Association.

The Cast Iron Research Association during the past year has made considerable progress. After three years' office as President, Lord Weir, in accordance with the Articles of Association, resigned, and was succeeded by Sir John Dewrance, K.B.E. A distinguished group of gentlemen in the ironfounding and engineering industries accepted the office of Vice-President.

The number of members has increased, and for the first time during this, the fourth year of the Association's existence, the minimum income stipulated by the Department of Scientific and Industrial Research has been reached. It has, in fact, been exceeded by a good margin, and it is hoped during the next financial year, the final year of the five-year period during which Government support was promised, to increase this margin to cover the whole of the shortage of income during the first three years.

During the year laboratories have been acquired where investigations and chemical, mechanical and microscopical tests are being conducted. In addition, important fundamental investigations are being carried out on a practical scale in foundries, and other researches are in progress at the Universities of Birmingham, Sheffield and Manchester, together with the National Physical Laboratory.

A number of research reports have been issued, and a considerable amount of material is available for early distribution. The Bulletin has been issued regularly each quarter.

The relations between the Association and the Institute have become exceedingly close. The delegate member appointed by the Institute to the Association, Mr. H. Field, attends Council meetings, and the Director of the Association has been invited to join the Council of the Institute. The two bodies have also co-operated with singular success in connection with work on a national specification for grey and malleable irons, now being considered by the British Engineering Standards Association. In this and in many other directions it is felt that the two bodies can work for the benefit of the industry.

Members of the Institute who would like information on the work of the Association are cordially invited to communicate with the Director, and it is hoped that every British manufacturer in the engineering and ironfounding industries will recognise the economic advantages of membership, by which, for a small annual subscription, benefits accruing from a total annual expenditure of over £7,000 can be secured.

American Foundrymen's Association.

The close association between the Institute and the American Foundrymen's Association is to be cemented next year, when an International gathering is to be held in the autumn at Detroit City. An official invitation is being extended to all members to participate. The system of the exchange of Papers has been continued this year.

Association Technique de Fonderie de France.

In the autumn of this year a joint meeting with the Belgian Foundry Association is being held in Liege, and members will be welcomed on that occasion.

R. O. Patterson, *President.*

W. G. Hollinworth, *General Secretary.*

Balance Sheet.

The accounts and balance sheet are presented herewith :—

INCOME AND EXPENDITURE ACCOUNT, for the year ended December 31, 1924.

EXPENDITURE.

				£	s.	d.
Postages				87	13	10
Printing and stationery, including printing of proceedings				496	19	6
Council, finance and annual meeting expenses	36	15	5			
Expenses in connection with Cardiff branch meeting ...	8	4	9	45	0	2
Illuminated address				11	0	0
Branch expenses—						
Lancashire	89	13	2			
Birmingham	82	18	7			
Scottish	83	19	9			
Sheffield	60	18	9			
London	42	17	0			
East Midlands	19	6	6			
Newcastle	101	11	7			
Coventry	20	10	6			
West Riding of Yorkshire	15	14	6			
Wales and Monmouth ...	16	14	0	534	4	4
Audit fee and accountancy				9	9	0
Incidental expenses				23	9	2
Salaries—secretary and clerk				400	0	0
Rent of office				65	0	0
Depreciation of furniture				9	9	8
Diplomas and certificates				53	8	8
				£1,735	14	4
Donation Birmingham Chamber of Commerce	10	10	0			
Donation Faraday Society ...	10	10	0	21	0	0
				1,756	14	4
Excess of income over expenditure ...				277	7	7
				£2,034	1	11

INCOME.

	£	s.	d.
Subscriptions received	1,913	14	9
Sale of proceedings	10	0	6
Interest on War Loan and cash on deposit	30	6	8
Donation—Birmingham Chamber of Commerce	80	0	0
	£2,034	1	11

LIABILITIES.

				£	s.	d.
Subscriptions paid in advance				101	11	6
Sundry creditors				320	5	8
The Oliver Stubbs Medal Fund—balance from last account	205	0	4			
Refund of tax on investment	3	9	0			
Interest to date	7	19	4			
	216	8	8			
Less: Cost of Medal, 1924	9	10	0	206	18	8
Surplus at December 31, 1923	9	10	0			
Add: Excess of income over expenditure for year ended December 31, 1924	277	7	7	999	14	6
				£1,628	10	4

ASSETS.

	£	s.	d.	£	s.	d.
Cash in hands of secretaries—						
Lancashire	2	15	1			
Birmingham	11	15	9			
Scottish	21	13	6			
Sheffield	77	5	0			
London	34	4	9			
East Midlands	28	18	11			
West Riding of Yorkshire	25	16	7			
Coventry	18	2	8			
Wales and Monmouth	7	6	0	227	18	3
General Secretary				5	16	8
Lloyds Bank, Limited—						
General account	269	19	5			
Deposit account	400	0	0	669	19	5

Assets—*continued.*

	£	s.	d.	£	s.	d.
Oliver Stubbs Medal Fund—						
£342 5s. 7d. local loans £3 per cent. stock at cost ...	200	0	0			
Balance in hand Lloyds Lloyds Bank, Ltd. ...	6	18	8	206	18	8
Investment account—						
£100 5 per cent. National War bonds						
£350 5 per cent. War Loan at cost ...				432	10	1
Furniture, fittings and fixtures—						
Per last account	94	16	11			
Less: Depreciation 10 per cent.	9	9	8	85	7	3
				£1,628	10	4

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.

(Signed) J. & A. W. Sully & Co.,
Chartered Accountants, Auditors.

Diploma Winners.

The President remarked that doubtless members would be interested to learn that the following gentlemen had been awarded diplomas by the Council:—Messrs. D. Wilkinson, Birmingham: J. W. Frier, Newcastle; Jowett, Lancashire; and F. C. Edwards, Birmingham.

Presentation to Mr. O. Stubbs.

The President said he had now to turn to a pleasant task, namely, that of passing on to Mr. Oliver Stubbs an illuminated address in album form as a small recognition and as a reminder of the many signal services he had rendered to the Institute and to the foundry trade in general.

Mr. Oliver Stubbs, who received an enthusiastic ovation in rising to reply, said he was deeply sensible of the honour that had been done him. Already he had received from a previous President an illuminated address in recognition of the little he had been able to do on behalf of the Institute and the foundry trade. The address in his possession was a very large one, and when the suggestion was thrown out to him that he should accept another address, he had hinted that it might take book form, so that it could be handed round to his friends. Although he had gone out of office, his interests were closely bound up with those of the Institute. Personally, he felt that was the proper spirit to promote. It was only right that those who had got the experience should continue to give the younger members the benefit of that experience. Although, as he had already remarked, he had retired from active duty as an office-bearer, he still did his very best to attend all the meetings. He noticed that all the past presidents of the Institute were not with them that morning. To his mind that was rather unfortunate, because he did think that some of the gentlemen who were absent might have got to the annual gathering. At the meeting of the Council on the previous evening something had been said about the formation of junior branches. Personally, he was a firm believer in this, that the success of the Institute entirely depended on the manner in which they looked after the interests of the younger men. He was a believer in the idea of getting hold of the young. If they treated them in the proper way and with the right measure of tact they would come out right at the finish. He was delighted to notice that two of the junior members of the Lancashire branch were with them on this occasion, and he hoped the Institute would develop along the lines of giving every possible measure of encouragement to the young men connected with the industry.

Induction of New President.

The President said that the next item on the programme was, to him at all events, a very happy one. He could assure them that the Presidentship of an Institute such as theirs was no easy matter. So far as he was concerned, however, he had regarded it as a labour of love. Certainly he had rather enjoyed the work. At the same time, it was arduous, and to some extent he had pleasure in handing the duties over to his successor. He proposed, therefore, that the new President of the Institute for the ensuing year should be Mr. J. Cameron, of Kirkintilloch, the senior vice-president.

Mr. F. J. Cook (past-president), Birmingham, said it afforded him pleasure to second the proposition made by their good friend, Mr. Patterson. With all due respect and reverence for those who had gone before, he was bound to say that he felt Mr. Cameron, of Kirkintilloch, would make an ideal President. He submitted his name with the greatest confidence.

The proposition was put to the meeting and carried with acclamation. Mr. Cameron was duly invested with the chain of office by Mr. Patterson.

Mr. J. Cameron, in acknowledging the honour, humorously remarked that it was only last night he began to realise the job he had taken on. Mr. Patterson and the other Presidents of the past had not taken their duties and responsibilities at all lightly. There was no doubt of this, however, that within the last four or five years the Institute had been getting a little more ambitious. As a matter of fact, it had been asking a great deal more from its President than was the case in the earlier days. They were not content now with merely a simple outing and a few papers. The social element as well as the practical and scientific aspects of the Convention had been fully developed and explored. He was conscious of his own limitations, but he yielded to none of those who had occupied the presidential chair when he spoke of the admiration he had for the Institute and its work. With the help he would get from the senior vice-president and the junior vice-president, as well as the co-operation that would come from an admirable Council, he would do his best to maintain the high traditions of the past.

Election of other Officers.

The President remarked that he had now a very pleasing duty to perform, and that was to submit the name of Mr. V. C. Faulkner for the post of senior vice-president. His enthusiasm for the industry was well known, and he had literary powers above most of his colleagues in the membership. It did seem to him that Mr. Faulkner would make an excellent President when his time came along for holding that office.

Mr. Oliver Stubbs seconded the nomination of Mr. Faulkner, senior vice-president. Those who had come into contact with the latter gentleman knew he would make a thoroughly good officer because he had the best interests of the industry and the Institute at heart.

The proposition was put to the meeting and carried unanimously.

Mr. Faulkner, in the course of a brief acknowledgment, said he had to thank the members most sincerely for having elected him as senior vice-president. The impression had rather been borne in upon him that morning that the post was no sinecure. Next year the work might be of a more extended nature because London was rather a difficult district in which to organise a conference. Not only so, but they would have next year the International Congress in Detroit City. Personally, he hoped that as many members as possible would accompany him to America in October of that year. An International Committee was being formed, and his colleague (Mr. Delport) was leaving for the United States in the near future so as to bring back the necessary data and information. They were desirous of ensuring that not only Britain but Europe might be adequately represented in this conference.

Mr. Patterson proposed the election of Mr. J. T. Goodwin, of Sheepbridge, as junior vice-president, remarking that Mr. Goodwin was a very old and valued member of the Institute. He had taken a considerable interest in the formation and conduct of the British Cast Iron Research Association. He was confident that when the time came Mr. Goodwin would make an ideal president.

Mr. V. C. Faulkner, who seconded, said that Mr. Goodwin joined the Institute as far back as 1905. He had had a message from Mr. Goodwin regretting that a sudden call to town had prevented him from taking part in this conference. The Institute could congratulate themselves that Mr. Goodwin had allowed his name to go forward. The proposition was carried unanimously.

Mr. H. J. Young proposed and Mr. G. E. Roberts seconded the re-election of Mr. F. W. Finch as honorary treasurer, the former remarking that Mr. Finch was a founder of the Institute and its first secretary.

Mr. W. G. Hollinworth was re-elected general secretary, sympathetic references being made to his health. A telegram was dispatched conveying the greetings of the Conference. As the result of a ballot, Messrs. W. T. Evans, H. Winterton, T. Harley, A. Firth and J. Haigh were elected to the Council.

Messrs. F. J. Cook, T. H. Firth and O. Stubbs, all past-presidents, were re-elected trustees, and Messrs. J. & A. W. Sully & Company the auditors.

Whilst the ballot was being taken **Mr. Cameron** delivered his presidential address, in which he said:—

PRESIDENTIAL ADDRESS.

Gentlemen,—It is five years since our last Conference was held in Glasgow under the presidency of Mr. Riddell, and it is my privilege to welcome you again to Scotland, where I trust we shall have a successful gathering and be favoured with good weather.

It is a matter of regret that the coal and metal industries are extremely depressed, especially locally. Only the foundries making light castings have their output approaching the normal, while some of the larger shops and foundries have not been so quiet for many years. The industry, however, has weathered many a storm in the past, and it is to be hoped that the present conditions will speedily disappear. It is during such periods that progressive firms take advantage of the quiet spell to carry out improvements and re-organisation. There is time to overhaul obsolete plant, to improve practice and conditions of work, and to effect economies. It is indeed in such times that the accumulated experience and knowledge of the Institute become most valuable.

In the course of the year the Institute has been sorely bereaved by the loss of its first president, Mr. Robert Buchanan, and by one who, had his health not broken down, would have been elected your president to-day. In Mr. Broughall I was fortunate enough to make a warm personal friend, and have on more than one occasion enjoyed his hospitality. He was a fine foundryman, equipped better than most of us, and he put the stamp of efficiency on everything he undertook. The places left vacant in our ranks by the loss of those two members will be hard to fill, but their example is bound to be a stimulus to the younger generation of brilliant metallurgists and foundrymen who have in recent years become a promise to our future.

Now that our Institute has completed its twenty-first birthday and passed the adolescent stage, it is an opportunity to go back to the early days and note the steady growth and development and compares its standing and importance to-day with its modest outlook twenty years ago.

When we take into consideration the adverse factors which have operated for some time, the depression, the unemployment and the higher rates of subscription, the progress made cannot be considered otherwise than satisfactory. The actual work accomplished may be gauged to some extent by the reports of Papers published in the Proceedings and also in the technical Press. There are also many unpublished which are given and discussed at different branches. In Scotland the interest among the members and their large attendances at the regular meetings is most gratifying, whilst the discussions are invariably spirited and interesting. Another prominent and satisfactory feature in the work of the Institute is to be found in the keen interest and excellent attendances at the meetings of the Council, in spite of the long distances many of the delegates have to travel with the cost and loss of time involved. Facts such as these are a sure index of interest and prosperity.

The standard of the Papers given is rising in a very noticeable degree, both in respect of quality and variety as well as scope. Frequently an excellent Paper is read by a keen practical worker, to whom, in some cases at least, the necessary literary work is a real labour. Sometimes when hearing or reading a Paper and discussion something new or original is suggested, and one should take advantage of this by giving it a thorough and patient trial in the foundry.

We are still very conservative and reluctant to leave the beaten track. During the last few years, however, we have seen abroad foundrymen who have not been afraid to strike out on new and original lines in respect of cupola work, gating of moulds, testing and pattern making, and more recently in obtaining cast iron in its strongest physical structure and composition, not occasionally by chance, but regularly and uniformly. Let us trust that our Institute will be encouraged to leave "rule of thumb" and take its share in discovering and making known improved methods and procedure. It should be superfluous to-day to repeat the advice often given that a log be accurately kept daily with full details of cupola charges, output and time-table, and that this be followed up by a daily or frequent test of the metal.

The subject of education has been one of the leading themes for years in presidential addresses. There is no necessity to dwell on the subject. Much is being done in the progressive branches to develop this good work quietly and steadily. It is work in which the Institute takes a deep and real interest and in which it takes the leading part. France has taken up this subject very thoroughly in their specially organised and complete arrangements recently instituted. The main point is to interest the student in his craft, to give him at least some elementary knowledge of the constituents of the metals and raw materials, with instruction as to the proper methods of treating them. The student must be convinced that in his own interests such knowledge is essential, should he have the least spark of ambition and aspire to the position of foreman or manager. Within the last few months two foreign moulders were advertised for a position abroad. Eventually two were selected, both young working moulders, one of whom had taken advantage of the excellent Foundry Technical Institute at Falkirk, the other, who was not within range of similar facilities, had taken a correspondence course on the subject. This was one of the main factors in their securing responsible and remunerative jobs with good prospects of promotion. Membership of our Institute is invariably a point in an applicant's favour for such positions, especially when he has taken advantage of any technical and practical training organised by the branches.

A year ago in his presidential address Mr. Patterson referred to the activities of the British Cast Iron Research Association, and expressed the hope which was entertained regarding its future activities after the difficult initial period through which it had passed. At that time, nearly at the end of its third year of existence, it had obtained a number of members, but its research programme was scarcely in being, and it had not succeeded in raising in any single year the minimum income stipulated by the Government. However, the Council entertained such hope of the future that they undertook with the Government that not only should the minimum income be secured during the succeeding two years, but that the difference between the actual and stipulated income for the first three years should be obtained. The fourth year, closing at the end of this month, has indeed brought a very striking change. Not only has the minimum income been secured, but a considerable fraction of the deficit of the first three years has also been raised, and the future has never been brighter than at the present time. The quarterly Bulletin has been issued regularly; there is a continuously increasing use by members of the Library and Information Bureau. A number of members have been advised on difficulties arising in foundry working, and many have expressed considerable satisfaction with the results, and still more members have been personally visited by the director and consultant. A research programme is in full swing, and investigations are proceeding at the Universities of Sheffield, Manchester and Birmingham, and more recently an important piece of work has been commenced at the National Physical Laboratory. In addition, the Association has acquired its own laboratory and has increased its staff. Important work is also being carried out in the works of various members. The co-operation between the Institute and the Association has increased considerably, since the Institute's delegate member now acts as a member of the Council of the Association, and the director of the Association has been invited to join the Council of the Institute. The two bodies are also co-operating very closely through the Joint Test-Bar Committee in connection with the establishment of national specifications for cast and malleable iron, the I.B.F. specification being used as a basis for grey iron.

In regard to the future of the industry, there is a vast field for improvement in method, in organisation and in research. The work of the moulder is most interesting. It calls for skill, for resource, for experience gained from the ever changing varieties of work. Too much of his time is taken up in the preparation and handling of sand in ramming and lifting heavy boxes. Modern method is in the direction of eliminating many of these by mechanical means and confining the moulder's work to the exercise of his skill. Great improvements in plant for this purpose have been made, and their adoption by enterprising firms has effected considerable economies in cost of production and on cost. In this respect a plentiful supply of the cheap power about which so much has been heard will be essential, particularly if the advantage of the electric furnace is to become a practical proposition for more general use. There is a growing demand for castings of quality, particularly in regard to cast iron. Engineers require reduction in weight without loss of strength, and the latter improvements in internal combustion engines call for quality which can only be produced by the combination of scientific knowledge hand-in-hand with efficient foundry equipment and procedure. Members of the Institute have taken a leading place in this respect and there is endless scope for further demand and development.

The centre of all foundry work is the cupola, and it is interesting to know that the British Cast Iron Research Association have tackled this important subject, collecting the various details involved, with the view of reaching some approach to reliable standard practice.

Much work has yet to be done in regard to testing, blending and use of sands, particularly in the way of making use of local material. The employment of oil sand cores has received a good deal of attention and is becoming more general, with good results. In this subject alone there is a whole field of useful research.

The problem of transport, especially in foundries engaged in the lighter classes of work, has not, except in exceptional cases, received the consideration which it requires. In a Paper read in Glasgow in February, it was pointed out that in a light castings foundry melting 30 tons per day, the materials handled amounted to approximately 255 tons, 150 tons by the moulders and 105 tons by unskilled labour. These figures, although approximate, are illuminating and show the desirability of making use of modern methods to effect considerable saving in energy, time and unnecessary labour.

So far, I have noted in a very rough sketch a few of the more striking points in the work and progress of the Institute in the past and for the future. It may be on account of the foundryman's art being so intricate and so elusive and consequently so interesting, but in any case it is a very striking fact that our Institute has the faculty of getting the very best out of its office-bearers. The past presidents in particular have given a splendid record of service. They have built up and maintained the present position and have brought to the Institute both honour and dignity. This efficient and constant service has not been confined to presidents, but has been general throughout the branches where the more unobtrusive, but none the less efficient work done by local presidents, committees and secretaries is the most valuable asset any Institute could possess.

Our object at this anniversary period should be to appreciate the spirit of loyalty, enthusiasm and service of those who have gone before and who have so nobly borne the burden of the early struggles. Inspired by their example, let us not be content with the elimination of failures or defects, but let us strive to improve and still improve working conditions and quality until substantial improvement is attained in the melting of metal and in the quality and finish of the castings. To attain this one has to take some trouble, but help is to be found in the interchanges of experience and visits to works which membership implies, and the reward is the realisation of at least part of our ideal, a keener interest in our own work and increased satisfaction and confidence from our customer. I can honestly affirm from my own personal experience that since becoming a member of this Institute I have gained much, primarily in the many friendships made, which to me are even more valuable than the knowledge and experiences which have been considerable.

Gentlemen, I thank you for the honour conferred upon me, and I shall do what I can to maintain the high standard set up by my predecessors in office.

Votes of Thanks for Address.

Mr. J. Shaw, Sheffield, said that if Mr. Cameron had provided them with a foretaste of what they had to expect in the coming year, then they were assured of good things. The President had touched on the practical side of the work, and he had given them an incentive to strive to do better in the future. They had been greatly helped by what Mr. Cameron had said to them that day. It afforded him pleasure, therefore, to move that the thanks of the members be extended to the President for his interesting inaugural address.

Mr. F. J. Cook, Birmingham, in seconding, remarked that he had a good deal to do with the earlier history of the Association. As the oldest past president of the Institute he could appreciate as much as anyone else the progress that had been made. He well remembered with what fear and trembling the original nine floated the Institute. Two of the original founders were present that day. They had no conception where they might ultimately get to with the Institute. Certainly at first there was a great deal of struggle to push the Association forward, but it was a delight to all of them to note that progress had been made in numbers, while they had also gained in prestige. He felt certain that the good work would continue to be enhanced by the acquisition of the present President.

Retiring President Thanked.

The President, in calling for a vote of thanks to the retiring President for his services during the past year, remarked that Mr. Patterson had visited all the Branches He had done what he could to uphold the honour of the Institute, and they were grateful to him for his efforts. Mr. Patterson had undoubtedly put his heart into the work. They knew he would do that, but he had surpassed himself during the year and had put in an extraordinary amount of activity.

Mr. J. Shaw, Sheffield, in seconding, said visits to Branches in different centres of the kindom entailed a great deal of time and thought. That was altogether apart from the correspondence that the President had to undertake in replying to points raised by individual members.

Mr. R. O. Patterson, in acknowledging the vote of thanks, said he was very grateful for their recognition of his work. He could assure them that his year of office had been most interesting. He had visited every Branch of the Institute except one. The experience he had gained had been of invaluable service to him. He had the feeling that the educative advantages of the Institute were not stressed as they ought to be. The meetings for discussion on points of mutual interest and difficulty had gone a long way towards improving the earning capacity of the members. That, at all events, had been his own personal experience, and he had been a member of the Institute since 1905. Nowadays he felt that he must have known very little about foundry work when he joined the Institute.

The remainder of the session was devoted to the reading and discussion of Papers.

Civic Reception.

In the afternoon, and before proceeding to the City Chambers for a civic reception, Mr. Cameron, on behalf of the Institute, placed on the Cenotaph a laurel wreath, carrying the letters "I.B.F." The members and friends were the guests of the Lord Provost, Magistrates, and Town Council of Glasgow. They were received in the Satinwood Salon by Bailie Angus McDougall, who was accompanied by many of the other magistrates of the city, as well as members and officials of the Corporation.

Bailie McDougall, addressing the company in the Banqueting Hall, reminded them that the Institute was formed 22 years ago. It was inaugurated with the idea of promoting the intellectual welfare of the members. The other side of its origin and inception was to make, if at all possible, for the advancement of the foundry industry. Personally he was glad that he was in a position to congratulate them on the success that had been attained. The demands of modern engineering were now very exacting, and with competition both severe and intensified, it really behoved all foundrymen to take advantage of every opportunity of acquiring knowledge of materials and methods. It did seem to him (Bailie McDougall) that the Institute of British Foundrymen offered a valuable medium for the acquisition of such knowledge.

Mr. John Cameron, the President, appropriately acknowledged the kindness of the Corporation to the members of the Institute. To his mind there was no more suitable place in the whole kingdom than Glasgow for a civic reception to a body such as theirs. Glasgow was strongly tied up with the foundry industry as well as with the huge coal and metal industries. Since that was the acknowledged position, a welcome from its civic rulers was bound always to be very acceptable.

Mr. R. O. Patterson, the retiring President, and Sir Archibald McInnes Shaw joined in the oratory, which, on account of the heat, was brief. In the course of the afternoon the guests were served with light refreshments.

ANNUAL BANQUET.

The annual banquet was held in the Grosvenor Restaurant.

After the usual loyal toasts had been proposed by The President, and duly honoured, Mr. R. O. Patterson, retiring President, proposed the toast of "The City of Glasgow," which, in the absence of the Lord Provost, he coupled with the name of Bailie Angus McDougall.

He explained at the outset that the early history of Glasgow commenced in the sixth century. Owing to the exceptionally favourable position of the city geographically, it developed its boundaries very extensively. So much was that the case that whereas the population of Glasgow in 1801 was some 17,000 odd, it was to-day well over a million. It had the mastery of the sea on one side, while it was surrounded by collieries that provided excellent coal. As Englishmen well knew, Glasgow was capable of producing excellent pig-iron. In the earlier stages of its career Glasgow had tremendous difficulties to contend with in order to gain an access to the sea. Indeed, some years ago the River Clyde was only fit for the navigation of small boats. An immense sum of money had, however, been expended in order to bring the sea to Glasgow, and the outlay in that direction had made for the general development and advancement of the city.

Bailie Angus McDougall, in replying to the toast, said it was often a moot point for discussion whether the Clyde made Glasgow or Glasgow made the Clyde. The greatest problem, however, that faced the city at the moment was the one of extension. No doubt Glasgow was indebted to the Clyde Trust for the foresight and management they had shown. The city had been favoured certainly in having the natural facilities of the Lanarkshire coalfields just at hand to develop their industries, but even making every allowance for all these things, he was going to assert that Scottish foresight had contributed to make Glasgow what it was to-day. As a matter of information to their English guests, he would point out that Glasgow had 53 persons to the acre, compared with 33 in Liverpool and Manchester, 21 in Birmingham and 16 in Leeds and Sheffield. They would be ready to recognise after hearing these statistics that the problem of Glasgow in the matter of density of population was a very pressing one. If the city could only extend its boundaries right out into the country it would be able to prove helpful to the citizens. It would give the latter breathing space. The problem was a pressing one. At the moment it was being discussed in London, and indeed it was that circumstance which accounted for the absence of Lord-Provost Montgomery from the present function. In the course of his address while proposing this toast Mr. R. O. Patterson, the Past-President of the Institute, had made some humorous reflections on the uncomfortable night he had spent in a city hotel alongside which the Glasgow tramcars seemed to run incessantly, and far from noiselessly. On that point he (Bailie McDougall) observed that the tramways manager in Glasgow was concerned not so much about the question of rubber wheels for tramcars as the rubber wheels of the competing omnibus.. Personally, he did not think it was altogether a bad thing that they should have this keen competition on the streets of the city. Indeed, he rather welcomed the buses. It seemed to him that if the buses could give good service then in spite of all the Corporations in the world they would win eventually. If they could not, then the tramways would still continue to hold their own.

The President announced that it had been necessary to make one or two adjustments on the toast list owing to the absence of invited guests. The toast of "The Foundry and Allied Industries" would now be proposed by Mr. H. Thomson Clark, manager of the "Glasgow Herald," and the reply would come from Sir Archibald McInnes Shaw and Bailie A. Ghogan, of the Central Ironmoulders' Association, Falkirk.

Mr. H. Thomson Clark said since the knowledge had come to him that he was to propose this sentiment he had been trying to realise what the foundry trade in Glasgow and the kingdom really represented. He had been trying to analyse the word foundry, and if his assumption was correct as to its meaning then the foundry industry must be one of the key industries. Prince Henry, in a recent speech in Glasgow, had ventured to remark that Clyde labour was synonymous with excellence. Whether that reputation would be conceded by those from the other side of the Border he could not say, but apparently from the look of the audience when the haggis was brought those present appeared to be thoroughly appreciative of Scotland. (Laughter.) Then he understood that it was coming on to a period of 25 years since the Institute was founded. Knowing that circumstance as to their history, he would ask them to cast their minds back over the last quarter of a century. If they did so, then it seemed to him they would be able to appreciate the considerable advance that had been made in the foundry trade.

Sir Archibald McInnes Shaw predicted that Mr. John Cameron would make one of the best presidents the Institute of British Foundrymen ever had. Although trade at the moment might be dull, they were not dispirited. But the dullness was not confined to the foundry and allied industries—it was dull in many other places. British foundrymen were a scientific body of men. They did not know in these difficult times whether they could make money or not, but if they could make good castings that was everything. The making of good castings was the one thing that worried foundrymen. Generally speaking, however, the British foundryman was a man of great resource. He knew the methods and processes of his trade, and he was consistently out for improvement. He was well aware that foreigners were trying to beat

Britishers in many things, but he held tenaciously to the view that they would never beat Great Britain in foundrymen.

Bailie A. G. Logan, whose name was also associated with the sentiment, said he had been a foundryman since he had been able to do anything at all. As a foundryman he took a pride in knowing everything that pertained to the foundry. Not only so but he felt proud of the fact that the workmen at all times seemed to take a pride in the work they were producing. If he knew anything at all of the aims of the Institute of British Foundrymen he should say that one of their chief objects and desires was to encourage training so that the production of output might be the best obtainable from the combined application of science and skill. He agreed with Sir Archibald McInnes Shaw in saying that there was no danger from foreign competition in the foundry and allied trades so long as they had every means of applying research and scientific production, combined with the physical skill of the workers themselves. As Scotsmen, however, and as foundrymen they were proud of the fact that they were capable of turning out men who could go to the ends of the earth and carry on the industry. Falkirk, the centre of the light castings industry, produced more than eminent football players. It was a district that was capable of producing very good castings. There was a feeling in certain circles that the Institute of British Foundrymen was an organisation that belonged to the employers. He had heard that remarked before, and he wanted to warn the members of the danger of such a feeling. It ought to be removed as soon as possible. Something ought to be done to show that the Institute welcomed all into its organisation, and the aim was to improve work and scientific foundry practice. If they could dispel that feeling, then Mr. John Cameron would have rendered, during his year of office, an inestimable service to the Institute of British Foundrymen.

The Toast of the Institute.

Mr. James Weir thereafter proposed the toast of "The Institute of British Foundrymen." He explained that he had been asked by his brother, Lord Weir, to express his sincere regret at not being with them on the occasion of this banquet. Lord Weir had received an urgent call, which he could not see any way of avoiding, and personally he could assure the President that no one regretted the absence of Lord Weir more than he did. (Laughter.) He felt, however, he could adequately represent his brother in expressing appreciation of the Institute of British Foundrymen. The Institute was undoubtedly a vital and living force in the development of the industry with which it was associated. The art of casting metals was still far from being an exact science—in fact it was only emerging from the era of the domination of tradition and craft skill. So much the more important, therefore were the annual Conventions of the Institute in forming a clearing house of information, data, and experience, and in co-ordinating the allied sciences of metallurgy and engineering. Within his own experience he had seen the enormous progress which had been made in the technique of the industry, and in the elucidation of the underlying principles governing it. But they could not have failed to notice that no sooner had they solved the problems of to-day than the progress of engineering and the other industries which they served set still harder problems for to-morrow. The internal combustion engine, for example, with its extreme temperature gradients, had necessitated an entirely new type of practice and research. In fact, he personally thought it was not too much to say that the further progress of the internal combustion engine depended on the foundryman. On the other hand, the progress of aeronautics, with its dominant requirements of lightness, had equally given rise to new problems for the foundry calling for new methods of solution. In both of these fields of development their local branch had taken a worthy part. Indeed, in that connection he felt disposed to say that the Institute of British Foundrymen was to be congratulated on its progressive policy and its broad outlook. That was evidenced by the fact that papers had been exchanged with French, Belgian and American Societies. Thus they were keeping themselves in close touch with the progress which was being made in other countries. In addition to that they must keep in view the activities of the Cast Iron Research Association and the British Engineering

Standards Association. Of course if an enlightened and progressive policy were all that were necessary their industry would, indeed, be in a happy state. Unfortunately, however, good castings were only a means to an end. They shared with the rest of the industries the severe depression of the moment. The present industrial conditions necessarily meant hard conditions and scarcity of labour for the foundrymen. Moreover, their industry was not a protected one. It must bear the brunt of foreign competition. There seemed to him to be only one way of meeting that, and that was to get right down to the job. If they put brains into their methods and organisation, and if their operatives would have sufficient flexibility to meet changing conditions, then he was quite convinced that nobody would beat them back. Great Britain had the best chance of any country. It had a good reputation, and he was glad to think it still had the first call on the world's markets.

Mr. John Cameron, in acknowledging the sentiment, said he had to thank Mr. James Weir for taking his brother's place at this time. Lord Weir had been good enough to send him a nice letter explaining his absence, but his place had been filled to some extent by the presence of Lady Weir. It was with somewhat mixed feelings that he stood before them that evening. Frankly he had never been so proud of any position he held as of the fact that he was presenting the President of the Institute of British Foundrymen. Although he felt proud of the Institute and himself that night his pride was intermixed with the regret they all felt in the loss of Robert Buchanan—the first President, and a magnificent Scotsman. He made himself a friend to everyone in the industry. Although the deceased was the first President of the Institute his interest in its welfare was keen to the very end. The memory of those who had gone before encouraged the others to live up to their example. They would strive to see that under their management the Institute would not lose the honour and dignity secured for it by those who had gone before. Touching upon the fact that the work of the Institute was latterly taking on a more international character, the President alluded to the exchange of papers between France and America. Next year the Institute was to be invited to take part in one of the international congresses which on this occasion would be held in America. Later on this year one on a smaller scale was to be held in Belgium. Reference had already been made to the fact that on the following day the members of the Institute were going to be the guests of many good friends in Falkirk. In Falkirk they would have an opportunity of seeing castings made that went to every corner of the globe—civilised and uncivilised. Proceeding, the President went on to say that the work of the Institute was a splendid one. It had nothing to do with the mundane matters of making money or bargaining with labour. It had on the other hand a great deal to do with interesting the men and even the apprentices. It set out with the ideal of making apprentices and men take a greater pride in their craft and in generally equipping them for the highest position which the art of the foundrymen offered. There were many connected with the ironfounding industry—he was speaking more particularly of employers now—who had not time to come to the Branch meetings and take part in the discussions. He appealed to such employers, however, to give encouragement to the men to go out to the meetings. From his own experience he could testify to the good he had derived from taking part in the work of the Institute, and if employees were afforded facilities and encouragement by the employers so as to identify themselves with the Institute it would lead in the long run to the development and advancement of the industry.

Colonel J. A. Roxburgh, president of the Glasgow Chamber of Commerce, proposed the toast of "Scientific and Technical Institutions," and this he coupled with the name of Professor Mellanby, D.Sc., the president of the Glasgow Section of the Institution of Mechanical Engineers. Colonel Roxburgh said he took the view that the time was past when anyone could carry on a business or an industry in a water-tight compartment. In the old days each man was a law unto himself. He had been struck with the public-spiritedness of the foundrymen. Most of them, like himself and others present, were in business to make money out of it but the foundrymen seemed to be in business to benefit their neighbours and the world in general. People who were in possession of these sentiments and lofty ideals certainly required no words of his to commend them. His notion was that at the present time the scientific and technical institutes required to get right down to the root of things. They required to get down to facts and first costs. He had the belief also that in the processes which they operated or controlled they ought to strike out in order to see in what direction they could improve their work. The scientific and technical institutions were useful in the way of investigation, and in the direction of showing people who were interested how to improve processes and methods. They served a useful part in training the young to take their rightful places in the industries with which they were associated. It had always seemed to him that they could not bestow too much praise on the various scientific and technical institutes for the work they were doing in the country. Many of those present must know from practical experience that these institutes were doing excellent work and that they were rendering useful service to the country.

Professor Mellanby, with whose name the toast was coupled, referred to the benefit which had accrued to craftsmen in Glasgow by the fact that there had recently been combined meetings of the Glasgow Branch of the Institute of British Foundrymen and the Glasgow Section of the Institution of Mechanical Engineers. These meetings had been unique in that representations were present from the engineering shops in the shipyards, and as the outcome of the discussions they had learned a great deal as to the problems associated with the treatment of Diesel engines, for example. He was grateful to Colonel Roxburgh for the kindly references he made to the scientific and technical institutions, and he felt glad to learn that there was a general appreciation of the admirable work they were doing in the country.

" The Scottish Branch of the Institute of British Foundrymen " was afterwards proposed in appropriate terms by Provost Wm. Muirhead, of Falkirk. Mr. James Affleck, B.Sc., the President of the Scottish Branch, made a suitable acknowledgment.

Amongst those present were:—Mr. John Cameron (who presided); Bailie Angus McDougall; Mr. James Weir, of Cathcart; Sir Archibald M. Innes-Shaw, Glasgow; Mr. H. Thomson Clark, manager of the "Glasgow Herald"; Rev. Dr. McLean Watt, minister of Glasgow Cathedral; Mr. R. O. Patterson, retiring past-president; Professor A. L. Mellanby, D.Sc., President of the Glasgow Section of the Institution of Mechanical Engineers; Colonel Roxburgh, President of the Glasgow Chamber of Commerce; Mr. J. T. Forgie, Hamilton (Messrs. Wm. Baird & Company, Limited, coalmasters); Mr. J. M. Mowat, secretary of Messrs. Wm. Jack & Company; Mr. James Affleck, President of the Scottish Branch; Provost Muirhead, Falkirk; Mr. A. Logan, of the Central Ironmoulders' Association; Mr. John King, chairman of the National Light Castings Association. The croupiers were:—Mr. Wm. Bell; Mr. J. Longden; Mr. Oliver Stubbs, past-president; Mr. V. C. Faulkner, London, senior vice-president; Mr. F. J. Cook, past-president; Mr. Tom Bell; Mr. G. A. Dudley. The musical director was Mr. J. C. Dorsie, while the stewards in connection with the banquet were Messrs. H. Winterton and J. Longden. A feature of the menu was the prominence given to "the haggis." The fact that the "great chieftain of the pudden race" was ushered in with full musical honours—typically highland at that—occasioned great amusement amongst the English visitors.

THE PRESENT STATUS OF THE LABORATORY INVESTIGATION OF SANDS.*

By H. Ries, Ph.D.†

The laboratory investigation of moulding sands is not a new idea, for tests of one sort or another have been tried for a number of years, the fineness test being perhaps the one most commonly applied. Many of these tests have been made, however, according to the individual ideas of the experimenter, so that they conformed to no common standard, and we consequently lacked a common basis for comparison, which is, of course, very unfortunate.

In recent years there has been a strong movement not only in the United States, but also in Europe, looking both towards a refinement of laboratory test methods, as well as their standardisation. The advantage of this is almost self-evident, but the reasons may be stated here.

Standard tests (1) enable the consumer to determine the qualities of new sands, and intelligently compare them with others already in use; (2) permit the producer to keep a check on the uniformity of his product; (3) make it possible for the consumer to check all shipments as received in order to determine whether they conform to his requirements and specifications; and (4) are of value for daily control in the foundry. The last of these advantages is by no means the least, and its rapid spread in the United States, accompanied by reports of those who are using it, testify to its importance and value.

Whilst the different tests, which will, it is hoped, eventually become standardised, may be large in number, it is not to be thought that all of them will be used for foundry control. Indeed, the number employed for the latter purpose will probably be limited, but additional ones may serve

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* This Paper was submitted on behalf of the American Foundrymen's Association to the Glasgow Conference of the I.B.F.

† Dr. Ries is Chairman of the Sub-Committee on Tests, Joint Committee on Moulding Sand Research.

for the examination of new sands submitted to the consumer by the producer, and still others may be used mainly in research work on sands.

The important point, however, as is generally realised, is the necessity of getting the various methods standardised. In addition they should be as simple as possible, and those which are to be used daily in the foundry should not only be easily understood, but the apparatus employed should be as nearly foolproof as possible, and of a durable nature.

In the present contribution, the writer intends to deal chiefly with what has been done in the United States, but this is not to be taken as an indication that American eyes have been closed to the work of their fellow investigators across the sea. Indeed, they have followed these efforts in the same lines with the keenest interest and appreciation. Some references to and comparisons with foreign tests will be made.

Joint Committee on Moulding Sand Research.

In December, 1921, there was organised a Joint Committee on Moulding Sand Research, acting under the auspices of the American Foundrymen's Association and the Engineering Division of the National Research Council. This committee included not only representatives of the foundry industry, but also one from each of the several technical societies or other scientific organisations which might be interested in such an investigation.

An executive committee was selected to exercise control over the entire investigation, except the handling of the funds required. The latter are kept and disbursed by the treasurer of the American Foundrymen's Association, which is the financial and chief technical sponsor of the joint research.

As the work of the investigation was somewhat diversified, it was recognised at once that sub-committees would be required to take charge of and carry on the several phases of the work. As a result there were organised sub-committees on (1) conservation and reclamation; (2) geological surveys; (3) tests; (4) finance; and (5) publicity. Sub-committee number four was particularly important, as such a broad investigation could not be carried on without funds. It is a pleasure to remark that contributions to the fund for research have been appreciable.

To refer more specifically to the work of the Sub-Committee on Tests, it may be said that the development of standard tests by this committee had a two-fold importance, because they were not only to be used by the foundrymen themselves in their own laboratories, but were also to be used at the testing stations supported by the American Foundrymen's Association, where the sand samples collected by the different state geological surveys—to date over 800 samples from 15 states—are being investigated.

A point not to be overlooked is that each testing method recommended by the sub-committee on tests is tentatively adapted for one year's trial, in order to determine by use whether it meets all demands, needs revision, or should be replaced by a better test discovered during its probation period.

The recommendations thus far made by the Sub-Committee on Tests have been printed in a pamphlet which was issued by the American Foundrymen's Association in June, 1924.

Fineness Test.

This test, as at present recommended by the American Foundrymen's Association, is essentially a sieve test. For core sands with no clay the sand is sieved dry, but for those sands containing clay substance the sand is first shaken in water to which NaOH has been added, and the so-called clay substance separated from the "grain" by siphoning. For the fineness test sieves Nos. 6, 12, 20, 40, 70, 100, 140, 200 and 270* are used. That material which passes 270 is caught in the pan. The openings of the No. 270 are 0.053 mm. and the average diameter of the material remaining in the pan is about 0.035 mm.

For purposes of comparison, it is naturally imperative that the same sieve sizes should in all cases be used, although even now in the U.S. this is not always done. It is, furthermore, important that the sieves should be calibrated

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* These numbers refer to the U.S. Bureau of Standards sieve series.

before use, because even carefully woven ones may show variation in the openings for a given size. The diameter of the sieve openings, the diameter of the wires, and the allowable deviation or tolerance of each from the specified dimensions have been published by the U.S. Bureau of Standards.*

That the test works satisfactorily has been shown beyond doubt, and there is no difficulty in obtaining duplicate results which check quite closely if the sand is of uniform character. Some criticism has, however, been made of the so-called clay substance, which may include both colloidal clay and fine silt, and the point has been raised by some, whether for purposes of scientific investigation it might not be well to separate these two constituents. Whether it is essential for general foundry work is open to discussion.

Another point to be considered perhaps, is the effect of tap water on the process. Water from this source may contain electrolytes, and may vary in its composition from place to place. The question then arises, should the sand be tested with distilled water. From the foundryman's viewpoint this may be regarded as decidedly inconvenient, and moreover insufficient data are as yet available to decide whether it is necessary.

The method of determining the texture of the sand is different from that advocated by many foreign investigators and writers, such as Professor Boswell and others,† who commonly use the elutriation process, and, the author believes, regard it as better because, as they state, it separates the finer sizes. They, moreover, criticise the sieve test, because they claim it does not perform accurate sorting, since large elongated grains might go through the meshes endwise, and hence be caught on the finer sieves to be weighed with the fine particles, in whose company they should not be found.

In this connection attention is drawn to the following facts: (1) Elongated grains are, it is

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* Revised specifications giving slightly greater tolerance limits were issued by the U.S. Bureau of Standards in April, 1924.

† *See* P. G. H. Boswell, "A Memoir on British Resources of Refractory Sands for Furnace and Foundry Purposes," Part 1, 1918.

thought, the exception rather than the rule in most sands; (2) the elutriation method requires considerably more time than the A.F.A. sieve test; (3) the elutriation method requires the use of sieves for the medium and coarser sizes, but the larger sizes separated by water, come within the range of the finer sieve sizes of the A.F.A. test; (4) the A.F.A. method is in actual practical use in foundries in the United States, and is giving satisfactory results; (5) the A.F.A. sieve test separates particles down to 0.035 mm. dia.; and (6) although the author has seen the results of many elutriation tests plotted, he does not remember having seen any practical use made of this extreme separation of the smaller particles.

Expression of Results of Fineness Test.

Having separated the sand into its different groups of grain sizes, next must be considered the best manner of expressing the results of the tests. Obviously, to record them in tables is the most convenient way, but where a large number of sands are so arranged, a comparison of them is not always a rapid operation.

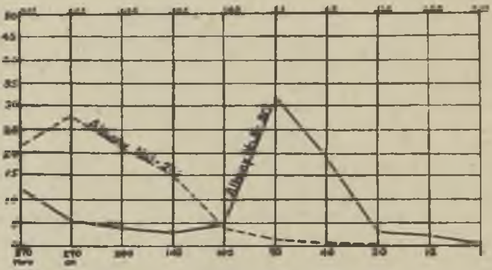

FIG. 1.—SIEVE MESHES PLOTTED WITHOUT REGARD TO SIZE OF THE OPENING.

This leads then to the possibility of expressing the texture graphically, as by curves, or by means of a number.

Fineness Graphs.

If curves are used to represent the texture one is obliged to choose between several methods any one of which may at least be considered fairly satisfactory. These are (1) the use of rectangular co-ordinate paper (Fig. 1), plotting the percentage of each sieve as ordinates, against the sieve sizes ranged as abscissæ. On such paper, the sieve sizes may be plotted at regular intervals, and the abscissæ representing them may be correctly spaced in proportion to the real size of the screen openings (Fig. 2). The first method is used by many, the second by few, and it is open to the objection that the coarser sizes take up all the room on the chart, crowding the smaller ones together at one end.

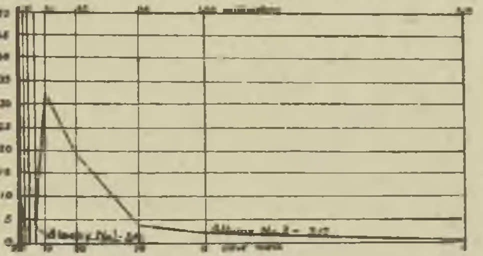

Fig. 2.—Sieve Openings are Correctly Spaced on Rectangular Co-ordinates.

(2) The use of logarithmic co-ordinates for the screen sizes while retaining the rectangular co-ordinates for vertical plotting of percentage retained by each sieve (Fig. 3). If logarithmic co-ordinates are used it seems best to plot the size of the actual sieve openings. Two types of curves appear to have been used, regardless of the kind of co-ordinates employed. One of these is the cumulative curve (Fig. 4), probably more used in Europe than America. The other gives the actual percentage retained on each sieve. It may be a matter of personal choice which one is used, but, to the writer, the latter of the two seems preferable, because any excess of certain sizes is detected at a glance, although it may be argued that the cumulative curve would also show it by a pronounced local steepening of the line.

Fineness Figure.

The second method of expressing the fineness is by means of a figure, which may be called the *average fineness figure.* This can be done in several ways. One, sometimes referred to as the Scranton method, consists in multiplying the weight of sand retained on each sieve by the mesh of the next coarser sieve. The sum of these products is divided by 100 and called the average fineness. The objection to this is that sands which differ markedly in their texture may give almost identical fineness figures, as the following examples (Table I) taken from a forthcoming Paper by Mr. C. M. Nevin will show:—

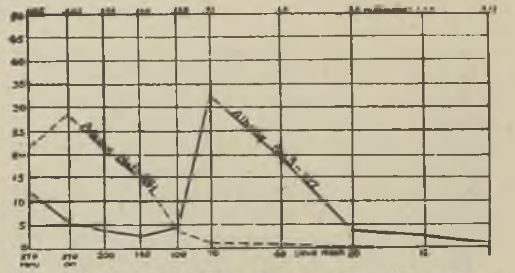

Fig. 3.—Sieve Openings are Correctly Spaced on Logarithmic Co-ordinates.

Table I.—*Illustrating that similar fineness figures are given by totally different sands.*

Mesh.	No. 1.	No. 2.	No. 3.
6	0.0	0.10	1.10
12	0.0	1.00	5.03
20	0.02	9.70	9.70
40	0.72	5.76	8.70
70	19.68	19.60	10.60
100	20.18	11.30	11.30
140	14.50	10.56	10.56
200	8.26	9.22	9.22
270	9.46	13.50	13.50
270 (Pan) ..	11.40	11.00	12.01
Clay substance ..	16.70	9.14	9.14
Aver. fineness ..	98	98	98

Better results are apparently obtained if the percentage retained on each sieve are divided by the mesh size of that sieve, and the sum of these taken, and yet this second method is not without its objections. The first one works best with coarse sands and the second with finer grained ones.

One may, moreover, question whether such an average fineness figure really shows as much as a curve, from which the percentage and distribution of the different sized grains can be read at a glance.

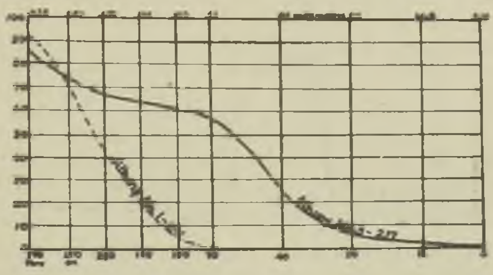

Fig. 4.—Cumulative Percentages with Sieve Openings on Logarithmic Co-ordinates.

Most foundrymen, it is thought, recognise the value of a fineness test. The texture of the sand serves to indicate the venting qualities of the material, as well as the smoothness of surface finish which it might produce, unaided by any facing material, as well as the approximate size of casting that can be poured in it. It is extremely useful as one of the tests to be applied in checking up new consignments of sand.

Grading Sands.

In a recent Paper before the American Foundrymen's Association, Mr. C. M. Nevin has presented some very suggestive ideas on the grading of sands by means of the fineness tests. His views worked out in connection with a study of some 60 samples of Albany sand. Plotting all those of the same producers grade on co-ordinate paper, it was found that they agreed quite closely.

This permitted drawing what might be called an *average curve.* If now on either side of this two other curves are drawn which include most of the variations from the average line, shown by the sands of that grade, and shade the area between these two lines, it gives what Nevin suggests calling an *area curve.* (Fig. 5, representing the area curve of No. 3, Albany.) Such area curves were constructed for the different grades of Albany sand. Having then the curve plotted, any new sand from that district can be fitted into its grade. This, of course, refers to texture, and not to any other properties, although permeability is within certain limits more or less associated with texture.

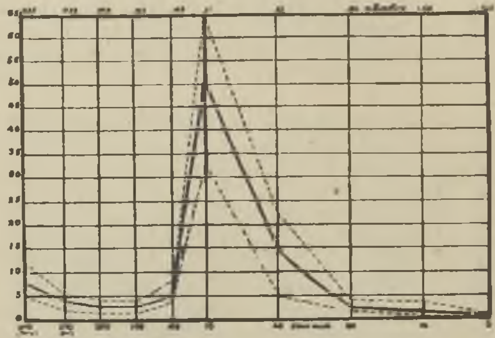

Fig. 5.—By Shading the Area Enclosed by the Dotted Lines an "Area Curve" for Grading Sands. Actually it is No. 2 Albany.

Now to apply the grading theory a little further, let it be supposed that some producer in another territory is selling a sand which he designates as No. 6 or 3 F., and yet whose fineness curve fits nicely in the area curve of a No. 1 Albany. Why should this not be called a No. 1 sand also? In other words, one might probably reduce these descriptions to common terms, or the same language. The idea seems attractive to many, and a sub-committee of the A.F.A. has been recently appointed to develop it, if possible. If practicable, it is a step towards the development of sand specifications, which may be given out by the consumer to help the producer to supply him with what he wants.

Vibratory Tests for Fineness.

Every industry has its short-cut methods for making certain tests, and the foundry industry is no exception. Indeed, as many know, a description of some was recently presented before the French Foundrymen's Congress.* In the United States some attention has been attracted to what is known as the Smith Vibratory Test, and as some rather strong claims have been made for this method, it may not be out of place to devote a few words to it.

Briefly stated, a mass of sand and water are shaken thoroughly by hand in a test tube or bottle about 6 in. high and 1 in. diameter. The suspension is then placed on a vibrator for half an hour, whereupon the grains of different sizes settle to the bottom of the tube, the coarsest on the bottom and the finest on the top, presenting a beautiful series of layers. The thickness of these is measured by means of a scale, thus obtaining the percentage of the several grades. The layer of finest material is classed as bond. Mr. Smith has sought to show that this one simple test may take the place of all the standard ones used in foundry control, but this does not appear to be the case, as the following comparisons taken from a Paper by Dietert on foundry control will show.

"Nearly all sand showed a larger amount of clay substance. A part of the bond measured in the vibratory test is pan material. The percentage of bond as shown by vibratory test does not enable one to estimate the permeability or strength of the sand. The standard permeability and strength tests can be made much quicker than the vibratory test." Where the same sand mixture is being used from day to day, the vibratory test will give an approximate idea of whether it is running uniform or not.

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* Procédé d'Etude experimentale des Sables de Fonderie, 4me Congres de Fonderie, Paris, November, 1924.

Fineness and Permeability.

Observations thus far made indicate, of course, that a general relation exists between texture and permeability, but it is only a very general one. If we could calculate the permeability from the fineness, it would be very convenient. Thus far no one has suggested a satisfactory method, and it seems doubtful whether it can be done.

Bonding Strength.

This all must admit is a very important property of moulding sands, and consequently one for which there should be a satisfactory means of measurement. Any test devised to measure the bonding strength should be simple, rapid, and require only easily operated and rugged apparatus. It is safe to assume that the test for bonding strength and that for permeability, to be referred to later, have thus far received more attention and have had more labour bestowed upon them than any other laboratory investigation methods.

It is not the writer's intention at the present to discuss the nature of the bond. Its presence is acknowledged, and that it plays a vital rôle in strengthening the sand and holding it together in the mould is admitted, as well as assisting it to resist the different forces which tend to disrupt it before, and even during the process of filling the mould.

There still appears to be some difference of opinion as to what forces are operative in disrupting the sand, that is, whether they are tensile, compression, or shearing forces, or a combination of these, which one of these the bond test should measure, or whether they are so related to each other that any form of test which measures the strength of the bond may be used.

There are in the United States three types of test which have been recommended for determining the bonding strength of green sands, viz.:—(1) The bar test which has been standardised by the A.F.A.; (2) a compression test, and (3) a tensile test. The last two are now under investigation by the sub-committee on tests, and recommendations may, no doubt, be expected in the not-distant future.

Bar Test.

This test involves compacting the green sand in a box mould under specified conditions, then removing the bar from the mould and drawing it over the edge of a plate at a given rate of speed. The weight of the piece breaking off varies directly as the strength of the sand.* The breaking of the bar is due mainly to the operation of forces of tension, and with care it is possible to get average breaks which do not vary by more than 5 per cent. as specified in the recommendations of the sub-committee. The one point to bear in mind is that the size of the piece which breaks off of the bar depends primarily (other things equal) on the strength of the bond.

The test as a whole is satisfactory, and is being quite widely used in different foundries for control work. The apparatus requires more space than that used for the compression or tensile test, and when the sand is too dry there is considerable shearing in the bar, so that the true strength is not obtained. It might be said, however, that when the sand gets to that condition it is too dry to work in the foundry.

Compression Test.

For this purpose, the sand is formed into a core, obtained by ramming it in a cylinder, broken in a suitable machine by compression, the results being expressed in lbs. per sq. in., or some other unit. Several types of apparatus are now being tried out in the United States, and all seem capable of giving good results if properly made. One point to be considered is the ratio of diameter to height of sand core tested, for cores of the same sand in which the ratio of these two dimensions vary do not always give the same compression strength per square inch.

A cylinder, 2 in. high and 2 in. dia., yields a higher unit strength than one which is 1¾ in. high and 1⅛ in. dia., the compaction being the same. From the view-point of mechanics of materials, the latter may be more correctly proportioned, but from the standpoint of practicability the former is

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* The strength is represented by the weight of the piece breaking off. *See* A.F.A. pamphlet on test issued June, 1924.

easier to make, because it can be moulded in the rammer used for the permeability test, but even after a satisfactory compression test has been made there remains some question as to whether it is an appropriate one for measuring the bonding strength of the sand. There seems no doubt that the chief factor which helps the sand to resist a compressive force is the bond surrounding the grains of sand, and hence it is assumed by some at least foundrymen are really measuring the bonding strength.

Tests which have been made on the same sand for compression strength, and with the A.F.A. bar test, have indicated that the curves of the two may run more or less parallel, but that where both show a peak the two peaks are not always in exact agreement. In favour of the compression test is the fact that the apparatus requires little space, and that it can be used on drier sands than the bar test can. Whether it is more delicate than the bar test is a matter of dispute.

Tensile Strength Test.

This has appealed to some, partly because it was thought more truthfully to measure the type of failure occurring in a green sand mould, but the test itself does not thus far seem to have been developed so that it is capable of being used as readily and with as little practice as the compression or bar test. Most of the experiments made for tensile strength have involved shaping the sand into a briquette similar to that used for testing cement. Such a briquette, if made of moulding sand, has but little strength and requires the most careful handling, and has not found much favour. A modification recently described by Wolf and Grubb* consists in ramming the sand in a core inside of a brass cylinder. This cylinder is divided horizontally, the upper and lower halves being carefully fitted, and kept clamped together while the cylinder is being rammed with sand. The lower end is then fastened to a base, the clamps removed, and tension applied to the upper half. The force required to pull the sand cylinder apart is thus measured. This apparatus is ingenious, and is claimed to be delicate, but it is

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* American Foundrymen's Association, Preprint No. 430.

not yet foolproof, and in untrained hands might give results of doubtful value.

Comparisons.

Whether or not the bar, compression and tensile tests all measure the same stress or not, there seems no doubt that they all determine the strength developed by bonding material in the sand, and that is one factor required, either in studying new sands or in daily foundry control. It is also true that all three of these tests are now in daily use in the United States for control work, being used for testing either single sands or mixtures. The first has been standardised, the others remain to be.

Permeability.

In view of the importance of this property, it is not surprising to find that many have developed apparatus for testing it. That a number of different types of apparatus have been tried in both America and Europe has been well brought out in a Paper by T. C. Adams presented to the American Foundrymen's Association at its Millwaukee convention.*

One important feature stressed in this Paper is that whilst all the different kinds of apparatus determine the ease with which air can be forced through sand, the permeability as determined is rarely expressed in terms of some common unit, so that the figures obtained with one apparatus cannot be checked with those of another.

Adams points out that the permeability apparatus all fall in one of two main groups, as follows:—(1) Those which determine with the aid of a permeability formula the permeability of the sand in some definite units (usually centimetre-gramme-minute units), and (2) those which give the permeability in some very arbitrary unit which depends on the construction of the apparatus.

All results from any apparatus of group (1) are comparable. Those obtained by apparatus of group (2) are only comparable when each apparatus made after a given design is strictly standardised, otherwise the results may not be compared except with other results obtained upon the one individual apparatus.

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* In press.

The Sub-Committee on Tests of the American Foundrymen's Association has spent considerable time on the problem of permeability, and not only were a number of experiments made to clear up doubtful points, but several pieces of experimental apparatus were constructed. Among the factors influencing permeability, which must be taken into consideration in devising a test, are grain size; amount and nature of bond; quantity of moisture in the sand; degree of compaction; height of sand column through which the air is passing, and pressure.

Variation in these factors brings about variation in permeability. The rate of flow of air through a sand is proportional to the pressure causing this flow. It is also proportional to the area of the cylinder, and inversely proportional to its length. This may serve to explain why the Test Committee recommended that the sand be rammed in a core of uniform diameter, height and compaction.

With such a standard core of sand the pressure required to pass the air through can be determined and the time required for a given volume of air to permeate the sand noted. Results which are comparable with those obtained on other apparatus where pressure are thus given, and time can be measured, provided the sand core is prepared in the same manner.

The original apparatus recommended by the committee was essentially that used at the Bureau of Standards. This, while accurate, was not sufficiently rugged, compact, or rapid for foundry use, and so the committee, after trying out several different types, finally evolved the small portable one which it has been recommended and described in the special pamphlet already referred to. It is constructed entirely of brass, with the exception of the two short legs of the manometer tube. It is also accurate when used as a standard apparatus, and the special orifices for rapid work add greatly to its utility. Although this apparatus was recommended not over eight months ago, there are now between fifty and sixty of them in use for foundry control work in the United States.

There may be other types of permeability apparatus devised, either in America or Europe, but the writer wishes to urge that they be constructed and manipulated so that they give comparable results. Some of those described in European magazines can be easily adjusted to give the same results as the A.F.A. model.

Base Permeability.

This may be a new term to many, and need explanation. It has been found, for example, that a given sand with coarse grain, but appreciable clay substance, may give a relatively low-permeability when tested by itself. If now the clay substance is washed out of the sand and the dry permeability of the grain determined alone, it may be found to be considerable. This is the base permeability. As stated by Dietert in a Paper previously referred to, "The base permeability is of utmost importance, for it compares the permeability of all sands under like conditions. Some high-clay sands are dense, due to the amount of clay they contain. If natural permeability is the only thing considered, one would class these sands as closing-up sands for heap-sand, while in reality they may have a very open grain-structure, which would be shown in the base permeability reading. When the clay-content of this sand is reduced by mixing it into the heap, its open grain-structure would act as an opener. All new sand placed in a heap-sand will be brought to some predetermined clay-content by sand control. In order to determine what the various new sands will do to a heap-sand they should have their base permeability determined."

Density of Sand.

In any test where the sand has to be compacted it is recognised that a varying degree of compaction will affect the results. Thus, with a given sand and a given moisture content increased compaction will tend to increase the strength as measured by the methods referred to above, and decrease the permeability. Recognition of this has been made by the sub-committee, and the force of compaction used in the several tests is that which gives a body having the same degree of density as the average mould.

Experiments made on different sands when compacted in cylinders show that uniform compaction is not obtained from the top to bottom of the core in all cases. Thus, in the permeability tests as recommended by the A.F.A. the core of sand made with the rammer is made 2-in. high, because it gives fairly uniform compaction throughout its length. A core, say, 4-in. high, if rammed all at once, would not show uniform compaction. To overcome this difficulty as much as possible, Dietert has suggested the use of "double-end-ramming," as it is called. This is done by having a movable rammer sliding into the cylinder from below. To prevent the cylinder from sliding down over it, a hole is drilled in the rammer for a pin. This holds the cylinder in place until the sand is put in it. The upper rammer is then let down into the upper end of the cylinder, and the pin is withdrawn before the sliding weight on rod of upper rammer is dropped. As a result of this equal ramming forces are applied to both ends of the sand specimen during the ramming operation, and more uniform compaction results.

Optimum Water Content.

It is probably widely recognised by now that the permeability and bonding strength vary with the amount of moisture which the sand contains, and that the quantity of moisture which gives the maximum development for either the bonding strength or permeability is called the *optimum water content.* Therefore curves can be plotted showing the permeability and bonding strength for different percentages of moisture. In all of the sands first tested at the Cornell University sand laboratory it was noticed that the curves for both properties showed a well-developed peak within the moisture range at which the sand could be worked. As more and more sands were tested, however, it was found that there seemed to be many exceptions to this.

Fig. 6 shows the permeability and bonding strength curves of over 200 sands tested within the moisture range at which they were workable. These have been divided into three classes, of which the upper pair of curves in each case may be taken as the type:—

In Class I the peaks of the curves agree; in Class II the permeability peak P occurs at a lower moisture content than that of the bond test curve B; and in Class III the position of the peaks is reversed. It will be observed that in several cases no peak is shown, due probably to the fact that it is developed when the sand is too wet or too dry to be workable. The reason for this is evidently to be sought for in the quantity and nature of the clay substance present, and has been discussed at some length in a Paper on "The Relation of Moisture to Permeability and Bond," presented by C. M. Nevin at the October, 1924, meeting of the A.F.A.

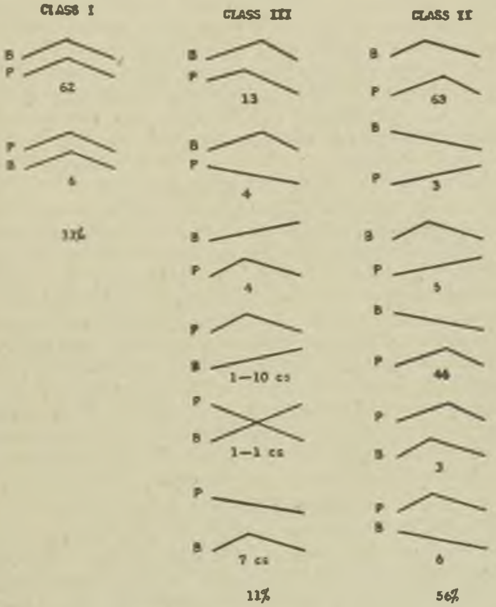

FIG. 6.—PERMEABILITY AND BOND STRENGTH CURVES OF OVER 200 SANDS TESTED FOR GEOLOGICAL SURVEY.

Moisture Determination.

Since the amount of moisture in a sand exerts an important influence on the permeability and bonding strength, frequent determinations of it may be necessary. The common method for determining the moisture content is that of heating the sand in a hot-air bath at a temperature between 105 and 110 deg. C., and finding the loss in weight. This is a comparatively slow process, and requires at least an hour. There is need, therefore, of having a rapid method applicable to all sands.

It is interesting to note, however, that certain rapid methods have been tried with some success in foundry-control work where the same sand or sands are in daily use. F. L. Wolf and A. A. Grubb* use an apparatus consisting of four electric heating chambers arranged to pass dry air at about 400 deg. F. (205 deg. C.) through as many samples of sand contained in small aluminium capsules. There is also an automatic weighing-device equipped with a chart that indicates the percentage moisture without calculation. A single test takes from 5 to 8 minutes, and 30 to 40 determinations can be run in an hour.

H. W. Dietert† has devised another rapid method based on the following principle:—If a tube is filled with water, and moist sand is put in it, the amount of water displaced will depend on the amount of water already contained in the sand. A definite amount of moist sand is therefore put in a water-filled cylinder. The water displaced overflows and is caught in a graduated tube, from which graduations the percentage of moisture in the sand can be read.

Refractoriness and Life.

These two terms, according to the writer's conception, do not mean the same thing. Refractoriness would seem to apply to the temperature at which a sand fuses; life refers to the length of time a sand can be used over and over without losing its important properties. There is as yet no standardised method of determining either of these properties, but studies leading to that end are under way.

There seems to be a diversity of opinion as to how a refractoriness test should be made, one

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* American Foundrymen's Association, Preprint No. 430 October, 1924.

† American Foundrymen's Association, Preprint No. 425, October, 1924.

group holding that the fusion point of the sand as received should be tested, while others believe that it is more important to determine the refractoriness of the bond alone. The writer is inclined to agree with the latter group, because in most sands it is the more resistant minerals, such as quartz, which compose the grain, and these are usually of high refractoriness, while the bond commonly contains fluxing impurities, which lower its fusion point.

There have not been many figures published on this point in the United States, but some interesting ones have appeared in a Paper by Rhydderch.* Aside from the fusion point of the sand, it is the opinion of many that the vitrifying point or softening point of the sand as a whole should be determined.

Longevity of Sands.

There is no doubt that other things equal, some sands deteriorate more rapidly than others, and require a larger amount of new sand to be added to the heap from time to time. One should not overlook the fact that the life of a sand will be influenced by the size of the casting made in it. Admitting that some sands burn out quicker than others, those sands which have a longer life or burn out less rapidly are the more desirable. and if this quality can be determined beforehand, it may mean a considerable saving to the foundryman.

Experiments are now under way to test out a method useful for this purpose. One suggested and used by H. W. Dietert and some others consists in heating the sand to a temperature of 600 deg. F. (315 deg. C.) for two hours, after which it is tested to determine its change in permeability and bonding strength. This test gives promise of being a reliable one. Mr. Dietert† has found that some moulding sands lost as much as 87 per cent. of their strength by the abovementioned heat treatment, while others lost as little as 16 per cent. Curiously enough, the permeability may either increase or decrease.

Dye Absorption.

One of the supplementary tests recommended by the Sub-Committee on Tests is that of dye absorp-

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* FOUNDRY TRADE JOURNAL, May 29, 1924.

† American Foundrymen's Association, Preprint No. 426, October, 1924.

tion, the object of which is to determine the nature and amount of the true clay substance in the sand or, to state it in different words, the colloidal matter. Theoretically, then, if a sand contains a high percentage of bonding substance, it should show a high dye absorption and *vice versa*. It cannot be said that there is unanimity of opinion regarding the value of this test, and, moreover, while it is true that a sand of high bonding-strength may show a high dye absorption, and *vice versa*, still it seems as if in many cases there is only a general relation between the two properties.

One may therefore be justified in seeking an explanation of this. Dye absorption is a surface phenomenon, and colloidal matter, because of the great surface area of the particles, would naturally absorb a relatively large amount of dye. But would not silica flour or fine silt also show the same property, and although it exhibits it to a less degree, one can easily realise that if a sand contained a considerable percentage of fine silt, that its dye absorption might be appreciable. Then, too, sands which have been heated to redness, a temperature sufficient to destroy all true bonding material, may still absorb some dye. So from these facts alone it may be concluded that it is not the colloidal bond only which takes up the dye.

To go still further, Holmes, in a Paper familiar to many, has called attention to the difference between mobile and static bond. According to Gramme's experiments quoted by Lemoine,* the static bond seems to give little or no strength to the sand. May this static bond not also absorb some dye?

Finally, in the dye absorption test as usually carried out, the dye used is crystal violet, which is an acid dye, and hence would be absorbed best by basic colloids. Might there not be acid colloids present which would react best towards a basic dye like safranine, for example? The concentration of the dye solution also plays an important *rôle*, and must not be overlooked. Notwithstanding these objections which have been raised against

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* M. R. P. Lemoine, L'Etat Actuel de la Question des Sables de Moulage, 4me Congrès de Fonderie, Paris November, 1924.

the dye test by some, it has been found useful by others who have used it satisfactorily in foundry control work. This may be due in part to its being employed for testing different lots of the same sand.

Chemical Analyses.

In looking over the literature one notices that chemical analyses of moulding sands appear to have been made more frequently in Europe than in the United States, which might lead one to believe that greater importance is attached to them in the former. The Sub-Committee on Tests has recommended a method for analysing sands which is practically the same as that ordinarily used, but a quantitative analysis is not regarded as essential in all cases.

It would no doubt be of importance in "steel" sands, and even many core sands, but for ordinary moulding sands the writer fails to see that it can perform any real service. As pointed out by him some years ago, it is not difficult to find brick clays that show a chemical composition identical with moulding sands.*

If there was a satisfactory and accurate method of making a rational analysis which was applicable to impure materials, it might give some interesting data, but such a method has not yet, so far as the author is aware, been discovered.

Mineralogy of Moulding Sands.

The writer believes that there is here an interesting field for study, which may lead to practical results. It involves, however, considerable careful petrographic work, which should be checked up with practice. Moulding sands are likely to be made up largely of the more resistant minerals, such as those which withstand the destructive effects of weathering and erosion. Of these, quartz would be the most common, but one sometimes hears the statement made that minerals of relatively low weathering resistance, like feldspar, may be present in considerable amounts. If this is really so, do they play any *rôle* in the behaviour of the foundry sands, which should be considered and may affect their commercial value? The statement is also made that mica is injurious. Is

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* Ries, H., "The Relative Advantages of the Physical and Chemical Examinations of Moulding Sands," Metal Industry (New York), 1908.

it really present in any considerable amount, and what is its effect? Lime and the alkalies are not considered desirable. If present, are they there as constituents of mineral grains or otherwise? Numerous other questions will suggest themselves, and whilst a petrographic study is being made of the sand grains, their form should also be considered to determine what effect this has on the properties of the sand. There is, then, in the microscopic study of sands a large and interesting problem.

Dry Sand Testing.

No reference has been made in the preceding matter as to whether the tests discussed are for green sand or dry sand, although their applicability may be inferred. Both the bar test and tensile test strength are assumedly for green sands. The compression test can be made on either green or baked sands. The same holds true of the permeability test. Baked cores are sometimes tested by fastening them in the end of the cylindrical sand container, making a paraffin connection and coating the sides of the core with paraffin. This permits air to be forced through the full length of the core. Baked cores are sometimes submitted to a cross-breaking test, and two of the compression machines now being tried are adapted for testing bars by cross-breaking.

SUMMARY.

Before closing this brief review the writer desires to emphasise again if possible the practical value and broadness of application of some of the tests which have been suggested. Tests like those for strength, permeability, fineness, life and refractoriness are, any or all, of importance.

(1) They may be applied to new sands for the purpose of determining how they compare in their properties with those already in use.

(2) They may be used by the sand producer to check his consignments and determine whether they are running uniform.

(3) The foundryman can use these tests to check new consignments which he is receiving from the quarry, so that if they do not agree with satisfactory sands from the same quarry previously received, he can reject the truck load. This is actually done.

(4) Last, but by no means least, the foundryman can use these methods for daily foundry control. employing them equally for sand mixtures as for individual sands. He may find that if his heap maintains a certain moisture content, permeability and strength, all goes well, but that if there is too much deviation from certain figures, the losses at once become noticeable.

A most interesting and concise statement of the application of testing methods to foundry control was given by H. W Dietert* at the Milwaukee meeting of the A.F.A. in October. Mr. Dietert states that in order to determine the value of sands for their particular work, all samples submitted are tested for permeability, strength, clay-substance, texture, base permeability, lime and longevity. Truck load consignments must check within 20 per cent. of values obtained from samples submitted. For control work in the foundry the properties determined are permeability, strength and moisture. with an occasional sieve test.

Further evidence regarding the value of control work is given by Wolf and Grubb in another Paper presented at the same meeting.† These two Papers present printed testimony, which has been confirmed by many others verbally, in some cases accompanied by a statement of the actual money saving which has been accomplished by their use.

It is felt that the establishment of what it is hoped may be regarded as standard methods of testing is a step in the right direction; in fact, the author is sure that it is, but there are still more steps to be taken, and the forward movement from one to the next will have to be made cautiously, and sometimes only after considerable research has been done.

It has been pleasing to hear the comments of approval of at least some of the tests made by friends across the water, but they should remember that all tests recommended by the committee are presented tentatively, and allowed to stand for a year for any criticism that anyone wishes to make. And so Americans welcome constructive comments not only from the foundrymen of their own country, but of those from other countries.

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* American Foundrymen's Association, Preprint No. 425. October, 1924.

† American Foundrymen's Association, Preprint No. 430. October, 1924.

DISCUSSION.

Mr. H. J. Young, F.I.C. (Newcastle-on-Tyne), said that this Paper, so far as it related to moulding sands, was apt to lead to confusion rather than conclusion. He had one criticism to offer and it was this, that nearly all the tests they heard about in this Paper had been on cold sand. There was an intense difference between tests in a laboratory and noting the behaviour of sand in actual foundry practice, at the moment the metal touched it. He had done certain other tests than those mentioned or described in the Paper, and had not been able to find any conclusive evidence that gases passed through the sand. They placed a pyrometer two inches or two and a-half inches from the metal, and it showed no indication of any temperature rise. If the gases were rushing through the sand as one had been led to imagine, the pyrometer would have indicated it. There was no indication whatsover of rise, and the pyrometer, they must not forget, was only a short distance away from the metal. He doubted if the author had used sand that was really permeable yet, and indeed if such had happened, how was it going to hang together for moulding purposes? Frankly, he did not believe that the tests referred to were permeable tests. They might be, but up to the present he had not thought it worth while to use them in his own laboratory. He supposed he would probably be severely jumped upon for ventilating these views, but he felt he must express his personal opinions on this Paper.

Mr. J. Longden said he was not proposing to take part in the discussion of the Paper itself, but he felt he must rise to reply to a remark made by Mr. Young. It did not matter whether the sand was permeable or not, the gases did get away.

Mr. H. J. Young: The permeability of the sand has nothing to do with that.

A question arose in the meeting at this stage as to whether Mr. A. Rhydderch, who had presented a summary of the Paper on behalf of Dr. Ries, could competently reply to the discussion. The President ruled that Mr. Rhydderch could reply to the discussion and the points raised if he was particularly anxious to do so.

Mr. J. E. Fletcher (Dudley) said he felt they ought to look at this Paper in the light of the valuable American work that had already been done, and they must judge of the value of that work by the ability with which this Paper was presented. To his mind it represented a comprehensive knowledge of sand-moulding research not only in America but in every part of the world. Touching first of all on the problem of permeability, which had already been dealt with by Mr. Young of Newcastle, he thought if they looked at the very elementary composition of sand and its building up they must realise that between sand grains there existed a number of voids. These voids had to be filled with air to begin with, and when the heat application came along the air between the grains began to expand. If that air expanded it must get somewhere, and being driven outwards it must naturally lower the pressure at the end of the spaces between the grains. The very fact of that lowering of pressure meant a vacuum which drew the gases that were liberated at the moulding face to the sand. There could be no disputing the fact that the question of permeability was of utmost importance and value. Some years ago he made a series of tests on the permeability of sand, while he also investigated the temperature gradient from the surface of the mould outwards. His experiments were made on moulds of varying thickness, and he found that permeability was obviously related to temperature. Personally, he had the feeling that permeability tests had not up till now been satisfactory for the reason that Mr. Young had raised. The most of their permeability tests had been carried out on cold sands. At the moment he was carrying out on behalf of the Cast Iron Research Association a series of tests, and they were trying to find out what the permeability was of the surface of the mould itself under actual conditions. It was a very difficult problem, and he was bound to say so far as they had gone it showed very valuable results. Mr. Young had raised a very important point in regard to the dual character of sand examination. The Paper itself referred to laboratory analysis. As foundrymen, however, they wanted to know something more about the behaviour of sand under actual working conditions. If simple tests could be continued to show a co-relationship, he personally believed that useful results for the foundry could be obtained. Dr. Ries, in his Paper, alluded to the Smith vibratory test. It was very similar to the one that he (Mr. Fletcher) had brought forward, and consisted simply of agitating sand in a certain volume of water contained in a tube. As the sand gradually fell in the tube it gave a curve. They could plot the curve on a time basis. These tests, up to the present, had been most useful, and he might mention that from the simple test he had referred to it was possible to get a certain idea of the porosity of the sand. That could be done by shaking a certain amount of sand in the water and noticing the drop of the water on the top of the tube. At this point Mr. Fletcher proceeded to the blackboard and gave an interesting demonstration of a process by which separation could be effectively carried out in the sand. He explained that by the funnel arrangement which he showed on the blackboard it was possible to get the correct sand grade and what it was capable of giving. He was hopeful, at least so far as permeability was concerned, that they of the Cast Iron Research Association would be developing along the lines he had indicated in his blackboard sketch.

Mr. Sutcliffe (Bolton) detailed the case of a dye gig, emphasising that laboratory experiments could not be applied to actual moulding conditions. He narrated an instance where he asked an operative if a suitable vent had been provided for the emission of air. He was assured that such had been done, but when he made the examination himself—as every wise and prudent man ought to do—he found that there was no vent at all for the air to pass through.

Mr. R. O. Patterson (Blaydon-on-Tyne) said he did not agree with Mr. Young at all in the observations the latter had made with regard to the permeability of sand. He happened to be a user of a sand slinger, and when the machine was started up about two years ago he had considerable difficulty with the moulds. From experience he had proved that a very coarse sand with a good percentage of bond gave the best results, and he never saw "scab." They employed now a coarse sand which gave a very considerable space between the grains. Practical experience—and it was that he was going upon—had proved to him and those associated with him in the work that the permeability of sand was an important point. Some time ago at his work they had an interesting experience in making railway chairs. In that instance the sand they used came from the Doncaster district. It was a coarse-grained sand with a good bond. They made railway chairs regularly at his works, and with the open type of sand they were now working with they had never such a thing as a "drawn" chair to-day.

Mr. J. S. Glen Primrose (Manchester) said that Dr. Ries, in the early part of his Paper, suggested sieves Nos. 6, 12, 20, 40, 70, 100, 140, 200 and 270 for the fineness tests. These figures, he would point out, referred to the American sieve series, and he did not consider they would convey any meaning whatever to those of their members who in this country used different standards altogether. American sieves were not stated or described in the Paper except by numbers. It was possible, he agreed, to establish some kind of co-relationship if anything to judge by or that was comparable with British sieves could be obtained. There was, of course, a very fine microscope, and the use of that, he knew, raised an interesting problem. He was ready to admit that the microscope would be increasingly adopted in the laboratory with a view to finding not only the petrological constituents in each grade of sand, but also the relative grain sizes, and to establish points whether they were sharp, rounded or angular.

Mr. A. Rhydderch, in replying to a few of the points raised in the discussion, said Mr. H. J. Young had rather confused him by jumping in at the deep end, particularly when he started by condemning high and low the question that was discussed in the Paper. He had heard Mr. Young aforetime, when discussing the chemical analysis of pig-iron, and then he was an enthusiast for control by analysis. Precisely the same argument applied to sand testing. There must be applied some essence of control in the elements that were to be used. The fact of the matter was that some sands were pronounced to be very good while others were reputed to be very bad. There were those amongst them who were prepared to argue that Manchester sand was the best possible, but on the other hand it was not difficult to find other people who solemnly declared that Manchester sand was quite useless. The strange thing about it was that most of those who made these contradictory statements might be doing the same class of work. Wherein lay the difference? The argument he put forward was this, that they must have some method of controlling these things. Could they not apply correction or check methods? It seemed to him that if they were to condemn a thing before they started trying it they might as well stop research. They must be fair and take a reasonable and impartial view of things. Nobody knew better than Mr. Young that it was possible to go on experimenting for many years before positive results were obtained. Of course, it was the easiest thing in the world—and everybody realised that—to get negative results. Proceeding, the speaker argued that the laboratory test was not strictly comparable with what they did in actual foundry practice in the works. Tests in the laboratory were invariably carried out on a new set of conditions entirely, and to have a comparable laboratory test they must carry it out at very high pressure. The speaker proceeded to contend that he still considered it possible to test the permeability of varying grades of sand by using the tube method described in the Paper. Wherever there was a variation in grain he considered it was possible to detect and locate it. Personally he had been very much interested in the demonstration Mr. Fletcher had given on the blackboard. He had been rather struck with the remarks made by Mr. Primrose.

Mr. J. S. Glen Primrose reminded the speaker that the point he had raised was for standardising sieve sizes and the adoption of a kind of uniform microscopical examination for determining the relative sizes and shapes of the sand grain.

Mr. A. Rhydderch: Dr. Ries does not tell you what sands they are. The curves are simply there for illustration purposes.

Written Contribution.

Mr. J. G. A. Skerl (Sheffield) wrote that it was very much to be regretted that Professor Ries had not been able to visit the conference to give his Paper in person, for he, and doubtless many others, would have welcomed the opportunity of discussing the progress of sand research methods and results at some considerable length, both outside and inside of the meeting room. With regard to the A.F.A. test methods themselves, the writer feels that detailed criticism of such pioneer work as has been done by the Joint Committee would be invidious and will confine himself to one or two general remarks, based on research work done with Professor P. G. H. Boswell and of late with the British Cast Iron Research Association.

Moulding sand research methods and tests should (1) be scientific and accurate; (2) be capable of reproducing foundry conditions and (3) yield results which allow of comparison between the various tests on the same sand. These ideals have not up to the present been attained in the laboratory, and all test methods must at the best be compromises, capable, however, of being correlated with results of foundry tests. Criticism must always consider this factor. From his own experience on sand research the writer would suggest that all tests be made to employ the same units. For example, the A.F.A. permeability and bond tests each contain a curious mixture of metric and English units, rendering mathematical treatment very tedious, as well as giving results which are apparently only empirical.

One of the greatest difficulties in sand research is to ensure the even ramming of test pieces, as, for example, in the permeability test. A moulding sand is a heterogeneous mixture of four states—solid, liquid, colloidal and gaseous, as represented in the sand grains, moisture content, the bond, and air in interstices. Each of these states behaves differently to physical forces, and each modifies the effect of these forces on the other states according to their proportion of the whole mass. For example, it is easier to ram a moist sand than a dry one. Since all sands have a different constitution, it is suggested that they each have an optimum pressure (ramming) value, and that the constant ramming devices as employed in the A.F.A. tests are of slight value and tend to mask actual facts, especially as the force employed in the permeability test is totally different from that in the bond test. Ramming is the most important factor to be controlled, and is, indeed, the basis of a moulder's art.

Finally, the writer would thank the author for a very lucid exposition of the American test methods and say how fitting it was that the A.F.A. had nominated to give this exchange Paper one who was a pioneer in sand research and who for upwards of twenty years had been seeking to advance the foundry trade of the world from his purely scientific Chair of Geology at Cornell. As a fellow geologist he again thanked him.

HEAT RESISTING CAST IRON.

French Exchange Paper.

By Andre Levi.

During the last twenty years the influence of temperature on cast iron has been made the subject of numerous Papers and researches. The greater part of these Papers may be described as theoretical research, the object sought being to determine the action of temperature on the physical properties of cast iron, and above all to explain the causes which bring about the modification of these properties.

It seems desirable to review the principal works touching on this question, with the object of arriving at conclusions of a practical character. As a large number of castings have to be submitted to high temperature and resist its effect, it is thought that an examination of such works may yield certain indications and enable manufacturing formulæ to be embodied forthwith—formulæ of interest both to the practical worker and the foundry manager.

The well-known works of MM. Charpy and Grenet have established the fact that under the action of heat grey cast iron undergoes a permanent, non-reversible increase in volume.

These workers showed that this increase was due to a graphite deposit resulting from the decomposition of the cementite $Fe_3C = 3\,Fe +$ graphite. They also proved that this reaction took place by heating even *below* the lowest critical point, *i.e.*, at temperatures below 725 deg. C. As regards a particular kind of cast iron, the amount of this increase in volume is the greater, the slower the heating. With a constant heating speed the rapidity of the phenomenon increases in proportion to the amount of silicon in the iron.

This is tantamount to saying that the annealing of the metal is accompanied by an increase in volume due to the formation of graphite. Nevertheless, it has been observed that the augmentation in volume in the course of successive heatings and coolings is much greater than the increase which may result from annealing and the decomposition alone of Fe_3C.

Outerbridge's Conclusions.

In 1904 Outerbridge[1] conducted a series of tests with cast-iron bars heated and cooled several times in the electric furnace. These experiments led him to formulate the following conclusions:—

(1) The increase in volume and also the expansion are not indefinite. After each heating operation the expansions appear in diminishing ratio and cease altogether after a certain number of heats.

(2) The coefficient of dilatation in a metal subjected to repeated heat tests does not remain constant. It may reach a value lower than half the coefficient of dilatation in an untreated metal.

(3) A heating, even if prolonged, produces no effect unless it is followed by cooling.

(4) The increase of volume corresponds to a decrease in specific gravity. In the course of his tests Outerbridge found that after 16 successive heats this specific gravity had changed from 7.13 to 6.86, that is, a decrease of nearly 4 per cent.

(5) In continuing his tests on thin plates heated by the Bunsen burner, he similarly found an increase of weight.

(6) A microscopic examination of these plates showed the existence, after treatment, of a series of cracks which would render the plates permeable to water and air.

The two experiments described below, which are particularly striking, enabled Outerbridge to illustrate practically the phenomenon he had studied.

To show the different action of temperature on cast iron and steel, Outerbridge subjected to repeated heats a steel tube into which he poured a cast-iron plug. After a few heats the steel tube *was broken* by the swelling of the cast iron. A second tube of wrought iron was filled with molten cast iron and the two ends were planed level.

After three heats it was found that the iron was projecting from the tube at each end owing to its having swollen.

Resuming his tests in 1908, Outerbridge[2] succeeded in getting the specific gravity of cast iron to fall from 7.13 to 6.01, which is equivalent to a decrease of nearly 13 per cent.

He points out, moreover, that the phenomenon of increase of volume appears to be more rapid in *soft* metal than in hard. With metal containing 0.5 per cent. combined carbon, he obtained an increased volume of 40 per cent. with 100 repeated heats at 650 deg., the same result being obtained with this metal after 27 heats at 790 deg.

To sum up, the work of Charpy, Grenet and Outerbridge appears to prove that the increase in volume is produced by repeated heats only if they are followed by cooling; that this phenomenon occurs even at temperatures below 725 deg.; that it is followed by a decrease in specific gravity and by an increase in weight of the sample; and that it invariably causes the formation of fissures, which produce porosity in the sample treated. It is necessary to note that in no case can the decomposition of the cementite alone explain the increase in volume by 40 per cent. found by Outerbridge.

For this reason he is disposed to attribute this phenomenon to the action of the occluded gases in the metal. He supposes that these gases undergo at high temperatures an expansion which in turn produces a permanent expansion of the minute cavities in which they are confined. This expansion would produce in the metal the porosity and the apparent increase in volume which have been described above.

The Work of Rugan and Carpenter.

Outerbridge's tests were resumed in 1908 and 1911 by Rugan and Carpenter. Without entering into the details of the experiments carried out by these authors, their conclusions are summarised: (1) In agreement with Outerbridge, Rugan and Carpenter find that the increase in volume does not occur unless the sample is sub-

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[2] "Iron Age."

jected to alternate heatings and coolings. Heating alone does not cause an increase in volume; (2) various tests showed that the extent of the increased volume is a function of the chemical composition of the metal. The increased volume found in three different metals varies from 35 to 38 per cent., and remains constant after about a hundred heats; (3) only grey cast irons show this phenomenon. The presence of graphite is therefore regarded as *an indispensable element* in increasing the volume; (4) increases of volume are augmented by an increase in the silicon content, and this takes place almost in proportion to the content of that element; (5) only a part of this increase in volume can be attributed to the annealing of Fe_3C; (6) increases of weight take a course approximately similar to that of the volume; (7) the greater the Si content, the greater is the final increase in weight; (8) the authors consider that they have thus demonstrated that increases in weight and volume are solely due to phenomena of oxidation, which operate specially on the free carbon, the silicon, the iron, and particularly on the silico-ferrite; and (9) microscopic examination shows that this oxidation takes place very specially along the lamellæ of graphite, which finally disappears entirely.

The increase in volume is said to be due to four causes: To the partial oxidation of the Gr (which phenomenon diminishes when Si increases and disappears entirely when Si = 6 per cent.); to the probable oxidation of the Si existing in the form of silico-ferrite causing the formation of $Fe + SiO_2$; to the oxidation of the iron uncombined with silicon; and finally, to a slight extent, to the expansion of the hydrogen, occluded in the metal. To sum up, Rugan and Carpenter consider that it is primarily a question of a process of oxidation.

In a second monograph (1911) the same writers seek to examine the influence of the different elements on the phenomenon of expansion. They admit, as the result of these tests, that phosphorus slightly diminishes the increase of volume, that the presence of manganese retards it considerably, and that sulphur is without influence.

Finally, as regards the action of the occluded gases, these writers consider that this action is negligible in regard to metals containing more than 3 per cent. silicon. On the other hand, with Si between 1.75 and 3 per cent., the action of the gases would effect an expansion of 1 to 2 per cent. When the silicon is below 1 per cent. the increased volume due to the action of the gases would amount to 10 per cent. of the total increased volume.

While making certain reservations as regards the ascription of the expansion to phenomena of oxidation (as will be seen later, this point has been strongly contested), the author retains the experimental fact which appears to him to stand out from the tests of Rugan and Carpenter: The elements which favour the formation of graphite accelerate the phenomenon of increase in volume; those which oppose this formation retard its occurrence. This first conclusion, which the author had already formulated in 1923,[3] has been confirmed by experimental researches made by Andrew and Hyman, which will be examined later.

It may be assumed forthwith that the proportionality between the Si-content and the expansion of the metal, established by Rugan and Carpenter, would be attributable rather to the property of the Si in promoting the formation of graphite than to the chemical properties themselves of that element. In fact, the penetration of the air into the mass of the metal will be all the easier in proportion as the number and the dimensions of the graphite lamellae are greater.

The experiments examined above, and, moreover, most of those carried out later by various workers, have all reference to the action on the metal of temperatures comprised between 650 and 850 deg. C., that is to say, approximate to or above the transformation points.

Before proceeding to examine these experiments, it appears interesting to analyse a study dealing with the action of superheated steam on cast iron, that is, with the effect of relatively low temperatures, 425 to 500 deg. C.

A very complete study of this question has been made by Campbell and Glassford.[4]

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[3] "La Fonderie Moderne," April and November, 1923.

[4] Eighth Congress on Testing Methods, "Revue de Metallurgie," 1912.

These writers, having observed the rapid corrosion of iron casting subjected to the action of superheated steam—a corrosion accompanied by an increase in volume—sought to determine: (1) The nature of (the) corrosion; (2) Why certain metals do not corrode; and (3) what must be done to prevent its occurence.

It may be noted, moreover, that Rugan and Carpenter had already found that cocks plunged into superheated steam at 360 deg. expanded, but they considered that this phenomenon was different from that of expansion at a high temperature. The work of Campbell and Glassford, however, appears to the author to bring out certain very interesting resemblances between these two phenomena. A first study consists of a micrographic examination of a dome-cock and flange which has been in use on the discharge side of the superheater of a separate furnace for two years. It shows considerable structural modifications in the metal.

In the first place, a thin coating of oxide is formed round the particles of graphite; then there are crevices which become wider and wider; finally, as the parts in direct contact with the steam are approached, the formation of a mixture of oxides and graphite is found, constituting a powdery mass devoid of strength.

This first examination, then, indicates progressive oxidation process of a very pronounced character, which takes place along the graphite lamellae.

Campbell and Glassford's Findings.

In studying the same phenomenon on bars subjected to the action of superheated steam (6.75 kg. (14.85 lbs.) at 425 deg C. for 30 days at first, then 90 days afterwards) Campbell and Glassford came to the following conclusions:—

(1) Under the action of steam, samples of white cast iron, steel and malleable cast iron show only one and the same type of oxidation. The samples have a skin regularly oxidised, to a very slight depth, and the oxide fills uniformly all the crevices which may exist on the surface of the sample.

(2) Under the same treatment samples of grey cast iron containing less than 1 per cent. Si show

superficial oxidation similar to the specimens of white cast iron or steel, but in addition a slight penetration of oxides following the largest plates of graphite is found.

(3) With Si between 1.25 and 2.50 per cent. there are the same appearances, but the penetration of the oxidation appears to grow with the increase of the silicon content and extends in depth.

The authors appear to conclude, therefore, with Rugan and Carpenter that the processes of oxidation increase proportionally with the increase of Si. In closing, however, they make one remark which is considered especially important:—

"It appears natural," they observe, "to conclude that the increase of the silicon content is related to the increased corrosion. Yet the very good resistance of a sample containing 2 per cent. Si might justify another conclusion, viz., that *the finer the graphite lamellae are, the less is the corrosion.* This conclusion is in accordance with practical experience, which shows that good gun iron (grey special cast iron) with 2 per cent. Si and Gr low) resists the action of superheated steam very well." In short, the two last researches appear to indicate that the increase in volume is due to a process of corrosion, that is to say, oxidation.

Okochi and Sato's Views.

Quite another point of view has since been advanced by certain Japanese scientists, whose work it is proposed to examine.[5]

A first investigation was carried out by Professors Okochi and Sato, the expansion curves being taken by means of the Chevenard dilatometer.

The following were the principal conclusions reached as a result of these tests: (1) The influence of oxidation is of little importance in regard to the increase in volume; (2) the expansion, during the first heat, is due to the decomposition of Fe_3C; (3) during the repeated heating and cooling, after the former the increase takes place twice: (*a*) At the point Ac; (*b*) at the higher temperatures; and (4) the increase at the point Ac (about 815 deg.) is due to the effect *caused by the pressure*

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[5] See the Communication to the Liège Congress (1922) by Mr. Tario Kikuta.

of the occluded gases in relation to the contraction accompanying the transformation Ac during the reheating, and the increase at the higher temperatures is due to the fact that the metal yields to the pressure of these occluded gases.

In order to accept this explanation, which approximates to that of Outerbridge, it must at the same time be admitted that the metal is not permeable to gas at high temperatures. Otherwise those gases would escape before causing an increase in volume. It would have to be admitted likewise that, inversely, the gases may penetrate the metal at low temperatures—this in order to explain the increases in volume following the further heats

Kikuta's Hypothesis.

Mr. Tario Kikuta undertook certain experiments intended to verify this hypothesis. He made a first series of tests for the purpose of measuring the velocity of the passage of air through a hollow cast-iron cylinder, the temperature of which was progressively raised. These permeability tests showed:—

(1) That the velocity of the passage of air through a hollow cylinder increases up to 600 deg. C. and then diminishes slightly, and (2) that the velocity of the passage of air is almost constant at the different temperatures, and is so up to 900 deg. After 34 heats this velocity decreases very slightly.

A second series of tests carried out on bars heated *in vacuo* showed that *these bars increased regularly in volume.* The two series of tests led Kikuta to reject the explanation of Okochi and Sato, as also that of Rugan and Carpenter, since no oxidation is possible *in vacuo.* To explain the increase in volume observed, he formulated a very ingenious theory which very well explains the cause of the formation of crevices and fissures noted by the preceding observers. The following is a summary: In the course of heating the

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[6] It may be remembered that when a cast iron bar is heated it expands regularly to the point Ac (about 815 deg.); at this moment a sharp contraction takes place, whereupon the expansion continues, following a regular curve. In cooling, the bar contracts regularly to the point Ar (about 725 deg.). At this point a sharp expansion takes place, after which contraction continues regularly.

expanding metal undergoes a sharp contraction at the point Ac; likewise, in the course of cooling and the shrinkage which accompanies it, a sharp expansion occurs at the point Ar. Now the metal is not a homogeneous substance, the distribution of the graphite being irregular: there are thick plates at certain points with thin lamellæ close beside them. The contraction and expansions which occur at the Ac and Ar points, and which are due to the dissolution and deposit of a certain quantity of free carbon, are very different in extent according as they are produced in the neighbourhood of thick or thin plates of graphite. The result is very considerable tensions at the different points of one and the same sample of metal. It is to these tensions, the action of which is specially apparent in the vicinity of the graphite plates forming acute angled fissures in the metal, that Kikuta attributes the phenomenon of increase in volume.

He expresses his conclusions as follows: The continuous expansion of grey cast iron *in vacuo* during the repeated heatings and coolings is due to *the differential expansion, to the different micro-proportions of the sample which produce numerous fissures or cavities in the neighbourhood of the plates of graphite.*

Moreover, he adds that: "In an oxidising atmosphere the expansion *is* accelerated by the oxides which are formed and which fill up the fissures or cavities originated during the Ar transformation." The action of oxidation on the increase of volume—contrary to what is accepted by Rugan and Carpenter—would therefore appear to be a secondary and indirect action.

It may be noted, however, that if this theory is capable of explaining the increase in volume by heating at 725 deg. C. or above, it does not in any way explain the increase in volume at the temperature of 425 deg., as studied by Campbell and Glassford. For, even admitting that the action of the superheated steam gives rise to phenomena essentially different from those accompanying a heat at 725 deg., it is nevertheless the case that a very marked increase in volume may be due solely to oxidation processes.

Nevertheless, the result of certain experiments by Portevin on the effects of hardening in grey cast iron appears to confirm Kikuta's theory to some extent. These observations relate to a study by Durand of the thermal treatment of cast iron[7]. As apparently the thermal treatment of cast iron (hardening followed by tempering and annealing) should prove of practical interest, it is thought well to dwell for a moment on this question, certain aspects of which fall within the general scope of the present study.

The work of Charpy and Grenet, as also that of Howe, has led a large number of scientists to consider that cast iron is constituted, from the point of view of structure, like a mixture of steel and graphite. From this view it follows directly that the properties of the metal will depend, on the one hand, on the composition or the shade (mild, medium, hard) of the constituent steel, and, on the other hand, on the quantity, dimensions and form of the graphite lamellæ disseminated throughout this steel; the latter play the part of inclusion, which inclusion causes in a very marked fashion a diminution in the mechanical properties of the constituent steel.

This view being accepted, Durand draws from it the following conclusions: Since the thermal treatment—the annealing, hardening and tempering of a steel—improves the mechanical properties very perceptibly, there is every reason to believe that the same treatment applied to cast iron should have the effect of improving the characteristics of its matrix of steel in a similar manner, and consequently those of the metal as a whole. The experiments made by Durand gave him the following results:—

Annealing carried out at a temperature of 900 deg. on test bars of grey cast iron shows that the treatment diminishes the tensile strength by about 30 to 40 per cent. The mean breaking stress after annealing remains practically constant, but the total breaking load is decreased by about 20 per cent., this fact being attributed by Durand to the graphite separation accompanying the annealing, which separation, in fact, he worked out by analysis. On the other hand, in dealing with test bars which had been oil-hardened

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[7] Report to the Académie des Sciences, 1922.

and afterwards tempered, he obtained an increase of tensile strength amounting to as much as 30 per cent. of the initial strength, and in certain metals an increase of over 40 per cent. in the height of drop. (After treatment the strength rose from 23 to 30 kg./cm.^{2}, and the height of drop from 65 cm. to 1.10 m.) (Technical specification of the French railways for shock tests.) This tensile increase is particularly marked after treatment in the case of metals having CC equal to about 0.60 per cent.

It may be noted that the metals tested had approximately the following composition: Gr., 2.70; CC, 0.50; Si., 1.18; Mn., 0.5; S., 0.04; and P., 0.2 per cent.

These tests confirm clearly the correctness of the view of Charpy, Grenet and Howe as to the composition of cast iron. It should be noted, however, that the experiments in question were carried out on test bars.

In discussing these experiments and their possible applications in the treatment of semi-steel cast-iron projectiles, Portevin points out that a large number of tests made on these projectiles have shown that any hardening followed by tempering rendered the projectiles porous. Certain shells subjected to the treatment increased in volume and were no longer fit to stand the specification compression test required by the Artillery. On being rung they gave a dull sound, an indication of defective mechanical properties. These defects were more accentuated by water hardening than by a milder hardening with oil.

It is reasonable to suppose that the hardening of a steel matrix enfeebled by graphite plates frequently forming an acute angle will produce blow-holes. All grey cast iron, however, is comparable to such a matrix. It is also evident that these blow-holes will be more pronounced in proportion to the thoroughness of the hardening, that is, they will be larger with water hardening than with oil hardening. These phenomena appear to be in every way comparable to the hardening blow-holes to be found in every steel casting which shows acute angles.

These observations appear specially designed to strengthen Kikuta's hypothesis, the hardening producing more markedly the same effect as the processes of internal tension to which he ascribes the expansion of the metal. In closing, Portevin[8] appears to favour the rejection of hardening followed by tempering cast iron.

In a second monograph Durand, returning to the question, points out that the increase in volume may be limited by the decrease of the silicon content in the metal treated and also by restricting the heat period—which is in accordance with the tests of Charpy and Grenet already quoted.

From an examination of the experiments summarised above, contradictory as their results may be, the following points nevertheless appear to stand out very clearly:—

(1) The increase in volume, which is found after a first heat followed by cooling, is incontestably due to the process of graphitisation, that is, to decomposition of the cementite $Fe_3C = 3\ Fe +$ graphite.

(2) The subsequent increase in volume is due both to the process of oxidation and to the action of internal stresses produced at the point Ar, this latter cause being evident after the heat tests *in vacuo* carried out by Kikuta and confirmed by the observations of Portevin on the effects of hardening (internal blow holes along the graphite lamellæ).

The author is, however, unable to agree with Kikuta to the entire rejection of the conclusions of Rugan and Carpenter with regard to the influence of oxidation on the increase of volume. The tests of Campbell and Glassford show incontestably that the oxidising action of the steam at temperatures not exceeding 425 deg. may produce a considerable increase of volume. It is evident, however, that in this case, the temperature being markedly below the critical point, Kikuta's hypothesis is not applicable. Therefore oxidation alone may, in certain cases, produce expansion.

Moreover, it was by heats at 650 deg. (that is, below Ar) that Outerbridge obtained increases of volume amounting to as much as 40 per cent. of the initial volume.

It is admitted that the two causes (oxidation and internal tension) act simultaneously, without, how-

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[8] Report to the Académie des Sciences, 1922.

ever, expressing an opinion on the relative influence of each of them upon the final increase of volume.

But, while admitting with Rugan and Carpenter the effect of oxidation, it is not thought that this process is, as they state, directly proportionate to the silicon content as a result of the rapid oxidation of the silico-ferrite.

As the author already stated in 1923[9], he still thinks that this proportionality is due, not to the presence of the silicon itself, but to its property of precipitating the graphite. Even at that time he considered that if, as Rugan and Carpenter find, metals with 1 per cent. Si increase in volume less than those with 2 per cent., this is because, with the increase of Si, there is produced an increase, not only of the quantity of graphite, but also and in particular an increase in the dimensions of the lamellæ of that element. Now, it is evident that the larger the graphite lamellæ are, the more the processes of oxidation due to penetration of the oxygen along these lamellæ will be facilitated on the one hand, and, on the other hand, the more apparent will be the effect of the internal stresses produced by the heat. This, moreover, is admitted by Kikuta.

The fact of the feeble oxidation of gun iron even when it contains 2 per cent. Si, which is noted by Campbell and Glassford, in itself confirms this hypothesis.

Now, if this hypothesis is accurate, it is evident that all the elements which, like silicon, precipitate graphite at the same time promote the increase of volume, and that, on the other hand, those elements which oppose the formation of graphite must retard that process. This is confirmed by work carried out subsequent to 1923 by Messrs. Andrew and Hyman[10] and by Mr. Donaldson.[11]

Influence of Elements on Growth.

Mr. Donaldson, in studying the action of repeated heats at 450 and 500 deg. C. on cast iron of different compositions, found that while chromium and manganese reduce the diminution in

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[9] See "Fonderie Moderne," A.T.F. Conference.
[10] Iron and Steel Institute, 1924.
[11] "Foundry Trade Journal," 1924.

tensile, after heating, the addition of nickel (an element whch precipitates graphite) has a contrary effect. After heating for 120 hours at 450 deg. C. he found a diminution of tensile strength of 7 per cent. in ordinary grey cast iron, of 6 per cent. in the same metal containing 2.43 per cent. Mn., of 5.5 per cent. with 0.39 Cr, and of 12 per cent. with an addition of 0.75 per cent. of nickel.

Andrew and Hyman, in making tests with repeated heats at 900 deg. C., reached similar conclusions, which they formulate as follows:—

Nickel and aluminium, acting like silicon, promote an increase in volume, and this not because these elements are specially oxidisable, but because they promote the formaton and the expansion of the graphite lamellæ. As regards chromium, it reduces expansion considerably without entirely preventing it. As a sequel to the examination of the work summarised above and as a result of the author's personal experience, he thinks he may finally formulate the following conclusions:—Cast irons subjected to repeated heats and coolings at temperatures not exceeding 900 deg. undergo an increase in volume accompanied by a diminution of all their mechanical characteristics. The increased volume following the first heating is due to decomposition of the cementite: $Fe_3C = Fe + Gr$.

The subsequent increases in volume are due to the combined effect of internal oxidation and the formation of fissures caused by the considerable stresses produced in the metal at the Ar and Ac points. The extent of these volume increases is dependent on the size and form of the graphite lamellæ contained in the metal.

Consequently, all those elements which favour the formation and agglomeration of graphite lessen the resistance of the metal to high temperatures. The action of those elements which form stable carbides, on the other hand, is unfavourable to the increase of volume in question. In the manufacture of heat-resisting cast iron it is desirable in practice to obtain in particular· (1) *A high Mn or Cr content* (about 0.40 Cr), these elements forming stable carbides which resist annealing. These carbides are of the type $(Fe\ Mn)_3\ C$. Their stability retards increase of volume subsequent to the first heat; (2) *a reduction of the amount of graphite by every possible means*; (3) *the formation of round graphite nodules and not of acute-angled lamellæ*, and (4) a judicious selection of elements such as Si, Mn, Cr and total carbon in order to secure the conditions set forth above, in a manner suitable for the ultimate purpose of castings required to withstand the effect of high temperatures.

Here it may be pointed out that cast irons low in total carbon have normally a very fine grain, and that on microscopic examination they show a highly divided graphite formed of very fine or curved lamellæ, or of round nodules. This type of structure is frequent in semi-steel cast iron with high steel content (25 to 30 per cent.), and particularly in cold- or semi-cold-blast metal. Moreover, it may be pointed out that this type of metal (total carbon low) may be obtained with a relatively high Si content, 2 per cent. or more. The result is that with a suitable admixture of silicon low total carbon can be obtained, while maintaining the combined carbon in the neighbourhood of 0.6 per cent. and even less.

Having made these remarks, it seems desirable to examine some particular cases of castings required to resist high temperatures, and let us see what compositions appear most desirable for such castings, taking as basis the theoretical conclusions we have formulated above.

It should be stated, however, that although these compositions are derived from theoretical reasoning, they have nevertheless been verified by the author in the manufacture of various articles and checked on castings which have given satisfaction in use.

Cast crucibles for containing lead baths, for hardening or tempering, or for melting alloys or white metals.

Here it is a question of castings which are generally heated by town gas in an atmosphere which is generally oxidising, and in direct contact with the flame. These castings are seldom perished by fusion (the heating temperatures being between 500 deg. and 600 deg. maximum), but usually by porosity. It may be observed that these castings have not to withstand any sort of mechanical stress, and that they generally remain rough foundry castings.

Under these conditions two formulæ may be applied: (1) White cast iron or white mottled iron with high manganese content to prevent any possibility of graphitisation, the silicon being kept low for the same reason; (2) semi-steel cast iron with low total-carbon content and low combined-carbon content, with a quantity of Mn sufficient to retard the graphitisation of this carbon, the S and P content being indifferent:—

T.C. < 3.0; CC < 0.5; Mn < 0.9; S, 0.15; P, 0.5 to 1.5; and Si > 2 per cent. A semi-steel cast iron with 25 per cent. steel with a ferro addition is quite suitable.

Thin grates for heating apparatus. The same composition with P increased to give fluidity, Si between 2 and 2.5 to prevent the formation of white cast iron, which would be too fragile:—

T.C. < 3.2; CC < 0.6; Mn, 0.9; S, 0.15; P, 1.5; and Si, 2 to 2.5 per cent.

Thick fire bars.—If the question of cost is not an obstacle, it is well to lessen the P content in order not to have too low a melting point. If the castings are liable to be perished by fusion the CC should be kept as low as possible:—

T.C. > 3.20; Mn, 0.7; P, 0.4 to 1.2; S, 0.15; and Si, 2.0 per cent.

It may be remarked that in all these castings the raising of the S content presents no disadvantage and is rather to be recommended, experience having proved that white or mottled cast iron with very high sulphur content resists the action of reheating very well.

Stoves, ranges, heating apparatus.—This type of castings must fulfil a series of almost contradictory conditions. As they are frequently enamelled, these castings have to undergo one or two heats, during which they are quickly brought to high temperatures. Progressive heating is rarely possible in this type of manufacture. This first heat and the necessity of avoiding excessive fragility, which would be very harmful during the manipulative stages through which these castings have to pass, render it impossible to obtain resistance to heat by the use of white or mottled cast iron, or even high percentage semi-steel. As these castings are also subjected to various machining operations (drilling), they have to be specially soft, particularly as their thickness seldom exceeds 3 to 4 mm. The limited thickness of these castings presents a danger in regard to fragility, but at the same time it necessitates the use of metal rich in phosphorus, as this element alone gives the metal the fluidity indispensable to the success of these castings.[12]

The same reasons which make it difficult to use semi-steel cast iron make it impossible to employ metals high in manganese or chromium.

In these circumstances, therefore, it appears difficult to embody the formula for a good heat-resisting cast iron, viz., the least amount of graphite possible with very low combined carbon. The solution may, however, be reached by another method. It is known that the size of the graphite lamellæ and consequently the grain of the metal increase with the increase of the Si content between 1 and 2.5 per cent. Si. But when in the neighbourhood of 2.5 per cent. nearly all the carbon is precipitated in the form of graphite, any further increase of silicon produces an inverse effect. The CC still remains low, but the total carbon content diminishes very rapidly. This total carbon being almost entirely in the state of graphite, with the increase of Si the lamellæ of the graphite are seen to become smaller and smaller and less numerous. *Pari passu* the grain of the metal becomes more compact until, as everyone has observed, a metal with 4.5 per cent. Si shows a grain indistinguishable from that of mottled cast iron, and a 10 per cent. ferro silicon has the appearance of white cast iron.

The author considers that in the case being dealt with (cast iron for stoves, etc.) it is desirable to take advantage of this property of silicon in order to lower simultaneously the CC and T.C. con-

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[12] The Author considers it well to keep the phosphorus content between 1 and 1.5 per cent. Above 1.5 per cent. the phosphorus, without increasing the fluidity of the metal materially, renders it extremely fragile. Experiments made on an industrial scale showed that thin castings with 2 per cent. P gave so much wastage from breakage in handling that it was found desirable to lower the P by the addition of hematite cast iron. Notwithstanding the relatively high cost of the latter, there was found to be a decided advantage from the point of view of ultimate cost.

tents He therefore recommends the following formula:—T.C. < 3.2; CC low; Si, 2.8 to 3.3; Mn > 0.4; S, 0.15, and P, 1 to 1.5 per cent.

This composition differs materially from the formulæ recommended by many specialists, both French and English. Many recommend a Si content of about 2.20 per cent. Nevertheless, the theoretical considerations which have been advanced in the present Paper and manufacturing tests carried out on a large scale have confirmed us in our opinion, and we recommend the above formula for all stove castings, whether enamelled or not.

Metal for Diesel motor castings.—For this type of casting practice appears entirely to confirm the theoretical results which have been described. It must be remembered that these castings have to stand great mechanical stresses while working in certain cases (pistons) at temperatures approximating to and sometimes above 650 deg. C. For these castings, therefore, the author recommends the use of semi-steel cast iron with high Mn content:—

T.C. < 3.2; Si, 1.8 to 2; Mn > 1.0; S < 0.10, and P < 0.30 per cent.

A slight amount of Cr (about 0.3) could not but prove beneficial. The author also considers that a P content below 0.3 is essential to obtain the maximum shock resistance. Professor Campion[13] has shown that the lowering of tensile resistance between 0 and 500 deg. is sensibly less with semi-steel cast iron than with ordinary cast iron. He is consequently inclined to employ semi-steel cast iron for Diesel motor castings. The author's conclusions agree with his on this point. The author thinks, however, that in the absence of Cr, the Si content should be kept between 1.8 and 2 in order to lessen the quantity of combined carbon, and not between 1 and 1.5 as is done in the case of semi-steel cast iron for shells.

Cast Iron which has to Undergo Normalising Annealing.—Certain castings, such as the water jackets of valveless motors, etc., are sometimes subjected to a normalising annealing for the purpose of neutralising the internal stresses and pre-

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[13] "Foundry Trade Journal," May, 1924.

venting possible deformations when working. In this case the castings undergo only one heat. According to what has been already said, the increase of volume, as also the porosity and the lessening of resistance which arise from it, can only be due to the annealing of the combined carbon. It is therefore well to keep to temperatures sensibly below 725 deg. in the course of this annealing. Moreover, the author advises starting with a metal having as low a combined carbon content as possible. This can be obtained very easily with a Si content equal to or above 2 per cent., according to the thickness of the castings.

Castings which have to Undergo Thermal Treatment.—As Durand has shown, oil-hardening at 850 deg., followed by tempering at 600 deg., can improve very materially the mechanical properties of certain cast irons. This treatment, however, does not appear desirable in the case of castings which have to stand high pressures. In all such cases, in order to prevent the increase in volume and the inconveniences resulting from it, it is necessary to reduce the heat period to the minimum. It is here unnecessary to seek to reduce the combined carbon content. As only the metals with combined carbon above 0.50 are capable of having their mechanical properties improved by this treatment, the author recommends for the purpose in question cast iron of the following composition :—T.C. < 3.3; CC > 0.5: Si < 1.20; Mn, 0.6; S < 0.10; and P < 0.3 per cent.

Castings having to Stand very High Temperatures approximating to the Melting Point of the Metal.—The considerations advanced in the present monograph do not apply to this type of casting, with regard to which the problem consists particularly in obtaining a product having a melting point as high as possible. The metal being regarded as a steel containing graphite lamellæ in a state of inclusion, it will at once be deduced that the melting point of the metal will be the higher in proportion as the steel constituting its matrix is soft. With the same object the sulphur and phosphorus will be eliminated. It is known, moreover, that graphite is in itself a refractory element, however slight its agglomeration, but that it burns fairly easily when it is in the state of extremely divided particles.[14]

It is for these reasons that it is desirable for this type of castings to get soft cast iron with low S and P contents, with combined carbon very low, and with the graphite formed of lamellæ as wide and thick as possible.

In closing this monograph the author desires to emphasise the fact that the formulæ given do not constitute a restrictive whole. They are not the only good formulæ, but represent merely one of the possible methods of obtaining heat-resisting cast iron.

He has here examined a series of scientific studies and sought to derive from them a general theory explaining the action of high temperatures on grey cast iron.

This theory has led him to adopt a certain number of compositions suitable for different types of castings which have to withstand the action of heat. The author finds, moreover, that the formulæ thus obtained agree generally with the results of practical and manufacturing tests. The greater number of them are no novelty, and have already been recommended by technical foundry authorities.

The foundry problems in regard to which a *general view* of this kind can be formulated are still extremely rare. The work of the foundry technical associations will without doubt serve rapidly to increase their number.

The author does not claim to exhaust such a complex question in the present Paper, but he would be happy if the examination and discussion of this work should serve to bring about, in the field of heat-resisting cast iron, a lasting agreement between metallurgical scientists and iron founders, for their well-considered collaboration appears to be more and more indispensable to all further progress in foundry work.

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[14] This is the case in castings which have to be enamelled. The object of the preliminary annealing to which these castings are often subjected is to produce partial consumption of the graphite lying at their surface, the presence of which forms an obstacle to the proper adhesion of the enamel.

DISCUSSION.

Mr. H. J. Young, F.I.C. (Newcastle-on-Tyne), said the author had presented certain conclusions, and he did not agree with many of these at all. In the first of his formulæ he gave T.C., 3.0; C.C., 0.5; Mn, 0.9; S, 0.15; P, 0.5 to 1.5; and Si, 2 per cent. Candidly he (Mr. Young) did not know how the author succeeded in using iron of that composition. Most certainly he said nothing at all about the cupola practice. For one thing, 2 per cent. of silicon was most undesirable. Certain of the other percentages were equally undesirable, and he could not understand why something entirely different from accepted practice should be recommended. Later on, the author ventured an opinion that many specialists, French and English, recommended a silicon content of about 2.20 per cent. He (Mr. Young) would not recommend it. The author, under the heading of metal for Diesel motor castings, referred to a temperature approximating 650 deg. C.—which, by the way, was one of the highest temperatures in Diesel engine work—and suggested a silicon content of 1.8 to 2 per cent. for that. In that paragraph he wound up thus:—"For these castings, therefore, the author recommends the use of semi-steel cast iron with high Mn content." A statement of that kind meant absolutely nothing, and the author might just simply have recommended the use of pig-iron. He (Mr. Young) felt that he could speak for some of the work done in this country, and he did not think there was agreement in Britain that the high silicon content the author recommended was used in connection with Diesel engine practice. High silicon content was very little used in superheater work. He made these observations as the result of his experience, and he should like the author to know that he was being contradicted on certain points.

Mr. F. J. Cook said he quite agreed with a good deal that Mr. Young had said. The author emphasised the point that the formation and size of graphite was of importance. In the earlier part of the Paper the author made that abundantly clear, and on page 77 he was responsible for the statement that there ought to be a reduction of the amount of graphite by every possible means. The conclusions of the author, therefore, rather bore out what he (Mr. Cook) had said in a previous Paper. He must, however, join with Mr. Young in condemning the analysis that was given for Diesel engine practice, because it was in every way contradictory to the methods adopted in this country. Moreover, he was going to claim that the castings made for Diesel engines with high temperatures in Great Britain were superior, or at least equal, to anything produced in that line on the Continent. Already he had dealt with this particular aspect of the question, in the Paper which he contributed to the North East Coast Institution of Engineers and Shipbuilders. On that occasion he stressed the necessity for small graphite. Then on the question of silicon content he personally should not recommend for Diesel engines any silicon content in excess of 1.2 per cent. There were circumstances, too, when they need not be afraid of silicon content up to 1 per cent. In Great Britain they were not altogether conservative regarding the practice of the past, and possibly some of the younger members of the Institute might find it advantageous to pursue an investigation of this kind.

Mr. J. S. Glen Primrose (Manchester) desired to know on what evidence Professor Levi stated on page 70 that the metal cast iron was not permeable to gas at high temperatures, whereas steel was very highly permeable. Although the statement was made that low total carbon was needed for fine-grained iron, the very desirable formation of early graphite iron was not necessarily dependent upon this, but chiefly on the casting rate. The recommendation to make Diesel motor castings with about 2 per cent. silicon was not in conformity with the latest and best practice in making maximum pearlite plus curly graphite castings where the reduction to 1 per cent. of silicon and under was found highly desirable.

Mr. Fletcher felt that in the general criticism the members ought not to ignore the valuable fore part of the Paper, especially in its reference to the recent work of Japanese metallurgists. The question of porosity in cast iron was of vital importance, because they were often too apt to take graphite as being entirely responsible for all the troubles. There was something in the point mentioned by Mr. Young that the space occupied by the graphite was a space that was not absolutely filled by that graphite. Round the edge of the graphite plate was a certain amount of porosity. It would be recalled that many years ago an ex-President of the Institute made the remark that there was no gas in cast iron. Things had progressed a good deal since then, and he thought it would be acknowledged that the influence of gas pores on the heat-resisting properties of iron was very considerable. There was no disputing the fact that the first part of the Paper was of extreme value, but he was just afraid, so far as the formulæ was concerned, that British foundrymen would take great exception to the analyses proposed.

Mr. J. W. Donaldson said he had read Professor Levi's Paper with considerable interest, and he regarded it as a very valuable contribution to the literature on this important subject of cast-iron heat treatment, particularly with reference to growth. The various deductions he had drawn from the numerous investigations carried out would be, he thought, generally accepted by all foundrymen. Professor Levi attributed the growth of cast iron after repeated heatings and coolings first to decomposition of cementite and second to internal oxidation and change in the metal at the critical points. While this no doubt took place with most irons, he would be pleased to have his theory as to what took place at low temperatures —440 to 550 deg. C.—with irons containing chromium where there was a contraction in volume accompanied by a decomposition of cementite. With reference to the composition suggested for Diesel engine castings, he would prefer a lower total carbon, say, 3 per cent., and a lower silicon content, say, 1 to 1.3 per cent., in order to increase rather than to lessen the proportion of combined carbon. The nearer it was possible to obtain a pearlitic structure under heat treatment by the addition of more manganese or by a small percentage of chromium or tungsten the better was the heat-resisting properties of iron and the smaller the change in volume.

The Author's Reply.

Mons. Levi, in reply to the discussion, wrote:—

Most of the criticisms were directed against a few lines which were devoted to Diesel engine castings where, as specified in my Paper, the castings are subjected to high temperature conditions, *such as the piston*. It appears to me that, so far as this subject is concerned, there has been a slight misunderstanding. It is established that cast iron having high silicon content has been rejected by practical men, but it is questionable whether this does not arise from the fact—special preparation excepted—that almost invariably that when the silicon content is greater than 2.0 per cent. the total carbon content is high.

I should have liked to know if the members who have, quite rightly, rejected silicon contents of 2.0 per cent. are prepared to discuss such cast iron but, *associated with low total carbon content*. I still believe that, in the absence of chromium (Text C.R.), the principal element to ensure a high resistance to heat is a low graphite content distributed in thin plates or round nodules.

If my memory does not fail me, Mr. F. J. Cook, for the *only Diesel engine casting* I referred to in my Paper, that is, the piston, has formally recommended in a very remarkable memoir a $\frac{\text{silicon}}{\text{total carbon}}$ ratio, which should give a figure ranging between 0.7 and 0.8 (" Engineering," 1920). This, with a total carbon of 3.0 per cent., gives a silicon content of between 2.0 and 2.25 per cent. Unfortunately, the original text is not available to me at the moment, and I am quoting from an abstract which appeared in "Revue de Metallurgie." As for other castings, it is established that one should reduce the silicon content according to the mass of the casting, and in certain cases do this until a figure of 1.0 per cent. is reached, as Mr. Cook has outlined. I am still of opinion that for pistons and cylinder jackets this figure is too low. Mr. J. S. G. Primrose is certainly in error in seeing on page 70 of my Paper confirmation that cast iron is not permeable to gas at high temperatures. I said exactly the opposite. The words used were " To accept Outerbridge's explanation, it is also at the same time necessary to accept that cast iron is not permeable to gas at high temperature." (Pour admettre l'explication d'Outerbridge, il faut admettre en même temps qua la fonte n'est pas perméable au gas à haute température). But *I did not accept Outerbridge's explanation*, and I showed later how the experiments of Kikuta contradicted this hypothesis. So far as the relationship between low total carbon and compact graphite is concerned, which was referred to by Mr. Primrose, I would draw attention to the fact that if compact graphite is obtained by other means it is nearly always associated with low total carbon. Howe, in his classical work on the Metallography of Iron and Steel, when dealing with certain irons containing compact graphite, states in the French edition:—" Malheureusement, il y'a lieu de croire que dans tous ces cas, cette compacité du graphite coencidait avec une teneur en graphite exceptionnellement basse, suffisante pour en expliquer la compacité "—total carbon, 3.16 per cent. (Unfortunately, there is every reason to believe that in all these cases the compactness of the graphite coincides with an exceptionally low graphite content, sufficiently so to explain this compactness.)

I can only state my complete agreement with the observation of Mr. Donaldson on the usefulness of chromium and tungsten (?) (French T).

Generally speaking, it is a pleasure to me to recognise the great skill and authority of the British foundryman on everything appertaining to Diesel engines, and for this reason I only devoted a few lines to the subject. Also I attach considerable importance to the criticisms made. On the other hand, it is with the greatest astonishment that I have read the observations made by Mr. H. J. Young. This gentleman insisted upon a temperature of 650 deg. C. for Diesel engine pistons, whilst Hurst (" Iron Age," 1921) stated this temperature may reach 900 deg. C.

Further on, in speaking of cast iron for heating apparatus (pages 78 and 79 of my Paper), I state that several British and French experts recommend for this type of casting a silicon content of greater than 2.25 per cent. However, I specified quite clearly that I referred to castings having less than 3 to 4 m.m. section thickness, cast green, and afterwards machined. Personally, I find 2.25 per cent. silicon to be insufficient. Mr. Young, however, quotes my words, and apparently recommends even for these castings a low silicon. If this is his advice, then such ideas, when they refer to very thin sections, are not only contrary to theory, but also against the most elementary precepts of foundry practice. If he uses it, Mr. Young may be quite sure that he will obtain white, unmachinable and useless castings. It seems impossible to me that an opinion so contrary to established foundry practice has actually been put forward by Mr. Young, who, judging from the isolated severity of his criticism, ought to be a particularly eminent specialist. On the contrary, if it is an established fact that a silicon content of 2.25 per cent. silicon has been recommended by authorities whom Mr. Young would contest, and that he himself takes exception, without actually saying it, to my advice, that it is necessary to have as much as 3 per cent. Si, I would therefore refer him to other authors recommending 2.25 per cent. silicon, such as, for instance, J. J. Porter (Report of the Committee on Standards—American Foundrymen's Association, 1910); G. A. Dyer ("Iron Age," pages 175 to 225, 1922), and the well-known book by Grunwald, "Technique de l'Emaillerie Moderne," page 37 (Si=2.20), etc.

Inter alia, Mr. Young questions the possibility of obtaining cast iron with a total carbon content of less than 3 per cent. and a silicon content of 2 per cent. This simply goes to show that he ignores the results obtained by simultaneously melting steel and ferro-silicon, which has been utilised in foundry practice for more than 15 years.

Mr. F. J. Cook writes to point out that in his reply to the discussion the author states that unless his memory fails him, he (Mr. Cook) had given a formula which with 3 per cent. total carbon demands a silicon content of 2.0 to 2.25 per cent. for Diesel engine cylinders. Either his memory has failed him or he has failed to read the formula correctly. The formula in question reads:—$\frac{C}{4.26 - \frac{Si}{3.6}} = 0.76$ to 0.82 for Diesel engine cylinders.

This calls for a silicon content of not more than half the amount Mons. Levi works it out to be.

LOW-TEMPERATURE HEAT TREATMENT OF SPECIAL CAST IRONS.

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

Cast iron used in the manufacture of certain castings, such as internal-combustion engine parts, especially cylinders, cylinder covers, pistons and piston rings, is subjected to temperature conditions which have a marked effect on the properties of the metal. Of recent years ironfounders, engineers, and metallurgists, have been confronted with this problem of suitable material, and many valuable and interesting contributions have been made on this subject. A series of Papers[8] were presented to the Scottish Branch of this Institute in November of last year, and these, with the subsequent discussion, describe very fully the position regarding oil-engine castings.

Low-temperature heat treatment of cast iron has been investigated by Hurst[1], Campion and Donaldson[2], Schuz[3], and Smalley[4], and is so well known to foundrymen that it is unnecessary to do more than refer to their work here. The effect of the additions of special elements to cast iron in order to improve its qualities has also been investigated, and the data so obtained is to be found in papers by Hatfield[5], Campion[6], Smalley[7], and Piwowarsky[10].

Some two years ago, the author commenced a series of experiments combining the effects of low-temperature heat treatment and the addition of special elements on cast iron. Part of the work dealing with the effect of manganese, chromium and nickel has already been published under the title of "Some Experiments on Cast Iron."[9] The present Paper includes that work and also extends the experiments to cover the effects of tungsten and vanadium, and the combined effect of chromium and nickel on cast iron.

The composition of the various irons, together with their tensile strengths as cast, are shown in

TABLE I.—*Chemical Analyses and Tensile Strengths.*

Mark.	P.	M.	C.	N.	V.	W.	C.N.1	C.N.2
	%	%	%	%	%	%	%	%
Graphitic carbon ..	2.48	2.55	2.24	2.50	2.49	2.24	2.54	2.55
Combined carbon ..	0.68	0.77	0.93	0.67	0.70	0.78	0.76	0.78
Total carbon	3.16	3.32	3.17	3.16	3.19	3.02	3.30	3.33
Silicon	1.48	1.52	1.40	1.56	1.45	1.89	1.89	1.21
Sulphur	0.054	0.014	0.04	0.095	0.084	0.064	0.06	0.09
Phosphorus	0.704	0.706	0.686	0.673	0.693	0.679	0.212	0.17
Manganese	0.97	2.43	0.973	0.943	0.994	0.764	0.71	0.64
Chromium	—	—	0.392	—	—	—	0.495	0.607
Nickel	—	—	—	0.746	—	—	0.245	0.300
Vanadium	—	—	—	—	0.124	—	0.013	0.020
Tungsten	—	—	—	—	—	0.475	—	—
Tensile strength, Tons per sq. in.	16.6	17.6	18.4	16.8	17.0	17.6	15.9	17.8

Table I. The plain iron was selected as one which is generally recognised as a good cylinder iron and one which has given good results in service. This iron, together with the manganese, chromium, nickel and vanadium irons, were prepared from the same cupola-melted metal by remelting in crucibles and casting into dry-sand moulds, 14 in.

TABLE II.—*Annealing Tests at* 450 *deg. C.*

Cast iron.	Duration of heating in hours	T.C.	C.C.	Tensile strength	Brinell hardness.
P.				Tons.	
	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
M.				Tons.	
	0	3.32	0.77	17.6	223
	40	3.29	0.74	—	217
	80	3.31	0.73	16.8	197
	120	3.35	0.55	16.5	183
	160	3.28	0.56	—	183
	200	3.33	0.54	16.4	183
C.				Tons.	
	0	3.17	0.93	18.4	248
	40	3.18	0.90	17.9	235
	80	3.17	0.85	17.5	212
	120	3.18	0.72	17.4	207
	160	3.16	0.69	17.2	201
	200	3.20	0.69	17.3	207
N.				Tons.	
	0	3.16	0.67	16.8	223
	40	3.18	0.18	16.0	167
	80	3.18	0.09	14.8	159
	120	3.16	0.08	14.8	159
	160	3.17	0.07	14.7	156
	200	3.15	0.07	14.7	149

by 1⅛ in. dia. The special elements were added in the form of ferro-alloys. In the case of the tungsten iron, difficulty was experienced in adding the ferro-tungsten, and in order to get an iron containing tungsten it was found necessary to vary the composition of the original iron by altering the silicon and manganese contents. The bars, however, were also cast from cupola metal remelted in crucibles. The two nickel-chrome irons were cast directly from the cupola without remelting, the nickel and chromium being added by the addition of Mayari pig-iron to the charge. This method of manufacture accounts for the higher total carbon and the variation of the other

Table III.—*Annealing Tests at 450 deg. C.*

Cast iron.	Duration of heating in hours	T.C.	C.C.	Tensile strength	Brinell hardness.
				Tons.	
V.	0	3.19	0.70	17.0	235
	40	3.20	0.18	16.5	174
	80	3.21	0.09	14.9	159
	120	3.22	0.09	14.6	159
	160	3.20	0.08	14.9	159
	200	3.23	0.07	15.0	152
				Tons.	
W.	0	3.02	0.78	17.6	212
	40	3.04	0.72	17.1	192
	80	3.07	0.63	16.8	183
	120	3.03	0.59	16.5	179
	160	3.07	0.60	16.5	183
	200	3.05	0.60	16.5	179
				Tons.	
C.N.1.	0	3.30	0.76	15.9	229
	40	3.23	0.68	15.6	223
	80	3.25	0.60	15.1	217
	120	3.23	0.56	14.9	207
	160	3.25	0.58	14.8	197
	200	3.26	0.57	14.9	197
				Tons.	
C.N.2.	0	3.33	0.78	17.8	225
	40	3.28	0.70	17.5	235
	80	3.27	0.64	17.2	217
	120	3.27	0.59	16.8	207
	160	3.27	0.60	16.8	201
	200	3.32	0.58	16.7	201

constituents. All the irons were cast at approximately the same temperature.

Heat-treatment experiments were carried out under the following three sections :—(1) Prolonged annealing tests at 450 deg. C. and 550 deg. C. respectively; (2) elevated temperature tests as cast and after prolonged annealing; and (3) growth tests. The method of experimenting and the results obtained from each test are considered separately.

TABLE IV.—*Annealing Tests at 550 deg. C.*

Cast iron.	Duration of heating in hours	T.C.	C.C.	Tensile strength	Brinell hardness.
P.				Tons.	
	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
M.				Tons.	
	0	3.32	0.77	17.6	223
	40	3.36	0.69	16.4	187
	80	3.30	0.46	16.1	171
	120	3.35	0.27	15.4	159
	160	3.35	0.25	15.2	148
	200	3.34	0.26	15.4	148
C.				Tons.	
	0	3.17	0.93	18.4	248
	40	3.16	0.57	17.9	207
	80	3.22	0.53	17.4	171
	120	3.20	0.49	16.8	159
	160	3.15	0.51	16.4	148
	200	3.21	0.49	16.4	148
N.				Tons.	
	0	3.16	0.67	16.8	223
	40	3.19	0.15	16.3	163
	80	3.20	0.05	13.8	138
	120	3.14	0.05	13.4	134
	160	3.20	0.04	12.9	129
	200	3.15	0.02	13.4	129

Annealing Tests.

Annealing experiments were carried out in two series of tests. In the first series, five bars of each iron were heated in an electric resistance furnace to a temperature of 450 deg. C. for 8 hours, allowed to cool overnight, then reheated the following day for the same period. At the end of every five days, corresponding to 40 hours' heating, a bar was removed and its composition as regards total and combined carbon determined,

TABLE V.—*Annealing Tests at 550 deg. C.*

Cast iron.	Duration of heating in hours	T.C.	C.C.	Tensile strength	Brinell hardness.
V.				Tons.	
	0	3.19	0.70	17.0	235
	40	3.14	0.18	14.8	170
	80	3.19	0.08	13.0	134
	120	3.22	0.06	12.0	129
	160	3.14	0.05	12.0	134
	200	3.23	0.03	11.8	129
W.				Tons.	
	0	3.02	0.78	17.6	212
	40	3.02	0.72	17.1	192
	80	3.00	0.52	16.2	179
	120	3.03	0.34	15.8	159
	160	3.01	0.28	14.9	143
	200	3.01	0.27	15.0	143
C.N.1.				Tons.	
	0	3.30	0.76	15.9	229
	40	3.28	0.67	15.1	207
	80	3.28	0.52	14.7	187
	120	3.27	0.43	14.0	—
	160	3.22	0.36	13.9	159
	200	3.28	0.37	13.8	159
C.N.2.				Tons.	
	0	3.33	0.78	17.8	255
	40	3.31	0.68	17.2	223
	80	3.31	0.56	16.6	187
	120	3.33	0.42	16.1	163
	160	3.33	0.40	15.8	167
	200	3.33	0.40	15.9	163

together with its tensile strength and Brinell hardness. The results are given in Tables II and III.

In the second series of tests, a similar procedure was followed, excepting that the bars were heated to 550 deg. C. instead of 450 deg. C. The results obtained are given in Tables IV and V.

Consideration of the results obtained in those tests show that prolonged annealing at 450 deg. C. and 550 deg. C. respectively produces changes in the various irons. In each case the combined carbon is decomposed, the tensile strength falls off, and the Brinell hardness decreases. The degree of change varies for the different irons and is more marked at 550 deg. C. than at 450 deg. C. In Table VI a summary of the results is given, showing the number of hours required to produce more or less stable conditions, and the percentage decrease in the combined carbon, tensile strength, and Brinell hardness when these conditions are attained.

On heating the plain cylinder iron at 450 deg. C. the carbide is decomposed to the extent of 34 per cent. This change requires 160 hours' heating to complete, and is accompanied by a decrease in the tensile strength of 7 per cent. and in the Brinell hardness of 18 per cent. Heating to 550 deg. C. produces a carbide change of 82 per cent after 40 hours' heating, the tensile strength falling off by 11 per cent. and the Brinell hardness by 42 per cent.

Influence of Manganese.

Increasing the percentage of manganese in the iron from 0.97 per cent. to 2.43 per cent. increases the stability of the combined carbon probably due to the formation of manganese carbide, which crystallises with the iron carbide, forming a double and more stable carbide. This is indicated by a smaller decrease per cent. in the combined carbon both at 450 deg. C. and 550 deg. C.

Influence of Chromium.

The addition of a small amount of chromium 0.392 per cent. produces a similar but more powerful effect than the 1.5 per cent. increase in manganese. The initial tensile strength is increased

TABLE VI.—*Percentages Changes Produced by Annealing.*

Cast iron.	450 deg. C.				550 deg. C.			
	Duration of heating in hours.	Combined carbon, decrease per cent.	Tensile strength, decrease per cent.	Brinell hardness, decrease per cent.	Duration of heating in hours.	Combined carbon, decrease per cent.	Tensile strength, decrease per cent.	Brinell hardness, decrease per cent.
P.	160	34.0	7.0	18.0	40	82.0	11.0	42.0
M.	120	27.0	6.0	18.0	120	67.0	12.0	33.0
C.	120	25.0	5.5	16.0	120	46.0	11.0	31.0
N.	80	87.0	12.0	30.0	80	94.0	18.0	40.0
V.	80	88.0	12.0	32.0	80	94.0	29.0	45.0
W.	120	23.0	5.7	15.5	160	65.0	14.7	33.0
C.N.1 ..	120	25.0	6.3	14.0	160	51.0	13.0	31.0
C.N.2 ..	120	26.0	6.2	21.0	120	49.0	10.6	36.0

considerably and also the percentage of combined carbon. This carbide, due to the presence of chromium carbide, is more stable under temperature, showing less tendency to decompose. The tensile strength and Brinell hardness shows smaller percentage decreases at 450 deg. C. At 550 deg. C. the decreases are somewhat similar to those obtained with the plain cylinder iron, but when the initial tensile strength is considered it is seen that even after stable conditions are attained by annealing the chromium iron at 550 deg. C., the final tensile strength is similar to that obtained in the cylinder iron as cast.

Influence of Nickel, Vanadium, and Tungsten.

Nickel added to cast iron to the extent of 0.746 per cent. produces little effect in the cast condition, but has a marked effect when the iron is heated. At 450 deg. C. it produces rapid decomposition of the combined carbon to the extent of 87 per cent., and at the higher temperature of 550 deg. C. decomposition is almost complete. This carbide change is accompanied by a large decrease in the strength and hardness.

A small percentage of vanadium 0.124 per cent. produces changes very similar to those produced by the larger percentage of nickel. The decrease in tensile strength after annealing at 550 deg. C. is most marked.

Annealing at 450 deg. C. the iron containing 0.475 per cent. of tungsten produces changes somewhat similar to those produced in treating the chromium iron at a similar temperature. Raising the annealing temperature to 550 deg. C., however, affects the stability of the carbide in this iron, and produces more rapid decomposition than is produced in the chromium iron under similar conditions. The changes at this temperature are somewhat similar to those produced in the manganese iron when similarly treated.

Influence of Nickel-Chromium.

The two chrome-nickel irons, owing to the difference in their carbon, silicon, and phosphorus contents, are scarcely comparable with the other irons. The principal difference between those two irons is the lower silicon content and higher chromium and nickel contents of the second. This difference in composition has a noticeable effect on the initial strengths and hardness of the irons, but little effect on their heat-resisting properties as the percentage decreases are somewhat similar.

TABLE VII.—*Elevated Temperature Tests.*

Cast iron.	Breaking temperature degs. C.	As cast.	Annealed for 200 hrs. at 450° C.	Annealed for 200 hrs. at 550° C.
P.	Degs.	Tons.	Tons.	Tons.
	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
C.	Degs.	Tons.	Tons.	Tons.
	15	18.4	17.3	16.4
	100	18.0	17.1	16.2
	200	17.8	17.1	15.8
	300	17.8	17.2	15.6
	400	17.8	17.1	15.2
	500	17.8	16.0	15.2
	600	12.8	11.0	9.4
W.	Degs.	Tons.	Tons.	Tons.
	15	17.6	16.5	15.0
	100	17.8	16.6	15.0
	200	16.6	16.0	14.9
	250	16.2	—	—
	300	16.1	15.7	15.0
	350	16.6	—	—
	400	17.0	14.7	14.2
	500	15.0	14.2	12.0
	600	10.2	9.3	7.1
C.N.2	Degs.	Tons.	Tons.	Tons.
	15	17.8	16.7	15.9
	100	17.0	16.6	15.6
	200	17.4	16.1	15.0
	300	17.8	15.9	14.5
	400	18.0	15.2	13.8
	500	15.0	12.2	10.6
	600	8.6	7.5	6.4

The second iron, however, even after prolonged annealing at 550 deg. C., has a strength superior to the first iron in its cast condition. The general effect of annealing on the two irons produces conditions somewhat similar to those produced on the straight chromium iron by similar treatment.

Consideration of Results.

Consideration of the various results indicates that low-temperature annealing decomposes the carbide with a corresponding decrease in the strength and hardness of the iron. The addition of small amounts of special elements has in the case of chromium, tungsten and manganese a stabilising effect on the carbide; whereas in the case of nickel and vanadium the decomposition of the carbide is accelerated. A small percentage of chromium, about 0.4 per cent., produces the best results. It might be noted here that this percentage of chromium is the maximum amount that can be added to an iron of the composition experimented with, larger amounts producing irons so hard that difficulty is experienced in machining them. Tungsten to the amount of 0.5 per cent. and manganese to the amount of 2.5 per cent. affect iron in a somewhat similar manner, but while increasing the stability of the carbide over that of the plain iron do not produce the same degree of stability as the smaller amount of chromium does. In iron containing both chromium and nickel, chromium exerts the predominating effect, the nickel allowing of the introduction of a larger percentage of chromium than would be possible if chromium were added alone. A similar result would no doubt be obtained by increasing the silicon content in the straight chromium iron.

Elevated Temperature Tests.

Elevated temperature tests were carried out on the plain cylinder iron and on the special irons showing the best results from the annealing tests, namely, the chromium, tungsten, and second chrome-nickel irons. Sufficient bars were not available to carry out tests with the manganese iron.

In carrying out those tests a set of bars from each of the irons was broken at temperatures ranging from atmospheric to 600 deg. C. A second set from each iron was annealed for 200 hours at 450 deg. C. and then broken over the same temperature range, while a third set was annealed for 200 hours at 550 deg. C. before breaking. In carrying out the tests the bars were heated in an electric-resistance furnace attached to the testing machine, the temperature being measured by thermo-couples fixed to the top and bottom of the bars. Each bar was maintained for half an hour at the temperature determined on before breaking. The results obtained from the various tests are given in Table VII and Figs. 1 to 4.

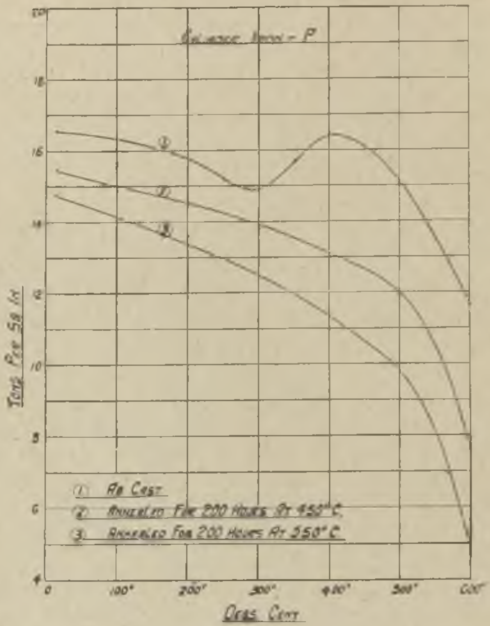

Fig. 1.—Elevated Temperature Tests of Cylinder Iron.

Consideration of the results in general indicate that if either of the irons are to be submitted to temperatures ranging from 450 to 550 deg. C. tests obtained in their cast condition cannot be taken as representative. In the cast condition the tendency is for the strength of iron to diminish slightly as the temperature rises and then to increase again with a further rise in temperature, attaining a maximum in the neighbourhood of 400 deg. C., after which the strength rapidly diminishes with increasing temperature. In the case of the chromium iron and to a lesser extent in the case of the chrome-nickel iron, the curves obtained are more regular, and in the chromium iron the strength is maintained to 500 deg. C. before falling off.

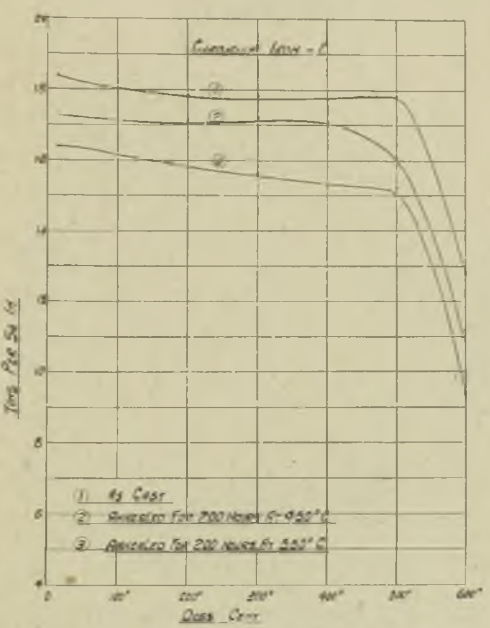

Fig. 2.—Elevated Temperature Tests of Chrome Iron.

Subjecting the irons to prolonged annealing at 450 and 550 deg. C. produces, as previously indicated, changes in their composition, with the result that when the irons are tested at elevated temperatures a considerable diminution in strength takes place. The curves obtained in each case are more regular, the strength diminishing uniformly as the temperature increases. The decrease in strength is fairly large, showing in the case of the cylinder iron when tested at 400 deg. C. decreases of 21 per cent. and 27 per cent, after annealing at 450 and 550 deg. C. respectively, and in the case of the chromium iron decreases of 4 per cent. and 15 per cent. after similar annealings and when tested at the same temperature. The decreases in the tungsten and chrome-nickel iron under similar conditions are intermediate between those figures.

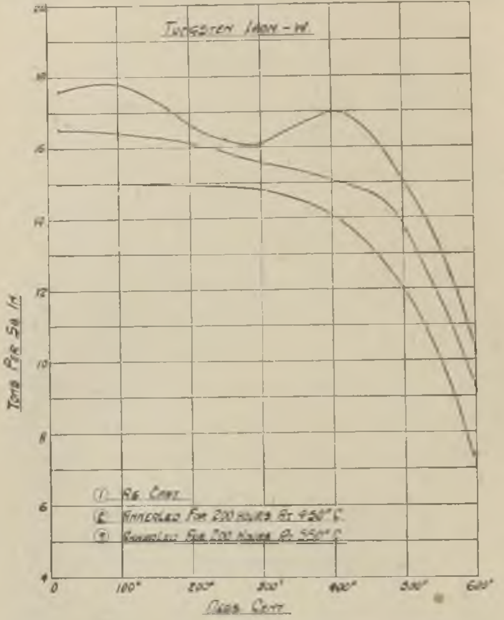

FIG. 3.—ELEVATED TEMPERATURE TESTS OF TUNGSTEN IRON.

The curves obtained on breaking each iron at temperatures from atmospheric to 600 deg. C. after prolonged annealing at 450 and 550 deg. C. respectively are given in Figs. 5 and 6. Testing at 400 deg. C. after a 450 deg. C. annealing the relative increases in tensile strength for the chromium, tungsten, and chrome-nickel irons, over the ordinary cylinder iron, are 32 per cent., 13 per cent., and 17 per cent. After a 550 deg. C. annealing the corresponding increases are 38 per cent., 30 per cent., and 25.5 per cent. At both temperatures the stability and superiority of the iron containing chromium is marked.

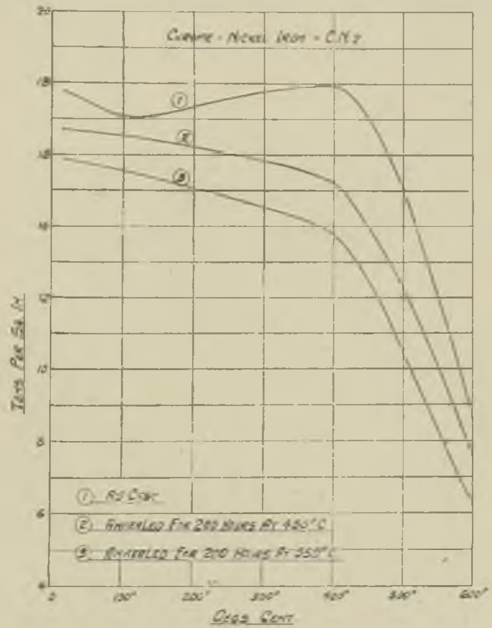

FIG. 4.—ELEVATED TEMPERATURE TESTS OF CR-NI IRON.

Growth Tests.

These tests were carried out on all the irons at a temperature of 550 deg. C. Two bars from each iron, accurately machined to 6 in. in length and 1 in. in diameter, were heated in an electric resistance furnace daily for a period of 8 hours, allowed to cool overnight, and reheated the following day. After five heatings the bars were removed and accurately measured by means of a Whitworth measuring machine reading to hundred thousandths of an inch. The average measurements obtained, together with the volumes calculated from them and the changes per cent., are given in Tables VIII and IX. A graphic representation of the results is given in Fig. 7.

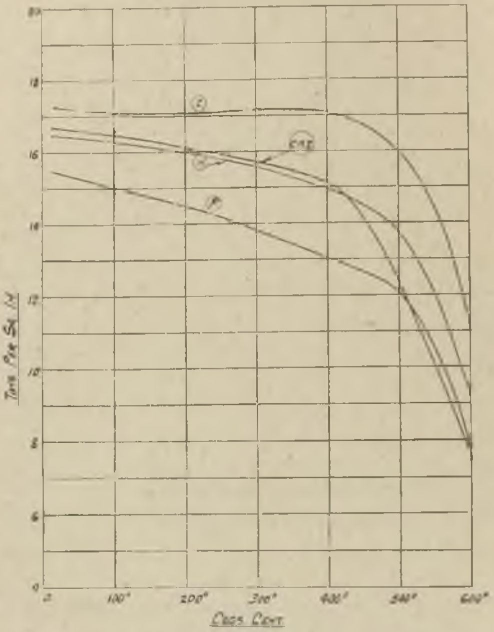

Fig. 5.—Elevated Temperature Tests after Annealing at 450 deg. C.

The amount of growth which takes place in each of the irons is small when compared with the growth of an ordinary foundry iron. This is shown in Fig. 8, where the results obtained from the different irons are given along with the results obtained from a foundry iron of the following composition: Total carbon, 3.29; graphitic carbon, 2.72; combined carbon, 0.57; silicon, 1.75; sulphur, 0.11; phosphorus, 1.54; and manganese. 0.16 per cent.

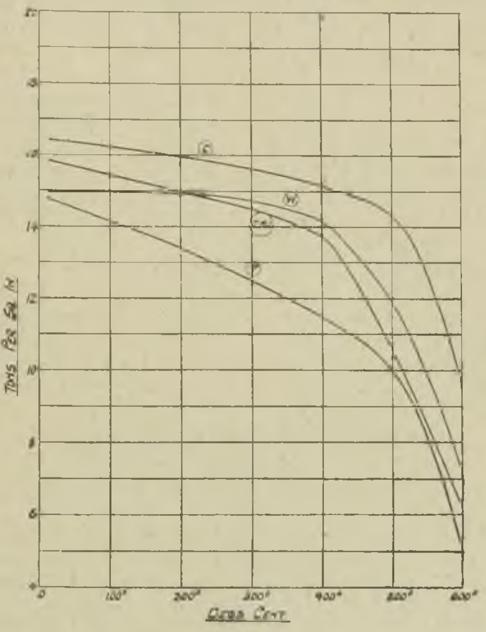

Fig. 6.—Elevated Temperature Tests after Annealing at 550 deg. C.

Growth in the cylinder iron attains a maximum after 10 heatings, when the volume increases by 0.13 per cent. The manganese and vanadium irons give curves similar to each other, the most growth taking place during the first 10 heatings and then slowly to 25 heatings with a slight tendency to rise; change of volume after 25 heatings amounting to 0.17 per cent. Growth in the nickel iron takes place slowly at first, but increases with the number of heatings yielding a volume change of 0.25 per cent. after 25 heatings and still increasing. There is little change with the tungsten iron, a maximum change of 0.04 per cent. being obtained after 10 heatings. With chromium there is contraction instead of growth. This contraction takes place slowly for 10 heatings, then more rapidly to 20 heatings, then slowly again to 25 heatings where the volume has decreased by 0.27 per cent. The two chrome-nickel irons do not show contraction, although they both contain a higher chromium content, the effect of chromium in producing contraction evidently being prevented by the presence of the nickel. Both irons show little growth, attaining a maximum of 0.08 per cent. after 20 heatings.

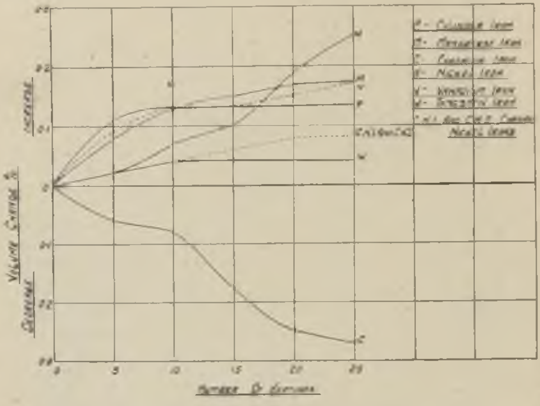

FIG. 7.—GROWTH TESTS AT 550 DEG. C.

Summary and Conclusions.

The conclusions derived from the various tests may be summarised and stated as follows:—

(1) Annealing cast iron for prolonged periods at temperatures of 450 deg. C. and 550 deg. C. respectively, produces changes in the composition of the iron which affect the strength and hardness of the material. These changes are due to decomposition of the carbide, and are more marked at the higher temperature.

(2) If cast iron is to be subjected to elevated temperatures, its strength at those temperatures cannot be determined on cast bars. The material has to be annealed at the working temperature until the carbide change is complete before making tests.

(3) Cast iron, if of suitable composition, will show very little growth or change of volume after repeated heatings and coolings.

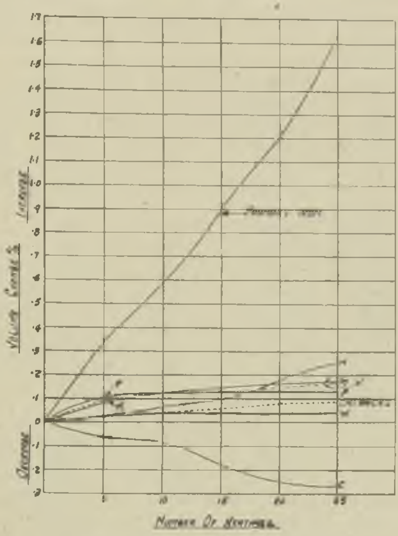

FIG. 8.—GROWTH TESTS AT 550 DEG. C.

(4) Small additions of special elements modify the properties of cast iron, both as regards annealing and strength at elevated temperatures as well as the growth properties.

(5) The addition of chromium to the extent of 0.4 per cent. modifies the properties of the iron to the greatest extent. The initial strength is increased by 11 per cent., the carbide is rendered more stable on annealing, with a corresponding smaller reduction in the strength and hardness; and the breaking strength at 400 deg. C. after

stability is attained with prolonged annealing is 25 per cent. greater than that obtained with a corresponding iron containing no chromium. Repeated heatings and coolings to 550 deg. C. produce a small decrease in volume instead of growth.

(6) Increasing the manganese from 1.0 per cent. to 2.5 per cent., or adding 0.5 per cent. of tungsten produces results somewhat similar to each other and similar to those produced by the chromium but by no means so marked. The growth of both irons is small, that of the tungsten being practically nil.

TABLE VIII.—*Growth Tests at 550° C.*

Cast iron	Number of heatings.	Length, ins.	Diameter, ins.	Volume, cub. ins.	Change per cent.
P.	0	6.0000	1.0000	4.710	0
	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
M.	0	6.0000	1.0000	4.710	0
	5	6.0004	1.0004	4.714	0.09
	10	6.0007	1.0006	4.716	0.13
	15	6.0009	1.0007	4.717	0.15
	20	6.0011	1.0007	4.718	0.17
	25	6.0010	1.0007	4.718	0.17
C.	0	6.0000	1.0000	4.710	0
	5	5.9992	0.9998	4.707	0.06
	10	5.9985	0.9997	4.706	0.08
	15	5.9979	0.9992	4.701	0.18
	20	5.9980	0.9989	4.698	0.25
	25	5.9978	0.9988	4.697	0.27
N.	0	6.0000	1.0000	4.710	0
	5	6.0004	1.0001	4.711	0.02
	10	6.0010	1.0003	4.713	0.07
	15	6.0025	1.0004	4.715	0.10
	20	6.0030	1.0008	4.719	0.19
	25	6.0035	1.0010	4.722	0.25

(7) Adding 0.75 per cent. of nickel or 0.125 per cent. of vanadium slightly improves the initial strength of iron, but renders the carbide less stable during annealing, a large amount of graphitisa-

tion taking place even at 450 deg. C. with a corresponding large decrease in the strength and hardness.

(8) The effect of adding both chromium and nickel in the proportion of 2 and 1 allows the use of a higher percentage of chromium, although it would appear that the benefits derived from the increased chromium as regards stability of the carbide and strength at elevated temperatures are more than diminished by the accompanying nickel. Better results would no doubt be obtained by omitting the nickel and increasing the chromium with additional silicon.

TABLE IX.—*Growth Tests at 550° C.*

Cast Iron	Number of heatings.	Length, ins.	Diameter, ins.	Volume, cub. ins.	Change per cent.
V.	0	6.0000	1.0000	4.710	0
	5	6.0015	1.0003	4.714	0.09
	10	6.0019	1.0005	4.716	0.13
	15	6.0020	1.0005	4.716	0.13
	20	6.0020	1.0006	4.717	0.15
	25	6.0021	1.0007	4.718	0.17
W.	0	6.0000	1.0000	4.710	0
	5	6.0002	1.0001	4.711	0.02
	10	6.0005	1.0001	4.712	0.04
	15	6.0008	1.0001	4.712	0.04
	20	6.0007	1.0001	4.712	0.04
	25	6.0008	1.0000	4.712	0.04
C.N.1	0	6.0000	1.0000	4.710	0
	5	6.0003	1.0001	4.711	0.02
	10	6.0007	1.0002	4.712	0.04
	15	6.0010	1.0003	4.713	0.06
	20	6.0010	1.0004	4.714	0.08
	25	6.0011	1.0004	4.714	0.08
C.N.2	0	6.0000	1.0000	4.710	0
	5	6.0004	1.0002	4.712	0.04
	10	6.0006	1.0002	4.712	0.04
	15	6.0008	1.0002	4.713	0.06
	20	6.0010	1.0002	4.714	0.08
	25	6.0010	1.0002	4.714	0.08

For permission to publish these tests, the author's thanks are due to Mr. James Brown, C.B.E., and the other directors of Messrs. Scotts' Shipbuilding & Engineering Company, Limited, Greenock.

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DISCUSSION.

MR. J. E. FLETCHER observed in opening the discussion that the Paper, in conjunction with the author's earlier work on the subject, would be appreciated by all who had anything to do with the low-temperature heat treatment of special cast irons. It seemed to him that those of the members who were interested in the heat treatment at low temperatures that the results obtained by the author bore out the work that had already been done in other directions. Indeed, if one might suggest a further series of tests, it would be on similar irons cast under " Perlit " iron conditions. That point was to be raised at another session of the present year's conference. His own personal view of the issue raised was that they ought to normalise before they began their tests and expected to derive results. In other words, they would have to begin a series of experiments of this kind from the dead level of " Perlit " iron. He was ready to agree with what the author had said as to the influence of nickel-chromium. Work which he (Mr. Fletcher) had done a few years ago rather demonstrated to him that the best results were obtained by adding about 0.5 per cent. of chrome. Of course, those who had to do with general foundries knew that chromium sometimes was not an unmixed blessing. Indeed, his advice to foundrymen would be to see that their scrap was taken care of, so that it did not become mixed with other castings. If that was not done, then he could easily conceive something happening which would neutralise all the apparent benefit. He agreed with Mr. Donaldson in keeping his chromium down to the neighbourhood of 0.5 per cent. He further endorsed the author's suggestion respecting silicon as a means of reducing accidental hardness.

Mr. F. J. Cook felt the members would all be in agreement as to the value of the Paper, but he was desirous of asking the author why he settled on 450 deg. C. and 550 deg. C. Perhaps Mr. Donaldson would say whether his choice was accidental or specific. His suggestion, however, would be this—that Mr. Donaldson should continue this work for the benefit of the members and submit conclusions and findings as to the structures of the various irons. He (Mr. Cook) was quite convinced there was more in the structure of the metal than in the actual chemical analysis. He made that remark advisedly and as the outcome of a great deal of experience derived from experiments which he had carried out.

He recalled an instance with two irons of similar chemical composition, one of which was cast in the ordinary way and the other in chill. Both samples were subjected for some years to superheated steam of possibly 550 deg. One engine had a condenser and the other had not, and after an interval of years, when the particular samples were polished it was found that the results were totally different—there being distinct signs of corrosion in one case and not in the other. The experience was a very practical one to him, but it confirmed him in practice which he had carried out for many years, namely, that of chilling cylinders, and particularly those which had to stand up to superheated steam. The same fact had emerged in connection with engines working regularly with superheated steam, namely, that where there was a chill in the cylinders there was no sign of corrosion or erosion. It was because of these results that he suggested to the author it would be for his own advantage and that of the members if he looked particularly into the structure of the iron. Mr. Donaldson's work and experiments seemed to prove that they did get better results from chromium than from manganese. He agreed that the physical properties were as good, and his own experience rather tended to show that the wearing properties would be greatly increased.

Comparative Value of Chrome Additions.

Mr. H. J. Young observed that the author had referred in his Paper to annealing tests and growth tests. His view on that point was that the annealing tests were in reality growth tests. Indeed, on that particular point he felt it was rather a pity the word "annealing" should have crept into the Paper at all in the sense that it was intended. Dealing with the influence of chromium, Mr. Donaldson made the following point:—"Even after stable conditions are attained by annealing the chromium iron at 550 deg. C., the final tensile strength is similar to that obtained in the cylinder iron as cast." Supposing that cylinder iron had contained one-half per cent. of silicon instead of 1½ per cent., he (Mr. Young) did not consider such a remark as the foregoing could have been possible. As to the addition of nickel, he thought it had no practical influence on pig-iron at all up to a certain silicon content. There was no real use at all in the addition of nickel there, because obviously they knew what the result was to be. It seemed to him that if they desired to ascertain the effect of nickel they had to take away the silicon and watch for effect. No doubt it would be an expensive business to compare cast iron without any silicon and with the addition of nickel instead, but he submitted that it would be a far more fair comparison than the one outlined in the Paper. At a later stage of the Paper and under the heading of "Consideration of Results," the author ventured the opinion that a small percentage of chromium, about 0.4, produced the best results. Then he added: "It might be noted here that this percentage of chromium was the maximum amount that can be added to an iron of the composition experimented with, larger amounts producing irons so hard that difficulty is experienced in machining them." He did not see that that statement was justified with a hot mould, because surely it was possible to produce machinable iron? Then the author mentioned that chromium iron showed contraction in certain cases instead of growth. He personally believed there were a number of irons on the market at the present moment that were showing contraction in that way. It applied not only to chromium iron but to other irons. That he considered was a serious matter for the makers and users of Diesel engines. Indeed, he knew of one Diesel engine manufacturer who would not look at chromium iron on that account. Mr. Donaldson made a further remark in his summary to the effect that the material had to be annealed at the working temperature until the carbide change was complete. He suggested to the author that the carbide change as explained in the paper could not have been complete at all. If the statements made as to the heatings and coolings were carefully analysed and the figures critically examined it would be found that the carbide changes were not quite so complete as the author's contribution assumed them to be. He agreed with Mr. Cook that structure ought to be determined, and on that point he suggested that two important elements had to be considered—what is in the iron and how does it act? Mr. Young thereafter entered into a criticism of the author's tables, and suggested reasons why they might be inconclusive. In conclusion, he was desirous of saying how much he appreciated the effort that must have been expended on a Paper of this description. How many amongst them would undertake a research of the nature revealed in the contribution? The work was altogether of intense value, especially to those members of the Institute who were dealing with and looking to the future of cast iron.

Contraction of Chromium Cast Iron,

Mr. J. S. Glen Primrose (Manchester) asked if the author could inform the members if he had determined what loss of chromium and nickel he had found by remelting the Mayari pig-iron. In view of the importance of rate of heating-up on the amount of graphite separated it would be interesting to know how quickly the bars named on page 99 of the Paper had been treated, as the slower the rate the more was the carbon precipitated, and also the greater the volume of growth. The low grade foundry iron named on page 105 of the Paper seemed a poor comparison to make, as the ratio of manganese to sulphur seemed ridiculously low. He would like to know if the author could explain the mechanism of the change on annealing the chromium alloy iron which was said to show a contraction instead of a growth on repeated heating, especially as Professor Levi quoted Drs. Andrew and Hyman as finding that chromium reduced expansion without entirely preventing it. It would be invaluable to know if the author could give any explanation of what the contraction of the chromium iron named on page 108 of the Paper was due to on repeated heatings and coolings to 550 deg. C.

Dr. Andrew, referring to the question put by Mr. Primrose, said he took it that after the heating a considerable amount of scale fell off. Certainly when Dr. Hyman and he carried out their work on this investigation they found that the scale differed with the different classes of iron. Some of the scale fell off very quickly. He should like, if at all possible, that the author would throw additional light on this part of his Paper. His tests had rather gone to show that not only did they get oxidation of the surface, but oxidation took place by way of the graphite.

Dr. Hyman and himself had considerable evidence before them at the time that the graphite showed oxidation. Mr. Donaldson might also explain whether he found any relationship between the graphite flakes and the growth, because Dr. Hyman and he had discovered that the larger the former flakes were the more intense was the growth.

Mr. J. G. Pearce, Director, B.C.I.R.A., Birmingham, asked the author what method it was proposed to pursue for rapidly discriminating between two irons?

Annealing of Cast Iron.

Mr. J. Shaw (Sheffield) said that so far as his own experience had gone the addition of chromium did not add to the strength of iron in test-bar work, but if they were dealing with large bodies he believed it did have a beneficial effect. He agreed entirely with the author in the observations he had made respecting people annealing castings without knowledge. An instance of that kind had been brought to his notice in regard to test-bars. They could not send out too strong a warning against the futility and waste of annealing without judgment and knowledge.

The President remarked that as this Paper proceeded and developed along the lines of original research and presented its experiments, tables and conclusion in a systematic manner, it was one of the most valuable types of contributions that could be put before them.

The Author's Reply.

Mr. J. W. Donaldson said he was personally rather sorry he used the term annealing. In reality the wrong word had been used. Perhaps it would have been better for him to have referred to it as "heat treatment." After all was said and done, the tests were not annealing tests. Generally speaking, they regarded annealing as prolonged heating, but in the present instance where, as the Paper clearly indicated, there had been repeated heatings and coolings, the phrase "heat treatment" would have been preferable to the use of the word "annealing." He supposed that that statement would now have the effect of removing a large amount of misconception. When writing the Paper he had not sufficient data at hand regarding the micro-examinations of the various irons. He had now obtained a certain amount of data on that point which would enable him to carry on his tests and develop them still further. In reply to what Professor Andrew had said, he had to mention that there were indications of oxide, and there was certainly a relationship between the graphite flakes and the extent of growth taking place. He would develop that point when he dealt with the question of micro-examination. Something had been said in regard to pearlitic iron, and his view was that the irons should be judged from their micro-construction more than from their chemical analysis. It was desirable, he thought, to have iron containing more or less such pearlitic structure as would maintain it in heat treatment. That might be done by the addition of chromium, manganese or tungsten. The first point, however, was to get a pearlitic structure, and to get it as nearly as possible amenable to heat treatment. Such other questions as had been raised in the course of discussion he would endeavour to deal with satisfactorily in a written communication.

Dealing with the various points raised in the discussion, the author, first in reply to Mr. Fletcher, admits that the phosphorus content of the various iron is too high. He would have preferred a phosphorus of 0.3 per cent. and in getting the irons prepared specified 0.5 per cent. maximum, but unfortunately this was exceeded. Mr. Fletcher's remarks regarding pearlitic iron and the taking of pearlitic iron as a base for investigations are of interest, and the author is in entire agreement with them. The development of a pearlitic structure and the maintenance of that structure as far as possible under heat treatment by the addition of special elements which render the carbide stable is necessary if heat-resisting irons are to be produced satisfactorily.

In reply to Mr. Cook's query as to why 450 and 550 deg. C. were selected for the heat treatment experiments, it may be stated that 450 deg. C. was taken as representing the maximum temperature likely to be attained in general Diesel engine practice, and 550 deg. C. as a temperature experienced under certain very severe conditions. With regard to the microscopic investigation of the various irons, that is at present beirg investigated, as the author realises how necessary the study of the structure or matrix is when considering the various changes produced by the heat treatment. Mr. Cook also raised the question of the effect of chromium and manganese on the wearing properties of the irons, but the author has no data to offer. He might, however, refer Mr. Cook to a recent Paper by Professor Mellanby (FOUNDRY TRADE JOURNAL, Vol. 30, page 476), where it is stated that resistance to wear may be associated with resistance to growth and that irons which showed little growth came out equally well when their wearing properties were tested.

The author is unable to state, in reply to Mr. Primrose's question, what loss is found in remelting Mayari pig-iron. The rate of heating up of the bars in the elevated temperature tests occupied about half-an-hour, so that very little change would take place before breaking. As regards the mechanism of the change taking place on heat treatment of the chromium iron resulting in contraction, the author is so far unable to explain, but is continuing his investigations. Andrew and Hyman's tests quoted by Mr. Primrose showing where chromium retarded growth, but did not prevent it, were carried out at 900 deg. C.

Mr. Young questions the use of the term annealing in connection with the first series of tests and suggests that the tests are really growth tests. The author admits that the word used is unfortunate, and would suggest that it be replaced by the words " heat treament." As regards the various points raised regarding the chromium irons, the effect of chromium on the structure and the addition of silicon or nickel in order to allow of an increased chromium content, the author agrees with Mr. Young that by the Perlit process a higher percentage of chromium than 0.4 could be introduced without increasing the silicon and also a much lower silicon could be used. Mr. Young states that the carbide changes are not complete in the 200 hours over which the tests were made, and suggests that further changes would take place under service conditions. While admitting this to a certain extent, the author is inclined to think that at least 95 per cent. of the change that is likely to occur has taken place at the end of 200 hours. The comparison of the various irons as regards composition, strength and hardness after the various heat treatments which Mr. Young makes, and his deductions regarding the condition of the matrix, are extremely interesting, and are largely borne out by microscopic investigations which the author has made.

In reply to Professor Andrew, it may be said that the growth bars were examined very carefully for scaling, but there were no signs of it observed. Microscopic examinations undertaken, so far, have shown that there are indications of oxide formation and also that a relationship appears to exist between the size of the graphite flakes and the growth.

Mr. Pearce asks if there is a quick method of testing for heat-resisting irons, but the author cannot give any beyond suggesting that it may be possible to form a rough idea from the structure and composition.

As regards the effect of pressure on growth, in reply to Mr. Longden, the author is unable to give an opinion.

The author is rather surprised regarding Mr. Shaw's remarks regarding his experience of test bars containing chromium, as the various experiments were carried out on bars cast 1⅛ in. diameter and gave the tests stated.

A NOTE ON THE PRACTICE AND PURPOSE OF PERLIT IRON.

By Horace J. Young, F.I.C., Member.

For introduction the author wishes to explain those circumstances under which this note has been written.

It is known nowadays to many people that the Perlit process consists of a definite foundry procedure correlated with an equally definite metallurgical control; the moulds are heated to a predetermined temperature to suit the metal with which they are to be filled, while the metal is controlled to a pre-determined composition to suit the average thickness and the mass of the casting it is to occupy.

Obviously, any one portion of the process, as above described and as set out in the patent specifications, can be made to reciprocate with the other and, therefore, it is possible to carry out the method and to attain the desired result in more than one manner. For instance, one foundry may find it convenient to vary the temperature of its moulds and to keep the metal constant; another to use different metals whilst using a similar mould-temperature throughout; whilst another may have such work as renders it better to vary both factors.

Not long ago the author, reading about this process in the technical Press, found it difficult to evaluate. Much of this difficulty was due undoubtedly to an extravagant and, in some instances, an inappropriate use of the description "pearlitic." A visit to the Continent, in the early part of this year, gave opportunity for personal investigation in various foundries using the process and turning out all classes of work, light, medium or heavy, as the case might be.

The final remark of this preface consists in saying that the process has been in operation in the foundries of the North Eastern Marine Engineering Company for so short a period as to make it impossible for the author to include many of the observations made in those foundries, but he has decided, nevertheless, to admit none made elsewhere and not under his supervision.

Of recent years it has become recognised, from results obtained under service conditions as well as those of many research workers, that grey cast irons containing little silicon possess superior properties to those of higher silicon ranges. Unfortunately, the obstacles in the way of using low-silicon metal often are, for very many castings made under usual foundry conditions, entirely prohibitive. The unreliability of ordinary cast iron lies in the fact that the metal has a varying "grain" according to its section—a complicated casting is "different all over," whilst a plain one has a metal "core." For instance, an ordinary test-bar casting is different in the centre from what it is nearer to the outside. Also is it recognised broadly that grey iron containing the maximum amount possible of combined carbon, without free cementite, is the best form in which any one particular cast iron can be—this form being described as all-pearlitic.

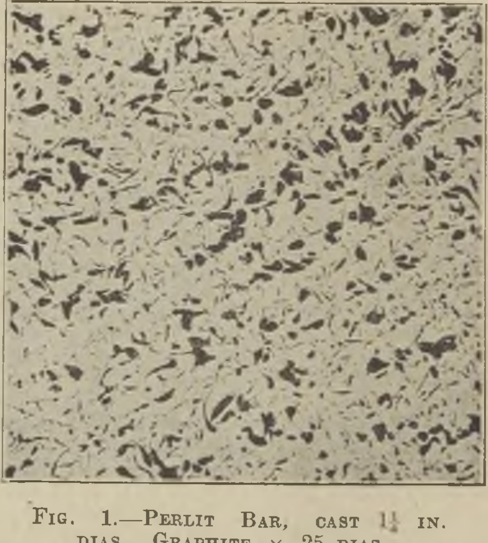

FIG. 1.—PERLIT BAR, CAST 1¼ IN. DIAS. GRAPHITE × 25 DIAS.

Added to these accepted facts is the knowledge that the graphite should exist in amounts below, say, 2.5 per cent., and that the dimensions, shapes and distribution of the voids, partly occupied by it, should be such as have been found to characterise those irons which have given the best service and exhibited superior physical properties. In other words, these voids should be short, thin, curly or nodular, and confined within the network.

In order to prevent this note from developing into a discussion of matter already proved and accepted by recognised authorities, the author has selected, from the large mass of evidence, only remarks made by British workers which have appeared in those issues of The Foundry Trade Journal of the dates given in parenthesis.

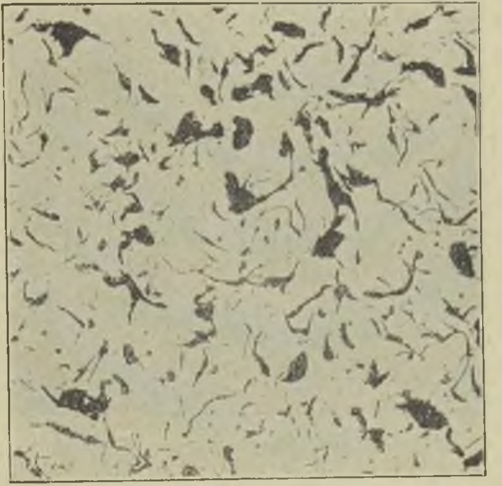

Fig. 2.—Perlit Bar, cast $1\frac{1}{4}$ in. dias. Graphite × 75 dias.

Hilton Mills (July 5, 1923 and July 19, 1923) writes:—"The tensile strength was under 8.0 tons per sq. in. Carbon estimations on the test bar showed: Total carbon, 4.20 per cent.; graphite, 3.40 per cent.; and combined carbon, 0.80 per cent." Further, he writes: "My real contention was, that a high pearlite content was only of use when combined with other structural characteristics, the chief of which is the requisite fineness of the graphitic carbon. A pearlite-graphite structure is undoubtedly the one to aim at, for strength in ordinary sand castings, but the graphite must be the right type."

J. Shaw (Dec. 6, 1923) wrote:—"The essential characteristics of high-grade cast iron may be said to be a fine distribution of the graphite, and a *purely pearlitic ground mass.*"

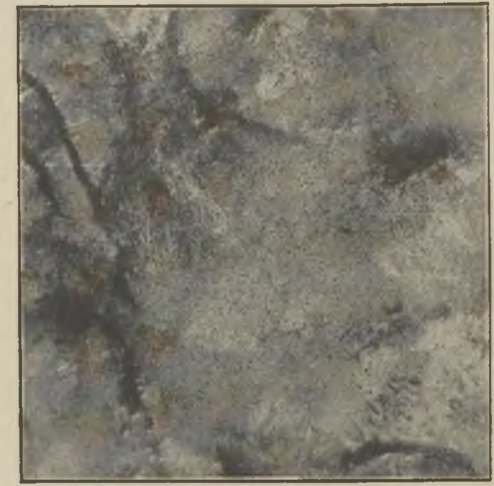

FIG. 3.—PEARLITE BAR, CAST 1¼ IN. DIAS. PEARLITE × 400 DIAS.

G. S. Bell and C. H. Adamson (May 8, 1924) state:—"It is fairly certain that the tensile strength varies directly with the closeness of the structures in a particular composition."

F. H. Hurren (May 22, 1924), describing the manufacture of motor-car cylinders, gives the analyses of three different parts *of the same cylinder* and remarks: "The figures are typical of many tests, and, as might be expected, the only difference is in the combined carbon and graphite contents."

J. E. Hurst (16-10-1924) says, in his Paper entitled "Notes on Pearlite Cast Iron" that the fact of Perlit iron being white when cast into a cold mould "at once differentiates between an ordinary cast iron of a pearlite-graphite structure and the product now known as pearlite cast iron." Further, he states "It is, generally speaking, well known that an all-pearlitic structure is advisable for the best general resistance to wear." Referring to other properties, he remarks "A most important additional point is that this high tensile strength is secured with a comparatively low Brinell hardness." He goes on to say "Whilst, broadly speaking, foundry metallurgists are well aware of the influence of rate of cooling on the constitution of cast iron, none of us has been aware of the fact that the rate of cooling could be modified in the manner proposed in the pearlitic cast-iron process, and for such modification to be accompanied by such gratifying results." Later, he continues "An all-pearlitic matrix is the best practice. It is his experience

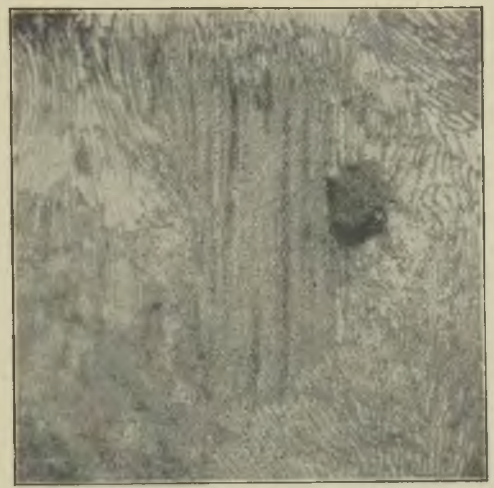

FIG. 4.—PERLIT BAR, CAST $1\frac{1}{4}$ IN. DIAS. PEARLITE × 1,500 DIAS.

with many cylinder problems of recent years that the lower the silicon content, the better the resistance to wear under almost all conditions appertaining in engine cylinder work, including internal-combustion engine or otherwise. From these points of view the pearlite cast-iron structure and the underlying features of the Lanz pearlitic cast iron as defined, fully justify their claims regarding resistance to wear. The distortion of cast iron under heat influences in the engine cylinder is another complex phenomenon

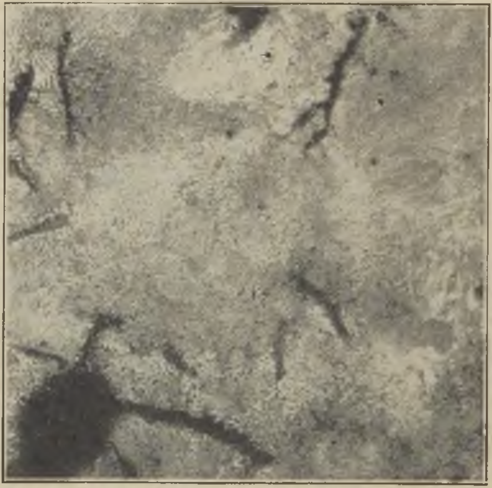

FIG. 5.—PERLIT BRACKET. SECTION $\frac{3}{4}$ IN. × 400 DIAS.

. . . . . it is shown here, and has since been confirmed by other investigators, that the lower the silicon content the greater the resistance of the pearlite constituent to decomposition under these circumstances. It is his opinion that a low silicon and an all-pearlitic cast iron are desirable conditions to obtain the best resistance to distortion arising from the above-mentioned causes." He states "It will be quite clear from the definition of pearlitic cast iron that it is intended to belong to the class of irons which have been described as border-line compositions, and we may expect that this being the case it would be extremely sensitive to the effect of the rate of cooling . . . . . there is no semblance of annealing in the process."

Prof. C. H. Desch (8-1-1925) said "The best cast iron is likely to consist of a strong steel, containing graphite crystals of such small size and so grouped as to produce the least weakening effect. The toughest steel has the composition of pearlite. . . . . There are many reasons why cast iron of close grain, with minute particles of graphite held in a pearlitic ground-mass, is desirable, apart from its strength and machining qualities. Chemical attack, such as the destruction of acid tanks by sulphuric acid, is associated with an open grain . . . . . he has met with striking instances of this action. Similar considerations apply to irons which are to be subjected to high temperatures and to the action of oxidising gases. It has been shown by Carpenter and others that 'growth' only occurs in graphitic

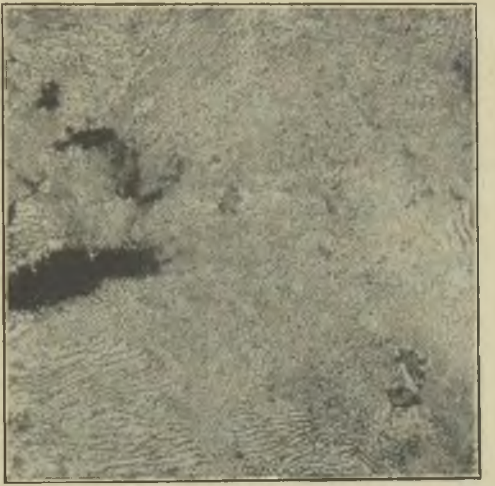

Fig. 6.—Perlit Bracket, cast $1\frac{1}{4}$ in. dias. Pearlite × 400 dias.

irons and is particularly marked in irons containing a high proportion of silicon."

A. Campion (22-1-1925) in a Paper upon the factors influencing the strength of cast iron said "The ideal casting-temperature would be such that the mould could be completely filled, whilst all constituents of the iron are completely in solution, and that they should begin to separate immediately thereafter." He describes suitable cooling conditions as resulting in "normal crystallisation prior to the saturation point of the carbide being reached. Objectionable graphite growth is thus prevented, and a mechanically sound structure is obtained."

FIG. 7.—PERLIT BUSH. CASTING THICKNESS, $1\frac{1}{4}$ IN. GRAPHITE × 25 DIAS.

Prof. T. Turner (29-1-1925) commenting upon the Lanz process said "He was interested to hear the figure of 4 per cent. as the total of silicon and carbon. He was reminded of something that happened forty years ago when he made experiments on silicon in cast iron, and when the bar which gave the best result in a series contained about 2.2 per cent. carbon and 1.8 per cent. silicon." Further, he stated "The importance was demonstrated of fine-grained graphite . . . . . in other words, it was desirable to produce it in a small flake and almost granular condition." "He was pleased," he said, "to feel that they could, by the application of knowledge now within their reach, ensure material of a high quality and of a uniform character, material which could be depended upon to resist shock, to give good wear, to give smooth running surfaces, and which would not creep or grow unduly when it was exposed to high temperature."

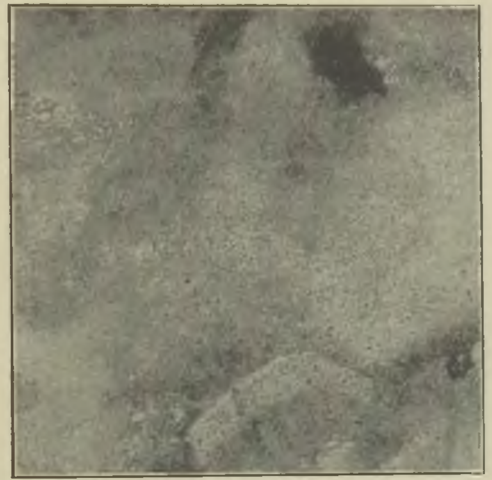

Fig. 8.—Perlit Bush. Casting thickness $1\frac{1}{4}$ in. × 400 dias.

A. Logan (19-2-1925) said "Slight changes of ultimate composition will produce drastic changes in structural composition. The retention of a little over 0.2 per cent. more carbon in the combined state, for instance, would be sufficient to take up the whole of the free ferrite, and the matrix would then be completely pearlitic." He calculated that 0.50 per cent. of combined carbon forms 59.52 per cent. of pearlite by weight or

54.60 per cent. by volume, and continued "It follows that the strongest irons are those which contain a minimum amount of graphite in the most finely divided form and preferably 'grouped,' and having in addition, a completely pearlitic matrix with only a small amount of phosphide eutectic present."

Having given the above references, the author thinks it unnecessary further to labour the point involved therein.

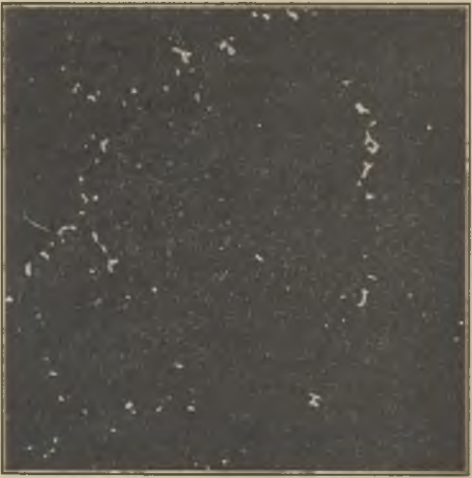

Fig. 9.—Perlit Iron. Phosphide Network × 25 dias.

Perlit iron possesses some unique properties, one of which is proved by the simplest practical test, namely, that one of trying to break it with a hammer. Recently the author cast a small bracket of Perlit iron, its dimensions being about 9 in. long, 6 in. wide and varying in section from three-quarters to an inch and a quarter. The casting was a poor one and a labourer predicted that he could break it with a tap of his hammer. Ultimately, two men struck it forty times with 20-lb. sledges and the casting remains unbroken. The structure of the metal in the $\frac{3}{4}$-in. section and in the $1\frac{1}{4}$-in. section is shown in Figs. 5 and 6 respectively. The magnification in each case is 400 diameters and clearly indicates the fineness of the lamallæ, the all-pearlitic matrix and the fine graphite spaces with some nodular ones.

All properly-made Perlit iron exhibits this remarkable resistance to impact, and the foundry workers are astonished by it. A practical test of this nature is more convincing, perhaps, to the engineer and the foundryman than abstruse results depending frequently upon particular conditions. It would appear to be irrefutable proof that a new and better cast iron has been discovered. When one attempts to visualise the reasons underlying the behaviour of the iron when subjected to this particular test, it becomes evident that the metal will be superior in other directions also. For instance, the size, shape and distribution of the voids, partly filled with graphite, will be superior to those in ordinary cast iron; the matrix will be at its best in all sections, and the grain-size will be more uniform and favourable. That these predictions are true in fact appears to be evident from the microstructure of the Perlit metal. Figs. 1 and 2 show the graphite in a bar cast 1¼ in. dia., whilst the pearlite in the same bar is so fine that much of it is unresolved by a magnification of 400 diameters, as seen in Fig. 3, whilst at the high power of 1,500 diameters the lamellæ exhibit a beautifully fine texture, as seen in Fig. 4. Similar results are to be observed in Figs. 7 and 8, which represent a bush, 24 in. long, 14½ in. outside diameter, and 1¼ in. thick. In all cases the Brinell hardness has been low, between 175 and 185 being the rule. The network is good, as shown in Fig. 9.

Of course, the photographs given in this note represent the initial results of the work in its very early stages, and it is to be expected, therefore, that much better results will be obtainable as control and experience are attained. Outstanding is the fact that, by this process, can be produced castings, of the thinnest sections if necessary, of low-silicon iron, which will be pearlitic throughout and have graphite voids and pearlitic matrix of superior types to those found in ordinary cast iron, namely, the higher silicon metal suitable for cold-mould practice.

By reason of their being little or no chilling effect upon the metal when it meets the hot mould surfaces, there will be no chilled shell formed, and, moreover, it is not unreasonable to suggest that there is a " hesitation " during which everything has a chance to " level up." This conception enables one to appreciate that much may happen to explain the absence of core and the presence of an all-pearlitic structure throughout an intricate casting made in this manner. Either hot or cold sand is a very poor conductor of heat, and, even though the above-mentioned " hesitation " may exist at or about the freezing point, it does not follow that the metal will pass through its pearlitic range so slowly as it would do in a cold mould (using a higher silicon metal).

Also it has to be remembered that the voids, partly filled by graphite, may be gaseous. Indeed, their shape and size may be determined by gas influence in the first place. Therefore, the superior voids found in Perlit iron, as compared with those in grey iron cast in cold moulds, may be due to the hot mould not causing the precipitation of these gases at the same period or to the same degree.

The author makes no presumption of understanding the mechanism of the Perlit process. He feels that it is likely to throw light upon many points which have been puzzling foundry metallurgists in connection with grey iron metallurgy; in any case it opens out a new field of research and of manufacture about which, at the moment, there is little data to work upon; all that is known is that the iron is different from and better than ordinary cast iron of higher silicon content, and that it conforms with the opinions of scientific observers as to what good cast iron should be were it possible, as it now is in this process, to make it more uniformly alike throughout any one casting.

The author wishes to express his sincere thanks to Mr. Summers Hunter and to the North-Eastern Marine Engineering Company for allowing this note, describing his impressions and experiences in connection with the starting-up of the Perlit process in their foundries to be presented to this meeting.

DISCUSSION.

The President said they had listened to a most important Paper from their friend, Mr. Young, and it might happen that in future years this meeting in Glasgow might be regarded in the light of a memorable occasion indeed. Time was now limited, but he thought they could still spare opportunities for those of their number who were anxious to create some little interest in the engrossing subject Mr. Young had raised.

Mr. J. Shaw (Sheffield) said that sometimes a few of the members did not always take Mr. Young's contributions at their full face-value, but on this occasion he felt they must all appreciate the importance of the Paper and the valuable information the author had placed before them. At the present time Mr. Young was doing a really good service to the Institute, and they must fully appreciate it. While he (Mr. Shaw) was in Germany in the course of last September, he gleaned some valuable data not only on the subject treated upon by Mr. Young but on the test-bar question as well. Mr. Shaw proceeded to describe two castings of perlit construction he had seen in Germany. He explained that he had sent a portion of the material to the Cast Iron Research Association and he had photographs which could be shown to anyone interested. His own feeling was they ought to recognise this process, even although it was German, and to improve upon it if it was considered to be a feasible proposition for the industry.

Mr. Rhydderch asked the author what he allowed for the permissible variation of the analysis. Also it would be interesting to know in relation to the temperature of the mould what variation the author allowed there. It struck him that some castings could be made with this process, but he rather feared the conditions would be impossible, or at least they would be found to be so, for many foundries. The point was, were they going to be impossible for every foundry?

Mr. D. Sharpe indicated that he had just returned from some interesting investigations into this matter in America. A great deal of work in the direction outlined in the Paper was now being done in America. The attitude now being adopted by the Americans was that all iron was under a perlitic condition and all they wanted to do was to fix it so that it could be realised and maintained in that condition. Personally, he had had evidence of foundries producing castings that reached 24 to 27 tons tensile. In these foundries they had been doing that sort of thing for some years. They were pouring their castings in cold moulds and producing material at or about the same cost as ordinary grey iron. The American, by keeping a very careful control over chemical analysis, was converting his foundry into a laboratory more than we in this country could ever hope to do. In America they were approaching this question from the flat rate of production, and they were looking to the treatment of the metal to ensure that, in the main, it was dealt with in accordance with ordinary foundry practice and conditions. He was not putting forward these arguments by way of rushing people in this country into a realisation of the possibilities or otherwise of pearlitic iron, but simply to testify to the fact as the outcome of personal investigation that pearlitic iron in a commercial way was being produced in America at the present time.

Mr. J. S. Glen Primrose said he would like to know what Mr. Young meant by discarding his own language and making use of the term "perlit iron." Was it not quite sufficient to refer to this as pearlitic iron? Perhaps Mr. Young did feel a little on this point, but, even so, he ought to tell them why he discarded the English word "pearlitic." Then there was one sentence in the Paper which to his mind was not very comprehensible. It ran thus: "Also is it recognised broadly that grey iron containing the maximum amount possible of combined carbon, without free cementite, is the best form in which any one particular cast iron can be—this form being described as all-pearlitic." It seemed to him that Mr. Young had yet to explain to them what he meant by the use of the word "maximum" there. Early in the Paper the author said: "In other words, these voids should also be short, thin, curly or nodular and confined within the network." He would really like to know what "network" was referred to in that sentence. Again, later, the author observed: "The matrix will be at its best in all sections, and the grain-size will be more uniform and favourable." The question he would put here was, "more uniform and favourable" for what? Towards the close of the Paper Mr. Young was responsible for this statement: "Therefore, the superior voids found in perlit iron, as compared with those in grey iron cast in cold moulds, may be due to the hot mould not causing the precipitation of these gases at the same period or to the same degree." Personally, he (Mr. Primrose) had never seen a precipitation of these gases. He supposed the author was rather asking them to believe it was a liberation and not a precipitation of the gases.

The Author's Reply.

MR. H. J. YOUNG, in replying to the discussion, remarked that he did not think it was necessary for him to answer the points raised by Mr. Marks. Other people had already done so, and particularly those who claimed to have made perlit iron as distinct from pearlitic iron. He still repeated, however, that it had never been substantiated that anyone had made Perlit iron seriously and with the same measure of control as was set out in the specification for the process. In reply to Mr. Shaw, he had to acknowledge that he had seen one of the castings made by the German firm referred to in the course of his remarks. There was no doubt these people had been set a very hard task, and one to which they were entirely unaccustomed. He (the author) personally appreciated the real difficulty that was involved in turning out that iron. The transference from cold moulds to hot moulds was an operation that required a great deal of research work. Undoubtedly, so far as the experiments had gone, it demonstrated that the process applied equally successfully to heavy castings as to light. It was all a matter of applying the operation properly. The casting on the whole was undoubtedly better, and they got the Perlit structure as distinct from the pearlitic structure in this country. A question had been asked whether the mould must be warm in order to get Perlit iron. His reply to that was candidly in the affirmative. Of course, everybody in this country knew all about pearlitic iron. As a matter of fact, he had been engaged in the manufacture of that since ever he started work. On the other hand, he had been making perlit iron during the past few weeks, and he was bound to say, speaking from practical knowledge and actual experience, that the manufacture of pearlitic iron had nothing whatever to do with the former process. The question had also been asked whether it was necessary to have some control over the analysis of the iron and of the heat of the casting. Personally, he felt that was an unnecessary query in the year 1925. The firm that was not following the principle of metal control at the present stage was not moving abreast of the times. For high-class work—such as Diesel engines—they must have that principle in operation, and the firm who was not doing it, or was unwilling to do it, must not condemn the practice. He was interested in what Mr. Sharpe had said about his American experience, but it was common knowledge that they had heard much about the things that America could produce and manufacture. In his own Paper he had dealt with actual practical experience, and from what he had seen he was bound to say that if indifferent iron was used the process would make that iron better. Not only so, but if the iron was good that iron would be rendered better by the process. This was the production of the moulds heated to a pre-determined temperature to suit the metal with which they were to be filled, while, on the other hand, the metal was controlled to a pre-determined composition to suit the average thickness and the mass of the cutting it had to occupy. He did not know that the word "perlit" was an alien word, or even that it was a German word. As a matter of fact, he believed he had been largely responsible himself for calling this "perlit" iron in Great Britain. His reason for introducing the word was to get away from the idea that this had anything to do with pearlitic iron. His own idea had been that it would be useful to call this "perlit" iron as distinct from pearlitic. Accordingly, no matter what Mr. Primrose might say to the contrary, he dissociated himself from any desire to introduce a foreign word. It did not seem to him that the other points raised by Mr. Primrose as to the "network" and the use of the term "precipitation" were of much importance to the particular issue that was being discussed.

Written Contribution.

Mr. J. E. Hurst wrote:—As my own Paper has been largely quoted by Mr. Young I feel called upon to contribute to the discussion on this subject of Pearlitic Cast Iron. I have already publicly stated in so many words that I have no doubt whatever that if the pearlitic process and material does comply with the definition and claims made for it, then it can be truly described as an important invention and a distinct step forward in foundry practice.

The fundamental features underlying the process and the improvements arising therefrom have been very clearly stated by myself from a study of published information and by Mr. Young from actual experience of the process.

Confining our attention to the two most outstanding points as follows:—(1) The fundamental feature that the cast iron must be white when cast normally into ordinary sand moulds; and (2) the fact that when cast "Perlitically," this iron is grey and has a uniform grain size across the section of the casting regardless of its thickness.

These two features have been the aim and object of all thinking ironfoundry metallurgists for many years, and I am sure that, like myself, they will be unable to accept the statement unaccompanied by evidence that this is accomplished by the pearlitic process.

I had expected to find this evidence in Mr. Young's Paper, as I have no doubt that he must have satisfied himself on these points. The fact that this evidence has not yet been given prompts me to suggest in detail the evidence I would like, and I am sure all foundrymen would like, to enable them to evaluate the pearlitic process:—(1) The chemical analyses of two bars which might be designated A and B, together with photographs of the fractures of the bars. These bars should preferably be cylindrical and not less than 1¼ in. dia. They should be cast from the same ladle A to be cast by the "Pearlitic Method," and B to be cast in either an ordinary green or dry sand mould, and (2) micro-photographs taken at several points from the outside edge to the centre of the pearlitic bar A would at once demonstrate the uniformity of the structure which is stated to be secured. Two series of photographs at these points, the one showing the graphite size and the other the network size would demonstrate this very clearly. The point could be still more strikingly demonstrated on a thicker bar, say, 6 in. dia.

This evidence would clearly demonstrate that pearlitic cast iron is actually white when cast in the ordinary way and has a uniform grain size when cast in the pearlitic way. These are the two fundamental features claimed for the process, and seem to me to be worthy of full and ample demonstration.

Finally, I am sure that such full and ample demonstration cannot fail to be of value both to the inventors, licensees, and to the process itself.

ADDENDUM.

In further reply Mr. Young wrote that they had, in the foundries of the North-Eastern Marine Engineering Company, already made heavy castings in Perlit. Fig. 10 shows a Diesel compressor cylinder-liner which weighed nearly two tons. Fig. 11 is a Diesel cylinder-head weighing five tons. The latter is one of the most complicated castings which those foundries have to make, and contains something like twenty cores. Fig. 12 illustrates seven locomotive superheat headers; a smaller type of complicated casting weighing 6 cwts.; and Fig. 13, Diesel fuel valves, weighing 2¼ cwts. The process appears to be applicable to any castings of any size or type, and can be worked in any ordinary modern foundry. The other day some visitors came to the works and were shown a large number of Perlit moulds being poured, which, considering the fact that two of those visitors were skilled foundrymen, and that we have been working the process for only a couple of months, proves the extreme error of those who say it cannot be done.

As experience is gained it will be possible to have smaller heads on the castings than those used in the ordinary way, and the author has seen cases where heads have been dispensed with altogether. Regarding reduction of scantlings, this naturally depends upon the design and type of

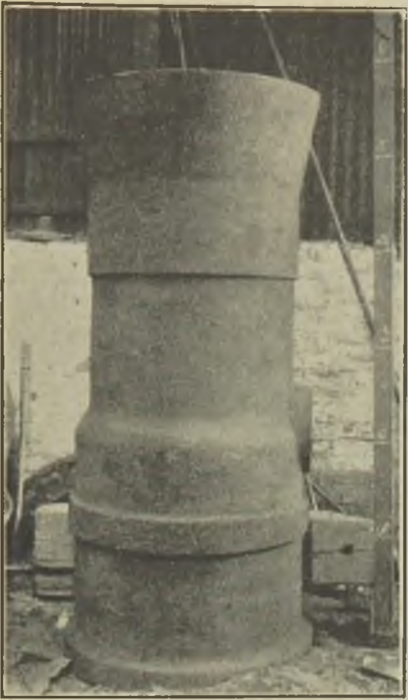

FIG. 10.—DIESEL COMPRESSOR CYLINDER-LINER MADE IN PERLIT IRON. WEIGHT NEARLY 2 TONS. CASTING THICKNESS VARIES FROM $1\frac{3}{4}$ IN. TO $2\frac{1}{8}$ IN.

work being referred to in any particular case. From 10 to 20 per cent. reduction will be possible in many instances; greater uniformity and superior resistance to fatigue and impact giving the metal a large advantage over non-Perlitised cast iron.

It was asked whether the mould should be hot in order to produce Perlit iron. In the author's opinion the process depends upon properly heated moulds associated with metal of the proper composition to suit the temperature of the mould. Do away with either of these things and "Perlitisation" is impossible. It is advisable to have the moulds as hot as convenient, in order to produce that "hesitation" effect to the greatest possible extent, and to extend the pearlite range so as to produce all-pearlitic structure in an iron of low-silicon content.

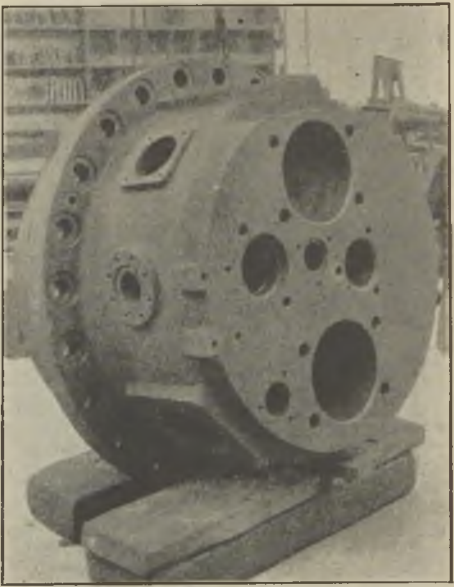

Fig. 11.—Diesel Cylinder Head made in Perlit Iron. Weight 5 tons. Casting Thickness varies from $1\frac{1}{4}$ in. to 4 in.

Anyone claiming to make Perlit iron by the ordinary cold-mould process cannot be conversant with the nature of Perlit. The very properties of the materials produced by this process depend upon the effects of the peculiar cooling conditions upon iron of particular compositions. In this connection the author is making some experiments upon the cooling-down of metal in a hot mould as compared with what happened in a cold one, also further experiments regarding the passage of heat through a sand-mould. These will be published in further papers.

A question was asked what variations were permissible in the composition of the metal. These are sufficiently wide to permit of easy control in any foundry with a laboratory. Most of such foundries to-day have as much control as will be necessary. Of course, in dealing with extremely heavy castings the limits are not so wide, but that is in accordance with cold mould experience. As a matter of fact the process is applicable to all classes of foundry work and to all modern foundries.

With further reference to the high tensile American iron mentioned by Mr. Sharpe. If this iron comes under that class of metals which contains free graphite and combined carbon, then it would be improved by being perlitised. The author knows of no foundry work where the process would be of greater value than in the place where they are trying to make castings of very low carbon iron melted, say, in an open-hearth or electric furnace. There is a very definite field of operations in this sphere, and such foundries could go on to an even lower carbon or silicon content, or a higher chromium metal, and be able to get good castings and machinable iron.

The question of the description "Perlit" was raised by Mr. Primrose. The well-known word "pearlite," used almost exclusively by metallurgists, describes a particular structure found *more or less* in all commercial grey iron. It has never been established as a trade description of grey iron castings, nor, to the author's mind, would it be a description of any significance. The word "Perlit" was coined to describe castings made under the conditions of this new process; in the works we talk about "Perlit" or "Perlit" iron; about "Perlitising" iron; about the "Perlit" process and so on; all of which convey, in a word, the meaning we desire to express.

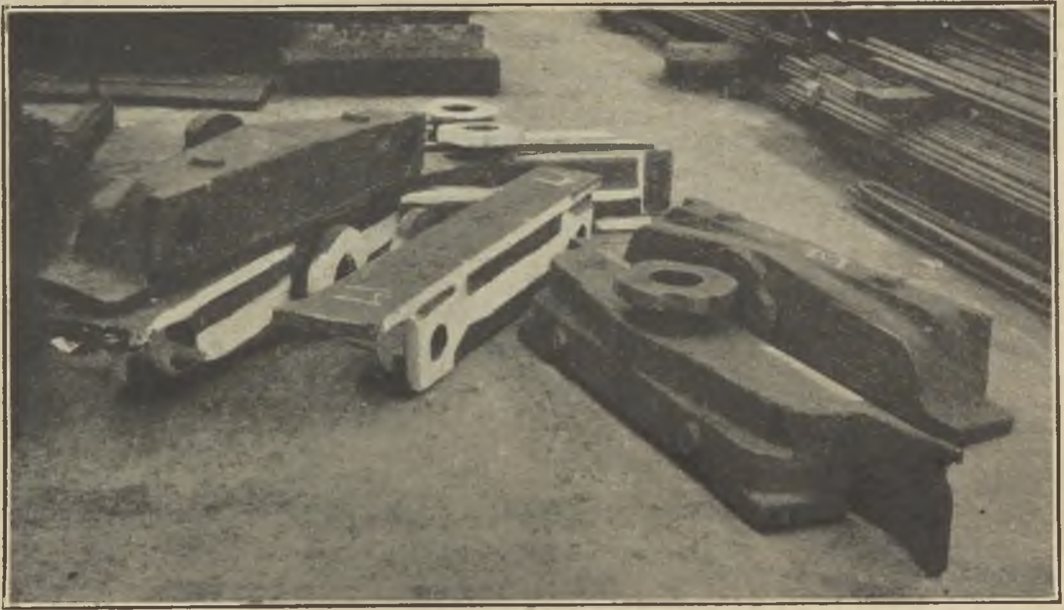

Fig. 12.—Seven Loco' Superheat Headers Made in Perlit Iron, each weighing 6 cwts. Casting Thickness varies from $\frac{5}{8}$ in. to $1\frac{1}{4}$ in.

Mr. J. E. Hurst's written contribution adds value to the discussion, and, although the author cannot accept Mr. Hurst's ideas as to what are the two fundamental features underlying this process, he welcomes his remarks. When iron is grey as cast, at a certain thickness, in a cold sand-mould, and is white when cast against a chill, we do not, because it is a familiar phenomenon, think it is particularly extraordinary. However, Mr. Hurst appears to find difficulty in realising that iron which is white or mottled, when cast in a cold sand-mould, will become grey when cast into a heated mould of similar dimensions. Our present knowledge proves that such must be the case. Cast iron, of any one composition, is more or less ferritic, or pearlitic or cementitic, according to the rate at which it is cooled through its critical points. In the case of the "Perlit" process we start with an iron which would be white or mottled or cementitic when cast into a cold sand-mould, and we heat that mould until an all-pearlitic structure is obtained. The greater the control the more nearly will the ideal be obtained.

That the condition of the graphite is modified is another feature which is to be expected from our present knowledge. That the initial "hesitation" gives a chance for a levelling-up of the temperature of the inner mould and cores and of the metal so that, to a great extent, all sections pass through the pearlite range at much the same speed and, therefore, finish up with much the same structure, is also reasonable. The author thinks that this is what actually happens, but as our knowledge extends so may our views alter. However, he has prepared specimens, and will send parts to Mr. Hurst and parts to the British Cast Iron Research Association. Also, at a later date, he will deal with this aspect of the process in a separate paper.

Really speaking, the two fundamental features of the process are that a lower-silicon iron than could be used in a cold mould is poured into a mould heated to that temperature which, the inventors have found, will produce an iron of pearlitic structure; the second feature being that this structure prevails throughout a complicated casting and is associated with a graphite structure better than usual. There are many other features of great interest, some of which apply to the elimination of foundry defects, others to the chemical composition and microstructure and others to the physical tests and behaviour of the metal in service. In view of the part Mr. Hurst has played in forming our past knowledge of cast iron, the author trusts that further knowledge and progress in our foundry industry will result from his interest in this new method.

When reading this Paper the author promised the members that he would publish no results other than those made and verified here in actual practice. In taking this attitude he was depriving himself of the use of much valuable work and data already published, and limiting his remarks to the meagre information obtainable in a few weeks previous to the publication of the meeting.

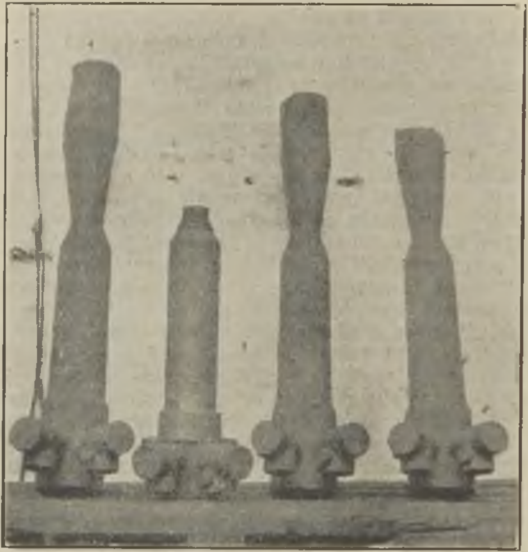

Fig. 13.—Diesel Fuel Valves, each weighing $2\frac{1}{4}$ cwts. Casting Thickness varies from $1\frac{1}{4}$ in. to $5\frac{1}{4}$ in. Made in Perlit.

It is possible now, however, to give some further data. It has been the natural procedure to compare our "Perlit" castings with our ordinary ones. In order to do this we made "Perlit" castings from a standard pattern, split them open, and compared them with similar castings, made in the ordinary manner. The results were interesting by reason of the fact that the ordinary ones were more or less imperfect when submitted to this drastic test of being split open. For instance, "Perlit" globe valves are practically free from flaws and of similar grain throughout all sections, whereas ordinary ones vary in grain and have porous or "open" metal at vital parts; also they usually have internal flaws and defects. So it has proved to be throughout all types of castings; those cast under "Perlit" conditions are superior, *as castings*, to ordinary ones. This getting of superior castings is a most important point, and means the reduction of "wasters" and a saving in costs. When abroad, the author was shown certain intricate castings—mass production—in which the percentage of "wasters" had been reduced from about 20 per cent. to almost nil, and this for no other reason than the adoption of the "Perlit" process. From what the author has seen now, he can quite believe the truth of this. In mass production the sheer perfection of the castings and the consequent cutting down of losses, in the foundry and the machine shops, more than justifies the new procedure.

Questions have been asked regarding strength. Here again the author's decision to give no other figures than his own has curtailed his remarks. Figures obtained in the course of every-day practice in the foundry from cupola-melted metal are to hand. In no respect are they experimental or "laboratory" results.

Some test bars, cast 42-in. long and 5¼-in. diameter, were cast in ordinary cylinder iron and also in "Perlit." Wishing to demonstrate the remarkable resistance to impact of "Perlit" iron as compared with ordinary metal, we tried to break these bars by hitting them with a "johnny" two-handled hammer weighing 140 lbs. Two blows sufficed to break the ordinary iron; the "Perlit" successfully resisted twenty-two blows, after which we broke it by dropping a 3-cwt. ball from a height of about 20 ft. It broke at the third blow. Among others witnessing this test was a chief superintendent of Lloyd's.

The fractures of these $5\frac{1}{4}$-in. bars are shown in Figs. 14 and 15, and demonstrate the difference between ordinary iron and "Perlit."

The table shows how our tensile and transverse are going.

From the above tests it will be appreciated that almost any quality of iron can be brought to conform with the requirements of the "Perlit" process. For those foundries specialising in cast irons of low carbon-content, no matter whether they be made by means of an electric or open-hearth furnace or by blowing air or gases through the cupola bed or receiver, or by adding low-carbon steel or iron to the ladle, the conditions of this process will lead to better castings and to higher-class metal. The same remarks apply to irons of the "alloy" class, for instance, those containing abnormal amounts of what are called impurities, namely, silicon or manganese, or those containing rarer elements, such as chromium or nickel.

It is recognised that immediately one leaves common cast iron and attempts to make castings of a better quality metal one walks into many foundry troubles. Probably this truth is the real explanation why so many foundries are unable, or unwilling, to produce a really superior iron. The "Perlit" process is, to the author's mind, the only practical solution of these difficulties which has been discovered. Special cast irons exist right and left, but a genuine and simple process of producing good and homogeneous castings from any quality of iron has not been available until now.

The running costs do not appear to be considerable, and the author hopes to present a Paper in the near future dealing with his experiences on this view of the matter. Almost any forced-draught core stove is capable of giving the required temperatures, whilst very economical furnaces are obtainable for heating floor-moulds.

In view of the fact that "Perlit" irons will compete for very many purposes with steel and with malleable iron, and also the improved foundry results as regards waster castings, there is little difficulty in seeing that foundries will adopt this new method with a view to actual reduction of costs and in order to increase their business.

In the foundries of the North-Eastern Marine Engineering Company, where the author is working, we are impressed so greatly by the results obtained in the foundry as well as in the machine and testing shops as to be looking forward to the time when all our more difficult castings will be made in "Perlit."

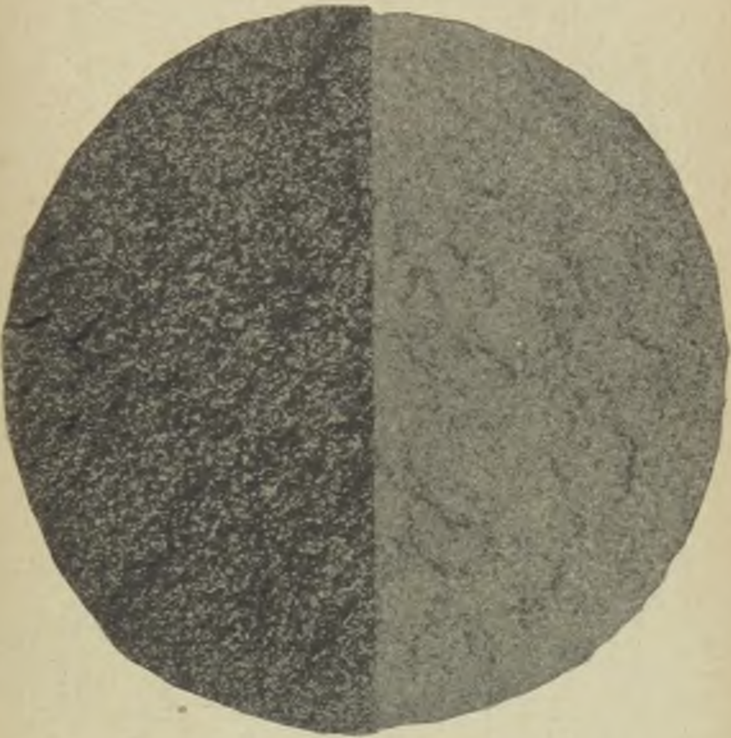

FIG. 14 (LEFT).—FRACTURE OF ORDINARY CAST IRON. FIG. 15 (RIGHT).—FRACTURE OF PERLIT IRON. BOTH WERE CAST $5\frac{1}{4}$ IN. THICK. ($\times \frac{3}{4}$.)

TABLE A.—*Tests Obtained from "Perlit" Iron.*

Casting.			Testbar.		Tensile Test.				Transverse Test.			
Description	Weight.	Variation in Section.	How Obtained.	Casting Thickness.	Diam.	Gauge Length.	Tensile.	Elongation.	Machined Size.	Distance between Supports.	Breaking Load.	Deflection.
	cwts			ins.	ins.	ins.	tons. sq. in.	Per cent.		ins.		ins.
Loco' Superheat Headers	6	⅝" to 1¼"	Cut from extended flange	1¼	0.798	2½	14.67 average of 11 castings	—	2 in. × 1in.	36	35.4 cwt. (average) of 11 castings	—
	tons											
Diesel Main Liners	2¾	2⅞" to 4½"	Cut from block extended on flange	7½	0.798	2½	17.20	1.0	1 in. sq.	12	3,096 lbs.	0.177
Another (cast on different date)	,,	,,	,,	,,	,,	,,	17.02	1.0	,,	,,	4,168 lbs.	0.261
Various smaller castings.	—	—	Tapered bars, cast in separate moulds.	1¼	0.798	2½	20.24	1.0	Tested as cast	12	3,950 lbs. (flaws)	0.157
				,,	—	—	—	—	,,	,,	4,010 lbs.	0.143
				,,	—	—	—	—	,,	,,	4,049 lbs.	0.172
				,,	0.798	2½	19.04 (flaw)	1.0	,,	,,	4,090 lbs.	0.153
			Similar bar from same metal, but cast in cold mould.	,,	—	—	—	—	,,	,,	2,819 lbs.	0.069

(NOTE.—These last five bars had a diameter of 1$\frac{3}{16}$ in. at the point of fracture.)

In this class of marine work hardly two castings are of the same dimensions, but in foundries dealing with repetition pieces the procedure could be organised so as to eliminate practically all wasters save those caused by actual bad moulding.

The author was told by a member at the Glasgow meeting that he did not like the process because the foundry would need to learn new ways. From the author's experience the main trouble with the ironfounding industry is that it is out of date and failing by reason of having had no " new ways " to learn. There is no reason why the future of cast iron should not be as great as has been its past, and everything points to the " Perlit " process being the first step in the right direction.

MALLEABLE IRON.

By F. H. Hurren, A.I.C, Member.

The malleable iron industry is one of the largest and most important branches of the foundry trade, but our knowledge has not progressed to anything like the extent one might have expected. The production of malleable iron castings as an industry commenced towards the latter end of the eighteenth century, yet present-time founders are still struggling with many of the same difficulties against which many of their forefathers had to contend. What is the reason? In part it may be due to the laborious nature of research and the very many variable factors which have to be considered. Malleable iron is full of original sin and troubles which, overcome in one direction, crop up in another. The malleable trade has suffered from an excess of secrecy and suspicion. Much of the research has been carried out by private firms at their own expense, and the knowledge so gained has not been published.

The output of malleable castings in Great Britain is quite considerable, the bulk of it being the white-heart variety, but it has the disadvantage of being divided amongst a large number of foundries, the individual output of each being relatively low. The small foundries cannot afford the expense of private research, are not sufficiently well organised to co-operate, and there is a dearth of easily available literature on the subject.

Research on malleable iron takes time. Investigations into casting and annealing cannot be made in a few days nor in a few weeks. The British Cast Iron Research Association will render invaluable service to the foundry trade by a thorough investigation of the difficulties and intricacies inseparable from the production of malleable iron castings. The scope of the necessary research is enormous, and will take years to bring to fruition, but the definite knowledge gained will be well worth the labour involved.

The present use of malleable iron is but a fraction of the potential uses. Malleable occupies a position intermediate between grey iron and steel stampings. It is used where grey iron is not of sufficient strength and ductility, but owing to its vagaries is being superseded by mild-steel castings and stampings. Unless the inherent difficulties in the production of malleable castings are tackled in earnest, future practice will tend more and more to its replacement by stampings and steel castings. If our knowledge were such that we could produce, without fail, a white-heart malleable iron which was soft and ductile, easily machinable, free from hard patches, with a tensile strength of over 20 tons per sq. in. and an elongation approaching 10 per cent., an enormous demand would be set up, and malleable iron would assume a position second to none. Such a state of affairs is not impossible. Tests have been made on white-heart malleable giving results of 23 tons per sq. in. ultimate stress, with 9 per cent. elongation, but unfortunately these results cannot be repeated with certainty.

Basic Differences Between Malleable and Other Castings.

Consider the differences between malleable iron and other casting materials. Malleable iron has a far greater contraction, making it liable to contraction cracks or sears; it has a greater shrinkage in passing from the liquid to the solid state, necessitating special methods of gating and feeding. It is practically unmachinable in the state as cast, and impossible to test in any manner other than a test to destruction. It has to undergo a long heat-treatment, which alters its dimensions and changes its chemical composition and microstructure. Incidentally, this heat-treatment introduces a risk of distortion and cracking. After heat-treatment, its utility can only be gauged by chemical analysis and its machinability. In the present state of knowledge, chemical analysis gives no exact criterion of practical value, as the composition varies according to the thickness of the part from which the sample is taken, and to the depth of drilling. It is not known what should be the proportions of combined and free carbon in different thicknesses of correctly-annealed material. Opinions differ as to the silicon content, also respecting sulphur and manganese. It is known with some degree of certainty that phosphorus has a deleterious effect, and should be kept as low as possible, preferably below 0.1 per cent. Analyses of different makes of malleable castings will reveal silicon contents varying between 0.35 and 1.1 per cent.; sulphur between 0.15 and 0.45 per cent., and manganese from 0.10 to 0.60 per cent. It is absurd to dogmatise, and a very long and careful research is needed to find some definite data on chemical composition. Even then foundrymen would have to compromise. Composition would naturally vary according to thickness of section, and in the same casting it is quite common to find sections varying from 1 in. down to ⅛ in. thick.

Present Position.

What is the extent of our knowledge of the science of producing malleable iron castings, and how can this knowledge be applied to control production in the foundry? We know that a high silicon content induces brittle castings, with a dark grey fracture similar to common iron. It is known also that a low silicon-content increases the difficulty of annealing; in fact, with a low silicon and high sulphur content annealing is almost impossible. The author has subjected samples of malleable iron containing 0.42 per cent. silicon and 0.45 per cent. sulphur to annealing temperature for 21 days, and at the end of that time only about one-sixteenth of an inch in depth was soft, the remainder of the section being practically unchanged.

Silicon Requirements.

The actual silicon content most desirable is, in the author's opinion, still a matter of conjecture. It is stated by various authorities that the silicon should be lower for heavy sections than for light sections. Complications arise when there are both heavy and light sections in the same casting, and in modern engineering practice this is the rule rather than the exception. All there is to work on is the fact that silicon below 0.4 per cent. appears to retard annealing, and above 0.9 per cent. there is introduced a risk of low strength, loss of ductility, and a state very little better than grey iron. The only possible course is to find the silicon range which best suits the general run of work and endeavour to keep within that range. In the Rover Foundry a silicon content ranging from 0.55 to 0.75 per cent. is called for.

Carbon Control.

Control of silicon is of great utility, but in the author's opinion what is of even more importance is control of carbon content. In the un-annealed casting the carbon should be wholly or mainly in the combined state. The latest theory propounded is that when a certain temperature is reached during the process of annealing, the combined carbon or cementite breaks down, and graphite or free carbon is precipitated. With increase of temperature this precipitation of graphite continues until the proportion of combined carbon falls to about 1.8 per cent. From this point, with continued heating, decarburisation takes place. Now it is obvious that the higher the total carbon content in the hard casting the longer must be the period of heating before the precipitation of graphite ends and decarburisation commences. In other words, to obtain good malleable, an increase in the total carbon content in the hard casting necessitates a longer period of annealing. The author's view, borne out by his personal experience, is that the most ductile, strong and easily machinable castings are associated with a low total-carbon content after annealing, this carbon being distributed as part graphite or temper carbon and part combined as pearlite.

From experiments which have been carried out over a number of years the conclusion has been reached that the best results are obtained when the total carbon content in the hard casting lies between 2.9 and 3.2 per cent., and it is thought this opinion will be confirmed by others.

Analysis of the usual brands of pig-iron supplied for malleable work invariably shows a preponderance of supplies with a total carbon content above the upper limit of 3.2 per cent. In many instances the author has found pig-irons with a total carbon content of 3.6 per cent., and even higher. The makers of malleable pig would confer a real boon on the founders if they would pay more attention to the composition of the material, and supply an iron with a maximum total carbon content of 3.1 per cent.

Influence of Total Carbon.

In connection with this subject numerous results of experiments could be given, illustrating the effect of total carbon, and the two following have been taken as typical examples. Two samples of hard castings were annealed under practically identical conditions of time and temperature. One contained 3.06 per cent. total carbon in the hard state, and the other 3.38 per cent. total carbon. Representative samples were taken for analysis after annealing. The results are given in Table I.

TABLE I.—*Result of Annealing Two Samples—One with High Total Carbon.*

	No. 1.	No. 2.
	Per cent.	Per cent.
Before annealing.		
Total carbon	3.06	3.38
After annealing.		
Total carbon	0.58	2.62
Comb. ,, ...	0.14	1.04
Free ,, ...	0.44	1.58
Silicon	0.56	0.61

It will be noticed that No. 1 only contained 0.58 per cent. total carbon, whereas No. 2 contained 2.62 per cent. No. 1 had lost 2.48 per cent. carbon during annealing, against a loss of only 0.76 per cent. carbon in No. 2. No. 1 was soft, easily machinable, and bent through an angle of 90 deg. before showing signs of cracking. No. 2 was soft and easily machinable, but fractured after bending through an angle of about 15 deg. It has been found repeatedly that malleable castings which are soft but non-ductile have a high total-carbon content, and under certain conditions only very slight decarburisation takes place even with an unduly prolonged anneal.

Graphite Precipitation.

Some time ago the Rover works was very much troubled by a certain casting showing a dull surface with black spots in small areas after machining. This occurred on about 25 per cent.

of the castings supplied, the castings giving no difficulty in machining, but being very brittle. Analysis revealed a high content of free carbon, and micro-sections showed graphite in a fine state of division. Repeated re-annealings at different temperatures for lengthy periods had but little effect on the carbon content. The author's original opinion was that the trouble was caused by high total carbon in the hard casting, but in the light of later knowledge would assume that a high temperature of annealing was partly responsible. The best results from malleable castings are obtained when the free or temper carbon is in the nodular form. It has been proved recently by Northcott that the rounded or nodular form of temper carbon is produced below 1,000 deg. C., and above this temperature the graphite assumes the flaky structure familiar in grey iron. It is reasonable to conjecture that in the castings just referred to, not only was the total carbon content high, but that some of the castings had been subjected to an annealing temperature exceeding 1,000 deg. C., and graphite had separated in a finely divided state.

Manufacturing Desiderata.

The manufacture of malleable iron castings comprises two distinct operations, the production of the hard castings, and the annealing process. The difficulties met with in the casting stage can be overcome by care and commonsense. Any faults due to the actual manufacture of the casting are usually discovered during machining, and before the article is put into service. Unfortunately, it is during the annealing process that trouble is most likely to develop, and castings which appear perfectly satisfactory fail in service, owing to structural weaknesses induced by incorrect composition. It has been part of the author's duty for many years to investigate causes of failure in service, and he can say, without hesitation, that the majority of failures have been due to irregularities of annealing, and in most instances due to lack of ductility caused by excessive carbon content. The text-book theory of annealing, and the one which is generally accepted, is that the changes occur in two separate phases:—(1) The elimination of carbon from the outer portions of the casting; and (2) a softening of the iron by precipitation of annealing carbon.

Chemistry of Annealing Process.

The universal practice in this country is to pack the castings with a mixture of red and black hematite ores. It is assumed that at high temperatures oxygen is liberated from the ore and reacts with carbide from the outer surface of the casting forming carbon monoxide and free ferrite. The carbon monoxide combines with further oxygen, to form carbon dioxide, which in turn reacts with carbon from the casting, forming carbon monoxide and liberating ferrite. These reactions are continuous, and at a later stage, free or temper carbon is precipitated. This is somewhat at variance with a later theory that, at a certain temperature, there is a partial conversion of cementite into austenite. On further heating the cementite breaks down, and graphite is precipitated. Continued heating results in decarburisation at the expense of the austenite and graphite.

From a number of experiments made, and the experience gained in the production of thousands of tons of malleable castings during the past fifteen years, the author doubts if the earlier and generally accepted theory fully explains the chemical physics of annealing. From tests made, not under laboratory conditions, but in actual works practice, several apparent contradictions arise. These may be worth enumeration.

(1) Castings of the same pattern, of similar original composition, annealed in the same oven under practically identical conditions, have ultimate compositions varying widely in carbon content.

(2) Loss of carbon takes place not only when the packing medium is oxidising, but also with reducing or neutral media.

(3) Loss of carbon does not appear to be directly proportional to mass.

(4) Whilst generally speaking, loss of carbon increases with increased time of annealing, notable exceptions occur.

(5) Intermittent rises and falls in temperature often result in a lower carbon content than a continuously maintained annealing temperature.

(6) Other elements, namely silicon, sulphur, and manganese, have a pronounced effect on the final result.

(7) Better results are obtainable by a lengthy anneal at a comparatively low temperature, than a shorter anneal at high temperature.

Detailed Consideration.

It has been found on frequent occasions in testing samples from the annealing ovens, that two castings of the same pattern taken from adjacent stacks, show considerable variations in carbon content. Drillings have been taken thoroughly to represent the samples, and to be comparable. Instances might be mentioned of total carbon contents of 2.06 and 1.48 per cent. respectively, when it might be reasonably expected that the results would be similar. What is the explanation? Is the ultimate composition influenced by the casting temperature?

If the process of annealing involves a supply of oxygen from the mixed ores used as a packing medium, why is it that loss of carbon occurs when neutral or reducing media are used? Yet such is the case, according to experiments personally conducted. A typical instance may be cited. Samples cast from the same shank of metal were packed respectively in the standard mixture of hematite ores, in coarse coke, and in well burnt sand. The lids and joints of the test cans were luted with a mixture of sand and clay, to exclude air as much as possible. The total carbon in the hard state was 3.3 per cent. A temperature of 950 deg. C. was maintained, in a gas-fired furnace, for 120 hours, followed by a slow cooling. Thoroughly representative samples were analysed with results shown in Table II. These show that with the mixed ores there was a loss of 1.5 per cent. carbon; with coke a loss of 1.0 per cent., and with sand packing, 0.90 per cent. carbon. If annealing is dependent on the oxygen derived from the ore, how has the elimination of carbon been arrived at when an oxidising atmosphere was not existent? Repetition of this experiment by treatment in one of the works annealing ovens was attended with similar results.

That loss of carbon is not proportional to the mass of the casting has been evidenced on numerous occasions in ordinary works practice, and also in a series of experiments carried out some few years ago. A number of samples were cast from one shank of metal, the samples varying in thickness from ¼ to 1 in. Batches consisting of one sample of each thickness were subjected to various short anneals, the results being very indefinite (Table III). Three examples may be cited, each batch being annealed under different conditions of time and temperature. The total carbon content in the original hard castings was 3.18 per cent., and the total carbon after annealing is shown in Table III. These figures need no comment. It would be imagined that according to the general theory of annealing, elimination of carbon would be proportional to the mass.

TABLE II.—*Results obtained from Annealing Similar Samples in Various Media.*

Packing medium.	Mixed ores.	Coke.	Sand.
	Per cent.	Per cent.	Per cent.
Total carbon ..	1.83	2.30	2.40
Comb. ,, ...	0.83	1.00	1.22
Free ,, ...	1.00	1.30	1.18
Silicon	0.64	0.61	0.58

TABLE III.—*Total Carbon Content in Annealed Samples Cast from Metal having the same Silicon content.*

Thickness	¼ in.	½ in.	¾ in.	1 in.
Batch 1	2.77	2.08	2.84	2.18
Batch 2	2.44	2.62	2.66	2.38
Batch 3	2.46	1.99	2.58	2.72

As might be expected, loss of carbon bears a close relationship to time at annealing temperature, but notable exceptions have been encountered. Several examples might be given, but one will suffice. A certain casting after annealing was soft but not ductile. Analysis showed a total carbon content of 3.16 per cent. of which 2.04 per cent. was free carbon. A further annealing for a total of 300 hours at temperatures between 900 and 950 deg. C., yielded a total carbon content of 3.01 per cent., of which 2.28 per cent. was free carbon. The only explanation suggested is that during the heating-up period of the anneal, the greater portion of the carbon was precipitated as finely divided graphite, and this state does not favour carbon elimination. It appears that success in annealing is only possible when the precipitation of carbon can be retarded until a considerable portion of the carbon has been eliminated. The carbon then precipitated takes the form of temper carbon, instead of as particles of graphite.

In some works, it is the practice, once the annealing furnace is up to heat, to maintain one continuous temperature for the full period of time. Other practice is to have periods when no firing is done, and the temperature in the oven gradually falls. It is then fired up again, raised to the required temperature, and again allowed to cool off gradually, these operations being repeated several times. The non-firing period is usually referred to as "soaking," and too often these soaking periods are made to coincide with the operator's meal times and evenings off. In the Rover foundry, each annealing oven is fitted with pyrometers, the smaller ovens with one thermo-couple, and the larger ovens each with four thermo-couples, all of which are connected to recorders. This system has the advantage of showing a complete day and night record of the anneal. Experience has shown that periods of "soaking" from 960 deg. C. down to 880 or 890 deg. C., are decidedly advantageous. In continuous firing and maintaining one steady temperature, free carbon is evenly distributed in a finely divided state throughout the mass of the casting, whereas intermittent firing and cooling appears to favour the precipitation of temper carbon in the nodular form. It is this latter which provides strength and ductility.

If malleable iron was a simple combination of iron and carbon, the theory of oxidation of carbon and final precipitation of annealing carbon would be capable of definite proof. The process of annealing is complicated by the presence of other elements, namely, silicon, sulphur, phosphorus, and manganese. It has been clearly demonstrated in grey iron that silicon reduces the solubility of carbon, and favours the formation of graphite. This function has been extended to malleable, and it is generally considered that with increased silicon content the loss of carbon decreases. This favours the theory that the primary attack during the annealing process is at the expense of the carbide. With a high-silicon content, carbon is thrown out of solution at a lower temperature, and the resultant material is higher in free carbon than would be the case if the silicon content was low. This is borne out in practice up to a point, but exceptions occur from time to time, and it is these exceptions which the general theory of annealing fails to satisfy. Two examples are given, but these are not isolated cases. Sample castings from the same pattern, but differing slightly in silicon content, were annealed in the same oven under practically similar conditions. After annealing, representative samples were taken for analysis, the results being shown in Table IV. The total carbon in the hard castings was 3.10 and 3.13 per cent. respectively. Observe that in sample A, although the silicon was higher than in sample B, yet there had been considerable elimination of carbon, whilst in B there had been only slight reduction. Two other samples cast from the same pattern were annealed under identical conditions. The total carbon in the hard castings was 3.05 and 3.21 per cent. respectively, and analysis after annealing is given in Table V. Both instances contradict the theory that increase of silicon favours the precipitation of free carbon. What is the explanation?

TABLE IV.—*Giving Results of Carbon Content varying with Silicon.*

	A.	B.
	Per cent.	Per cent.
Total carbon	1.10	2.50
Comb. ,, ...	0.42	0.79
Free ,, ...	0.68	1.7
Silicon	0.82	0.65
Sulphur	0.26	0.24

Personal experience has shown that manganese increases the difficulties of annealing. Many brands of malleable pig contain less than 0.2 per cent., and this small amount may be ignored. When the manganese exceeds 0.45 per cent. there is a tendency towards increased hardness in the finished castings. It would appear that manganese retards the annealing process, and introduces complications which may have a marked effect.

Table V.—*Tends to show that Decrease in Silicon favours Carbon Precipitation.*

	C.	D.
	Per cent.	Per cent.
Total carbon	1.80	3.05
Comb. ,, ...	0.83	1.52
Free carbon	0.97	1.53
Silicon	0.56	0.52
Sulphur	0.24	0.25

If the process is one of oxidation from the surface and diffusion of carbon outwards from the centre of the mass, one would imagine that increase of temperature would result in increased intensity of reaction. In other words, the higher the temperature attained, within reason, the greater should be the loss of carbon. Yet it is a well-proved fact that better results are obtainable by a long anneal at comparatively low temperatures than by a shorter anneal at higher temperatures. The only explanation which seems feasible is that at the higher temperature the cementite breaks down with precipitation of free carbon, further oxidation ceases, and the material becomes

Table VI.—*Effect of Time and Temperature on Final Composition.*

	No. 1.	No. 2.	No. 3.
	Per cent.	Per cent.	Per cent.
Total carbon ..	3.34	2.06	1.28
Comb. ,, ...	1.33	0.38	0.88
Free ,, ...	2.01	1.68	0.40
Silicon	0.61	0.59	0.61
Sulphur	0.25	0.25	0.23

passive. As a typical example of effect of time and temperature, the results given in Table VI are illuminating. All the samples were cast from the same material and pattern, and were annealed in a small gas-fired furnace where the temperature could be closely controlled. No. 1 was annealed for 78 hours at 960 deg. C., No. 2 for 86 hours at 940 deg. C., and No. 3 for 103 hours at 920 deg. C. One curious feature of these results is the effect of rate of cooling on the proportions of combined and free carbon. No. 1 was cooled very slowly to 600 deg. C., No. 2 to 700 deg. C., and No. 3 to 800 deg. C. Below these temperatures cooling was allowed to proceed rapidly. It will be observed that in No. 1 just over 39 per cent. of the total carbon remained in the combined form, against 18 per cent. in No. 2, and 68 per cent. in No. 3. From this it would appear that no harm is likely to result in cooling quickly below 700 deg. C.

Methods of Melting.

There are three methods of melting in malleable foundries, the crucible, the cupola, and the air furnace. In all probability the majority largely favour the cupola. Changes take place in composition during melting in the cupola, there being, as a rule, a loss in silicon and a gain in sulphur content. Numerous tests have been carried out in an endeavour to get an exact idea as to the extent of the changes. The author has proved to his own satisfaction that there is no appreciable difference between the calculated and the actual total carbon content. He has not been able to obtain any definite data as to the loss of silicon during melting. Different tests show different results, and the problem is complicated by the weight of the charges, the proportions of pig and scrap which make up the charge, and the volume and pressure of blast. One authority places the loss of silicon as high as 0.23 per cent., but personal experience has been to show, under normal conditions, an average loss of 0.17 per cent.

The sulphur content certainly increases during cupola melting, but the amount of increase is largely dependent on the quality of coke used, on the coke-iron ratio, and on the fluxing practice. During annealing it has been found on some occasions there is a still further increase of sulphur, whilst at times there is a slight diminution.

Phosphorus and manganese show little or no variation during melting, and are usually present in such small quantity as to have no pronounced effect.

It is the practice in many foundries to use a proportion of annealed scrap on each charge, and this practice has on occasion been strongly condemned. Personal experience has shown that small quantities have no ill effect, but the amount so used should not exceed 5 per cent. of the total charge. In greater quantities it appears to reduce the cooling range of the liquid metal; the iron, although appearing hot and fluid when tapped, rapidly becoming dull and viscous. The statement is sometimes made that the use of soft scrap introduces the danger of free carbon in the castings made from such a mixture, but it is difficult to see that free carbon will persist on melting. It is thought that in molten iron all the carbon must be present in the combined form. It is generally agreed that the presence of free carbon or graphite in the hard casting is deleterious, as this graphite is likely to remain after annealing and cause weakness. Graphite in the hard casting can only be due to a high total carbon content, coupled with a prolonged cooling through the critical range.

Distortion.

One of the most troublesome items connected with the production of malleable castings is distortion during annealing. Speaking generally, distortion in plain castings is due to bad packing in the ovens, to excessive heat, or to sagging of the annealing pans. Distortion in intricate castings may be the result of inequalities of expansion and contraction during heating and cooling owing to variations of thickness in the casting. Whatever may be the cause, distortion introduces the trouble and expense of "setting." This may be a fairly simple operation, or a very difficult one, necessitating the preparation of special dies and tools. Castings can sometimes be "set" in the cold, but heating-up is advisable. Opinions differ as to the wisdom of cold or hot setting, but it must be borne in mind that to obtain a permanent set the material must be stressed beyond its elastic limit. If the setting is performed in the cold there is a great danger of cracking; even if a crack does not develop, the casting has been unduly stressed, and considerably weakened in consequence. In hot setting there is a possibility that during the subsequent cooling the material will partially revert to its pre-annealed state. It is eminently desirable for some definite information to be obtained as to the maximum temperature to which it is possible to reheat malleable castings without risk of destroying the effect of annealing, and also the influence of time and conditions during cooling down again.

Cost of Annealing.

From a purely commercial point of view there are one or two items which demand investigation to enable malleable castings to be produced at a reasonable price and show a fair margin of profit. The two most expensive items are fuel and annealing pans. The old type rectangular furnaces, with fireplaces on either side of the bed, are reasonably cheap to erect, and the cost of upkeep is fairly low. At the same time, they are very extravagant on fuel. They will burn only a good long-flame type of coal, and will not burn slack or small coal. From careful tests made from time to time it is computed that this type of furnace consumes from 36 to 42 cwts. of coal per ton of castings annealed. More modern furnaces have a much lower coal consumption, but suffer from several disadvantages. The firing and manipulation of dampers is usually more complicated, and needs more highly skilled operatives. Firing is more continuous, and entails a night-shift. First cost is generally much higher, and cost of upkeep greater. All things considered, it may be found that the economy in fuel is more than counterbalanced by the increased trouble and expense in other directions. The development of pulverised fuel offers great possibilities in the malleable trade, and there is a wide field for the inventor in improving the efficiency of annealing furnaces.

Cost of Special Boxes.

Annealing pans add considerably to the cost of production. The effective life of an annealing pan varies from three to eight heats, and it will be found that the consumption is about 12 cwts. of annealing pans per ton of castings annealed. Many different types of annealing pans have been put on the market, but personal experience has been that with most of these patented types the weight of the pan is increased without a corresponding improvement of its effective life. The use of a high-chromium iron in pan manufacture reduces enormously the loss by scaling, but the cost is prohibitive. The price of this material is in the region of 3s. 9d. per lb., and as in the Rover Foundry the average stock of pans in use exceeds 90 tons weight, one can readily see that this item alone would entail an outlay of over £30,000.

Lines for Future Research Indicated.

From the foregoing it will be apparent that the manufacture of malleable iron castings is not a simple matter, to be lightly undertaken. In conclusion, it would seem desirable to indicate what appears to be the lines on which research is most necessary, and which would, to the greatest degree, assist the malleable founder in the problems with which he is so often confronted.

(1) The most urgent investigation is one on the production of pig-iron specially for the malleable trade. It has always appeared that the manufacturers of pig-iron look on the malleable founder as an outlet for iron which is unsuitable for steel making, and do not make a pig specially suited to the needs of the trade. In consequence, no two deliveries of iron even approximate to the same composition. It should be reasonable to expect from the blast furnace a pig-iron of guaranteed composition, with a medium-low total carbon, silicon within a specified range, and specified maximum sulphur, phosphorus, and manganese contents. This is possible in ordinary grey iron practice, and the Rover Company have purchased hundreds of tons of grey iron under such conditions. Why should it not be possible for the hematite pig-iron suppliers to supply to analysis? In the author's opinion it is a commercial proposition. If the foundry could be supplied with iron which only varied within known limits, many of the troubles associated with malleable iron would be eliminated, and the foundry would have definite

data on which to base their annealing practice. This is a matter of vital importance to the malleable trade, and unfortunately the pig-iron suppliers will go on in the old haphazard way until the trade as a whole insist on better treatment, and pressure can be brought to bear by united action.

(2) An exhaustive research into the effect of varying percentages of total carbon and silicon and their influence on annealing. What is the maximum and minimum carbon content desirable in the hard casting?

(3) A determination of the exact temperature range during which annealing takes place, and the effect of time on the ultimate results.

(4) Determination of the maximum total carbon content desirable in the annealed casting, and the proportions in which this should be split up between the free and combined states. Personal experience has shown that in sections up to, say, ¾ in. thick, to obtain the greatest toughness and ductility, the total carbon content should not be more than 1.8 per cent., and divided approximately equally as free and combined.

(5) Full investigation as to the respective merits of continuous and intermittent firing; and in the latter case, what is effected by periods of reduction of temperature, for what length of time should these periods extend, and through what range of temperature should they occur?

(6) A full research into the physical chemistry of annealing. Definite information is required as to the changes which occur, at what temperatures they occur, how long the changes continue, and in what manner rate of cooling modifies the result. In connection with this subject it is desirable to know the reason why in some instances carbon is eliminated whilst in others it is merely transformed in state.

(7) Is elimination of carbon caused by oxidation, and in what form must the carbon be retained to effect the maximum elimination?

(8) The conditions arising which cause carbon to be deposited as finely divided graphite, and how these conditions may be avoided.

(9) The effect of composition of packing medium on the annealing process.

(10) The influence of mass on the changes which occur during annealing.

(11) Whether casting temperature has any influence on the changes which take place during annealing, due to differences in grain size? It is reasonable to assume that both casting temperature and rate of cooling of the hard casting will cause modifications in grain size, and may, or may not, affect the ultimate result.

(12) The influence of subsequent work on annealed castings, such as brazing, or reheating for "setting"; and in what manner any deleterious effect can be avoided.

These do not embrace the whole of the researches urgently needed, but the solution of these problems would go far to help the malleable founder produce a reliable article, and rehabilitate malleable iron in the eyes of engineers and designers. Who will undertake this research? Will it be left to private enterprise, or have the British Cast Iron Research Association the power, ability and financial resources, together with the moral courage necessary for such a stupendous task?

If malleable founders would only realise that unity is strength, and pool their resources for their common weal, the author is convinced the results achieved would justify any means.

DISCUSSION.

Mr. W. H. Poole said he was well aware that many years ago the author was engaged in a research of malleable iron, and so it had afforded him much pleasure to hear this Paper read. There were, however, a few practical points connected with the contribution which it might not be at all disadvantageous to raise. He had been particularly interested in the tables giving the results of carbon content varying with silicon. He did not suppose the author would exclude the influence of gas—the oxidising of the gas atmosphere—but he should like to ask Mr. Hurren if in the samples experimented with, the other elements were identical. The notes on the question of carbon content were most valuable, but the difficulty at the present time, and it struck most of them very forcibly, was to get a pig-iron capable of supplying a suitable carbon content. Then another point he was desirous the author should enlarge upon was dealt with in one or two paragraphs throughout the Paper where reference was made to primary graphite. In some of the higher silicon irons, in spite of any obvious reason, primary graphite exercised a big effect on the annealing result. He was quite in agreement with the method suggested in the Paper of "soaking," but in the course of investigation he had been somewhat surprised to find firms who maintained the continuous temperature for the full time, actually taking their "soaking" periods during the process of annealing. As a result of the work Mr. Hurren had carried on, he would be glad to have information from him as to the possible effects of varying lengths of time in purely heating up. Then in regard to the condition of ore, his suggestion would be that there ought to be a periodical test of the actual black ore used in the process. On that point he wondered if Mr. Hurren could advise any method by which black ore could be maintained in the best condition. It would be interesting to practical men if there could be an elucidation of one other point, namely, as to whether there was any increase in sulphur. Sometimes in testing black ore he had found much sulphur, and in one instance there was 7 per cent. of it. Did Mr. Hurren consider that would be harmful in the ultimate annealing?

Mr. Harley remarked that many years ago he came to the conclusion that the use of malleable iron in the automobile industry was dying out, and the trend of events since had proved his contention right up to the hilt. He was speaking now for a large firm of motor-car manufacturers—the largest producers of motor cycles in the country, by the way. Their output aggregated something like 40,000 a year—and in their productions they had cut out malleable iron altogether, simply because it was not a reliable material. On that particular aspect of the question he did feel that its unreliability was very clearly indicated in the Paper now being discussed by the Institute. Of course, in the first instance it must be understood they were discussing English white-heart malleable, because he was ready to admit that the observations he was about to make might not equally apply to black-heart malleable. Mr. Hurren, in the Paper, had clearly shown the difficulty of obtaining pig-iron of the right composition for this work. He did not need to point out the difficulty of ensuring the exact composition in ordinary cupola melting. It was sufficiently bad with grey iron, but it was infinitely more difficult with malleable. Then with regard to the varying sections of patterns, he gave it as his opinion that it was a sheer impossibility to anneal correctly. If there was a varying section from one inch to a quarter of an inch, experience had shown with malleable iron that if the annealing was correct for the ¼-inch section it was useless for the inch section. He would go further and say that, as the outcome of his own practical knowledge, it was not possible with malleable iron to anneal properly a casting of one inch section. At the present time it seemed to him they were not producing malleable but simply a kind of superior cast iron. He proved these contentions many years ago in a Paper he submitted to the Birmingham branch of the Institute. Some twelve or fourteen years ago he obtained samples from all the leading makers and from the facts he brought out then he showed pretty conclusively that malleable iron as compared with cast steel could make no real competition. The steel process in the automobile industry was, in his opinion, a very simple one compared with that of annealing malleable iron. It was not to be understood that he was principally criticising this, but he was speaking with a view to getting the members of the Institute to consider this question for themselves. It was possible to prove from exhaustive research work on material that in regard to the important automobile industry, at any rate, the only people who were using malleable were those who could not get hold of cast steel. He regarded it as inevitable that malleable iron as made in this country by the white-heart process would become obsolete. For obvious reasons, and chiefly because he did not consider it was worth while, he had not gone into the various points raised by the author in his Paper.

Mr. E. Longden (Birmingham) said he was desirous of asking Mr. Hurren whether he had been successful in producing black-heart malleable iron in the cupola. Personally he had been nearly successful, but not quite. A point had been raised with regard to the condition of the ore, but he saw no difficulty on that score.

Mr. J. G. Pearce (Birmingham) said he for one refused to be scared into believing that the death-knell of the malleable iron industry had been sounded by the speaker of a few minutes ago (Mr. Harley). The Paper itself was a very good answer to some of the criticisms Mr. Harley had put forward. Towards the close of his contribution, Mr. Hurren inquired whether the British Cast Iron Research Association had the power, ability or financial resources, together with the necessary moral courage, to face a big research. To answer that query, he would refer them to three important points in connection with the malleable iron trade. Firstly, the number of producers was large; secondly, the average plant was small; and, thirdly, many of them lacked technical control. It was the second of these conditions which produced the results of which Mr. Hurren complained, but those of them who were connected with the British Cast Iron Research Association did not intend to let the position go by default. They were in close touch with the laboratories in various parts of the country, and they could arrange for experimental work on a commercial scale. The Association was fortunate in having a number of members who were interested in malleable production, and they were supplying some details of excellent results in practice. But the Association was even more fortunate still in its Malleable Committee, and an investigation had been commenced into the total carbon of white-heart malleable iron. Of course, the extent to which that could be carried out depended largely on the support that would be forthcoming from the malleable iron industry. He hoped that support would be readily forthcoming, because it was a task of some physical difficulty to get round so many different producers even in a comparatively small area. The particular material they were discussing at the moment was threatened with competition, not only from steel and casting steel, but from those other types of cast iron that were now beginning to receive so much attention. It would be a great pity to those employed and to the capital involved in the industry if it should be eliminated. They of the Cast Iron Research Association believed there was a field for such a research as he had indicated, and they considered further that it ought to be extended to its fullest possible limits. They did not see why this trade should be weak, especially when other branches of industry were able to maintain an organisation such as the Cast Iron Research Association. The latter had the technical facilities, and it was willing to undertake necessary research work if only manufacturers would support it by making themselves responsible for the comparatively small expenditure involved.

Mr. F. J. Cook said he also took exception to Mr. Harley's prediction regarding the ultimate position of the malleable iron industry in this country. Mr. Harley practically said that the malleable iron industry was dead, but he might point out to him that he knew of a large firm, specialising in motor cars, who at the present time used tons of malleable iron. It was far from going by the board, and personally, he could not see why a research could not be undertaken which would go a long way towards the re-building of a poor and downtrodden trade. He certainly agreed with Mr. Hurren as to the points he had raised relative to the effect of total carbon and the condition of primary graphite. These were two very important points. In any research which was to be undertaken they ought to consider the possible elimination of sulphur from the cupola process. He did not look upon that as an impossible proposition. If that and a few other points suggested by Mr. Hurren in his Paper could be dealt with they would go a long way towards raising the malleable iron industry to a higher condition than Mr. Harley thought it was at the present time.

Mr. F. H. Hurren, in replying, said he should like to thank Mr. Poole for opening the discussion. He did so particularly for the reason that he did not wish to remember how many years ago it was now since Mr. Poole came to him as a very junior assistant. In the interval they had both got considerably older and, he hoped, wiser. With regard to the point raised as to the influence of the atmosphere in the furnace, he did consider that the annealing pans were impermeable to furnace gases, but no doubt the atmosphere in the furnace was a very important factor in the annealing. In

Table I "the other elements" which were not enumerated were practically identical in both cases. He had been rather interested to hear that a firm starting with a total carbon of 2½ per cent. got such very good results. Regarding the question of the various lengths of time in heating-up, he had this to say that the heating-up period was a very important one. Rapid heating-up in his opinion invariably induced complications, and he believed that point had been pretty well brought out by one of the Institute's members at a recent meeting of the Iron and Steel Institute. With rapid heating-up there was a greater danger of peeling, and his own experience had been that a period of not less than from 32 to 36 hours should be taken between the commencement of the operation and the maintaining of an annealing temperature of 900-950 deg. C. From past experience of Mr. Harley—and he had considerable arguments with him—he knew that gentleman was not enthusiastic for malleable iron. He would, however, point out that although cast steel might be superior so far as the physical properties were concerned, it was not an easy material to manipulate. Furthermore, the expense in the upkeep of plant was considerably higher than that of the malleable iron foundry. One gentleman had pertinently asked in the course of the discussion why sulphur, if it retarded annealing, should be used in the annealing pans at all. That was a suggestion that was worth considering. Speaking for himself, he (Mr. Hurren) had not been able to obtain good black-heart material from the cupola, but he considered this was a research that was highly necessary. He believed this was an industry of very considerable importance in the Midlands. It employed a large number of men, but unfortunately haphazard or rule-of-thumb methods were adopted. It did seem to him that a research which ought to be a fairly simple thing would be of inestimable benefit to the malleable trade.

APPLICATION OF METALLOGRAPHY IN BRONZE FOUNDING.

By Francis W. Rowe, B.Sc. (Research Dept., David Brown and Sons (Huddersfield), Ltd.).

Though the weight of castings in non-ferrous alloys produced yearly is only a small percentage of the total metal castings made, yet if the respective value of the castings in the different materials—non-ferrous alloys, cast iron and steel—is taken, it will be seen that a very large sum of money is involved and that a much greater capital outlay and a greater value per ton obtains when making non-ferrous castings.

If for this reason alone, it is necessary for the non-ferrous foundry to operate on even more economical lines than the iron and steel founder. Furthermore, owing to the present state of the engineering and allied industries as few parts as possible are made in brasses and bronzes, owing to their relatively high cost; and the weight of these are cut to the minimum. Thus it is essential that the castings should be as sound and strong as possible as the latitude in strength and the factors of safety are smaller than formerly. Consequently, all the results of metallurgical research and all the help that metallurgical instruments can give should be employed by the bronze founder to ensure that his castings shall be as sound and reliable as possible.

In this respect the research work that has been done in universities and industrial laboratories throughout the world has proved of immense value to the bronze founding industry in helping to produce not only sounder castings, but castings of *regular* composition and strength and more fitted for particular duties in service.

Metallography embraces the study of the internal structure and constitution of metals and alloys. Since much of the internal structure of metals and alloys cannot be studied with the naked eye, the microscope must be largely used in examining their formation and constitution.

It is not the author's intention in this Paper to discuss the theory of the compound microscope, nor

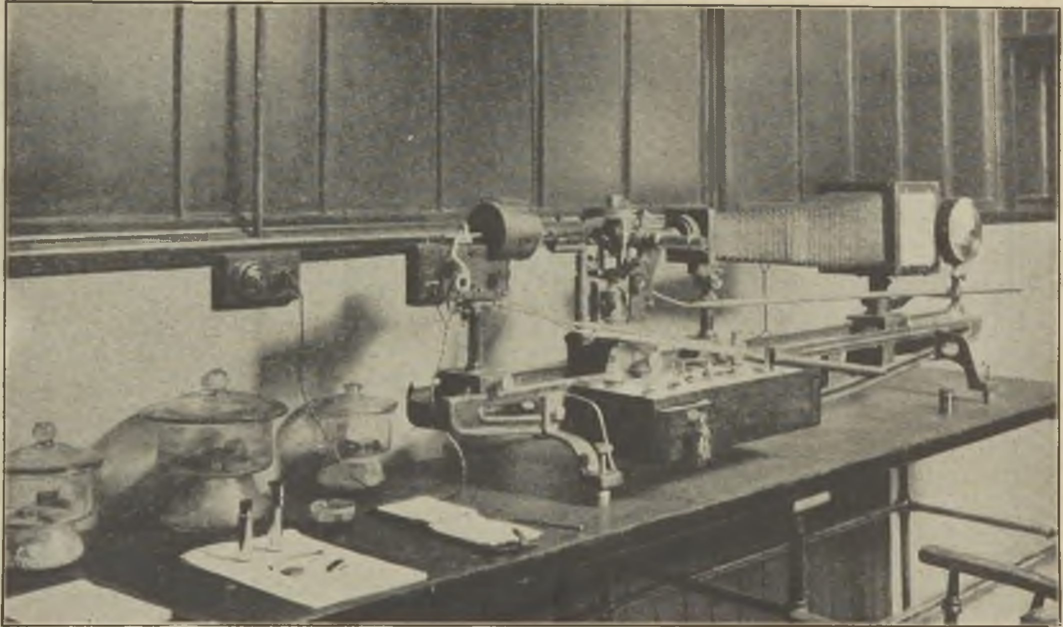

FIG. 1.—METALLOGRAPHIC OUTFIT IN RESEARCH DEPARTMENT, DAVID BROWN & SONS (HUDDERSFIELD), LIMITED.

describe in detail the mode of preparation of metallographic specimens, as such information is available in most text-books. It should be mentioned, however, that as much useful information can be gained from a metallurgical microscopic outfit costing £20 or £30 as from the more expensive research outfits such as that in Fig. 1, which represents probably the latest and best achievement in microscopes for metallurgy. It is only when the desire or necessity arises for preserving records, in the shape of photographs of the various structures, that such an equipment is essential.

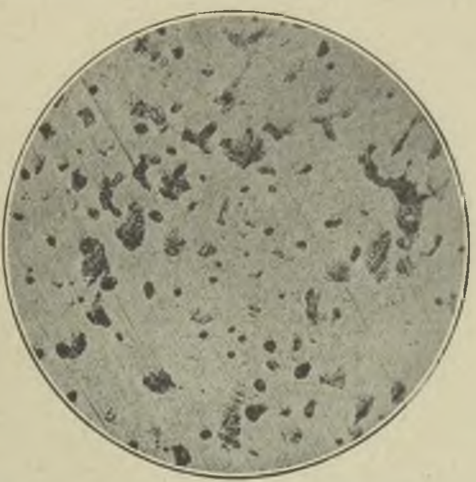

FIG. 2.—UNETCHED SPECIMEN—6 PER CENT. LEADED BRONZE × 200 DIAS.

Metallurgical specimens for the microscope are polished on successive grades of fine emery paper and finally buffed on a revolving wet pad using a superfine abrasive such as aluminium or magnesium oxide. This removes the scratches left by the finest emery paper. Such a specimen is then examined under the microscope (before what is known as etching) to obtain an idea of the soundness or otherwise of the specimen. Porosity is thus easily discernible in specimens which to the naked eye in the polished state or in the fractured state appear perfect and is shown up more clearly than after the specimen is etched, as the colouration of the specimen may mask the holes. In brasses and bronzes most non-metallic inclusions such as sand, slag, etc., are easily seen in the unetched state, and the presence of lead in such alloys is indicated. Lead is practically insoluble in the ordinary alloys, and thus appears in the solid metal as patches (smaller or larger according to circumstances) of the pure metal. This being soft is usually picked out during the final polishing, and thus the metal appears to have small black pits over the specimen.

FIG. 3.—UNETCHED SPECIMEN—LEAD FREE BRONZE SHOWING POROSITY IN INTERSTICES OF DENDRITES × 200 DIAS.

As porosity shows in a somewhat similar manner, it might be thought that confusion would occur as to which of the holes were due to lead and which to porosity, but actually this seldom occurs, as the lead appears in fairly regularly shaped patches, whilst porosity shows as jagged, uneven holes.

Figs. 2 and 3 illustrate this differentiation.

Revealing the Constituents.

After such examination the specimen is etched by immersing it in a chemical solution. The two most used etching reagents for brasses and bronzes are an acid solution of ferric chloride and ammonium persulphate solution.

The effect of the etching reagent is to corrode or colour the different crystals or constituents differently or unevenly. Thus after etching one is able to see the different constituents clearly. The different classes of constituents met with in non-ferrous alloys will be generalised separately.

FIG. 5.—SOLID SOLUTION × 100 DIAS. GRAIN BOUNDARIES AND DIFFERENTLY ORIENTATED CRYSTALS.

(*a*) Solid solutions consist of crystals which are composed of variable proportions of one metal dissolved in another. Solid-solution crystals are not necessarily of definite composition, but may vary between the limits of solubility of the component alloys. Such crystals being true solutions, it is impossible to distinguish the two components under the microscope.

An alloy composed of two or more metals in such proportions that they dissolve completely in each other presents under the microscope in its normal state a similar appearance to that of a pure metal. That is, a number of crystals of the same structure throughout, only the grain or crystal boundaries showing.

Fig. 14A shows a photomicrograph at 200 diameters of a solid solution in which these characteristics are visible, whilst Fig. 5 shows one exactly similar except that the composition of the alloy is such that the different crystals appear of different colour due to the light being reflected from the crystals in a different manner. Many alloys in the cast condition, however, though solid solutions, show a different appearance from those in Figs. 14A and 5.

FIG. 6.—SOLID SOLUTION × 50 DIAS. CORING EFFECT AND DENDRITES.

Fig. 6 shows a photomicrograph of an alloy of 80 per cent. copper and 20 per cent. nickel. The separate large grains are visible, but there is also an internal structure within the grains. This fir-tree or dendrite structure of what are known as "cored" crystals is common to many solid solutions in the cast condition, and is due to the method of solidification of the alloy. Solid solutions do not freeze at any definite temperature but over a range which may vary from 10 to 100 deg. C. In this instance the first solid portions to freeze out of the metal have been richer in nickel and the surrounding layers which have been built round the nuclei are progressively lower in nickel, and thus the difference in the rate of attack by the etching reagent. From the photomicrograph can be seen how the solidification has progressed in each grain. Thus an alloy is obtained consisting entirely of crystals of the same average composition but varying slightly in themselves. Such coring effects may be removed by annealing the alloy, although it must be pointed out that with some classes this internal coring is extremely difficult to remove—notably in the alloys of which the photomicrograph is taken—the copper-nickel group.

FIG. 7.—PHOSPHOR COPPER (9 PER CENT. P) × 50 DIAS.

Eutectics and Eutectoids.

(*b*) Eutectic signifies alloy with the lowest melting point. The eutectic of any alloy of two or more metals is that definite composition which solidifies at the lowest temperature. The solidifications of a eutectic takes place at one definite temperature, and not as with solid solutions over a range of temperature.

Eutectics, consisting as they do, of two constituents intimately mixed together, always present a duplex structure, though in many instances the higher powers of the microscope are necessary to show this feature. The "pattern" of the duplex structure of a eutectic varies with different alloys and different methods of cooling, but they can usually be easily identified as they possess similar general characteristics.

Fig. 8.—Tin Bronze Quenched 650 deg. C. × 400 dias.

Fig. 7 shows a photomicrograph of an alloy containing 9.0 phosphorus and 91.0 per cent. copper. The major portion consists of the eutectic of copper and copper phosphide with one dendritic crystal of copper phosphide. The alloy contains slightly more phosphorus than is required for the formation of all eutectic (8.2 per cent.), and thus some copper phosphide remains free. It will be noticed that the eutectic is coarser in some parts than in others, that is at the edges of the grain, though the grain boundaries are not usually distinguishable except by this feature.

Eutectoids, as their name implies, are similar to eutectics. The essential difference is that whilst eutectics are formed by the simultaneous freezing from the liquid state of two constituents of an alloy in definite proportions, eutectoids are formed by the decomposition in the solid at a definite temperature of a solid solution.

FIG. 9.—TIN BRONZE AS CAST × 400 DIAS.

The formation of a eutectoid may be perhaps best illustrated by a specific example. An alloy of 80 per cent. copper, 20 per cent. tin commences to solidify about 880 deg. C. At 790 deg. C. the alloy is quite solid and consists of a mixture of two solid solutions known as the alpha and the beta. This structure continues until the temperature reaches 525 deg. C. Fig. 8 shows the structure of such an alloy in this range being obtained by quenching a sample at 700 deg. C. and thus retaining the structure at that temperature.

At 525 deg. C. the beta solid-solution breaks up into a eutectoid composed of alpha solid-solution and delta solid-solution as its constituents. The appearance of the alloy in this condition is shown in Fig. 9. Fig. 10 shows the eutectoid at a higher magnification when the two constituents are seen more clearly.

Intermetallic Compounds.

(c) *Intermetallic compounds* are compounds of two or more metals of *definite* chemical composition. They combine with the other portions of an alloy similarly to a pure metal or a solid solution, and may form solid solutions or eutectics with other solid solutions or the pure metals. Certain classes of metallic compounds are easily identified by the fact that they solidify at one definite temperature and not over a range, and also the fact that they show no coring effect in the cast condition like many solid solutions.

Fig. 10.—Alpha-Delta Eutectoid in Tin Bronze × 2,000 dias.

Perhaps one of the commonest intermetallic compounds of this definite class that is met with in ordinary bronze founding practice is the compound copper phosphide Cu_3P.

The photomicrograph Fig. 7 shows this compound —a dendrite or crystal of the compound and the mixture of the compound with practically fine copper as a eutectic. Fig. 11 shows an alloy containing 4.5 per cent. tin; 1.5 per cent. phosphorus, and 94 per cent. copper. The structure consists of a ground mass of solid solution (alpha) of tin in copper, whilst the nodules are phosphide of copper Cu_3P.

General Characteristics of the Different Constituents.

It is difficult to generalise on the physical properties of various types of constituents, as exceptions are fairly frequent. Generally speaking, however, solid solutions are comparatively soft and ductile and capable of being worked cold. They are similar in this respect to the majority of pure metals. Eutectics are hard—generally much harder than their constituent metals—and are usually very brittle and find very little commercial application as castings, though here again exceptions must be made as one of the most promising of the aluminium casting alloys—Alpax—is the eutectic alloy of aluminium and silicon.

Fig. 11.—Free Copper Phosphide Nodules in Low-tin Phosphor Bronze × 100 dias.

Eutectoids are generally much harder than solid solutions but not so hard nor so brittle as eutectics and many commercial alloys—notably the bronzes and gunmetals—contain an appreciable and important proportion of a eutectoid.

Intermetallic compounds in their pure state are harder and even more brittle than eutectics, particularly those which show the characteristics of an intermetallic compound in a marked manner.

Examination of Raw Materials.

It must be confessed that, chiefly owing to the perfection of manufacturing conditions, the scope of the microscope in the examination of virgin metals is limited. Metals such as electrolytic copper, tin, lead and spelter and nickel usually come into the market in such a high state of purity that their performance for casting purposes may be relied upon and very little save analytical control is needed, and that only occasionally if standard brands are purchased. Perhaps the one exception is ingot copper.

FIG. 14.—ADMIRALTY GUNMETAL, AS CAST × 200 DIAS.

" Best Selected " ingot copper always contains an appreciable and important amount of oxygen. Copper which is free from oxygen will not cast soundly into ingots, and therefore, in the refining processes for copper, some oxygen is left in to ensure clean-looking ingots which will break with a nice fibrous fracture.

As there is no type of non-ferrous alloy which is better for containing oxygen, it is of importance to keep a careful watch on the possibility of introducing this constituent.

A good quality of B.S. copper should not contain more than 0.1 per cent. oxygen, and excess of this amount will result in poor castings being obtained with many alloys. The estimation chemically of oxygen in copper is a lengthy and intricate process, but the detection and rough approximation under the microscope is simple. Oxygen in copper appears as cuprous oxide as a eutectic with copper, and very small amounts are easily discernible.

Needless to say, electrolytic copper does not suffer from this impurity and is worth the extra cost for certain classes of alloys.

Alloys of the Bronze Class.

The basis of all alloys of the bronze class is the system copper-tin. The alloys which find use in engineering practice contain up to 16 per cent. tin and varying amounts of zinc, lead or phosphorus.

Pure copper-tin alloys—that is, those made without any deoxidant or addition of other metal—are seldom used nowadays. Copper-tin alloys are among those which are very susceptible to the presence of oxide. Oxide in these alloys renders them extremely sluggish when molten and liable to casting defects and serious weakness in strength due to lack of cohesion in the crystals. The oxide in these alloys is tin oxide—one which it is extremely hard to remove from the metal when once formed.

Consequently, the general practice is to prevent the formation of oxide by adding either zinc or phosphorus to the metal at the right time—*i.e.*, before alloying the tin.

Copper-tin alloys form an extremely interesting and important study from a metallographic point of view. Theoretically copper is able to dissolve 12 to 13 per cent. of tin. That is, alloys of copper with 12 to 13 per cent. tin should form a homogeneous solid solution. In actual practice this does not occur, as the comparatively rapid rate of cooling prevents the alloy from attaining what is known as its stable state, and very prolonged annealing is required before the alloys attain this final state. Actually, in ordinary bronze-founding practice, the limit of solubility is between 6 and 7 per cent., depending on the casting and cooling conditions. That is, an alloy of 95 copper and 5 per cent. tin will consist when solid of homogeneous solid solution (save for a slight coring effect) known as alpha, and will show nothing but grain boundaries under the microscope. Such an alloy, with care, can be rolled and drawn.

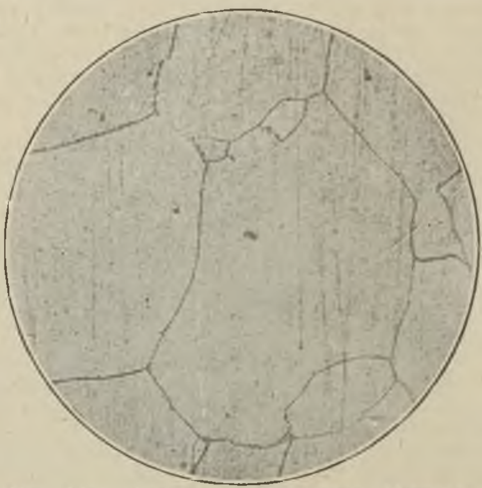

FIG. 14A.—ADMIRALTY GUNMETAL ANNEALED × 200 DIAS.

Above 7 per cent. tin it will be seen that a new constituent has made its appearance. This is the alpha-delta eutectoid whose constitution and formation was discussed in the paragraph on eutectoids. It is to this alpha-delta eutectoid that the bronzes owe their wearing properties. It is considerably harder than the beta solid solution from which it is formed, and great care must be taken to see that it is formed where the best qualities of the bronze are required. The author has known many failures and shortcomings in bronzes due to insufficient appreciation of the functions of this important constituent.

As has been pointed out previously, if a bronze is quenched in water from a temperature of 550 deg. C. or above, the beta solid solution is retained and no eutectoid is present. Bronzes in this condition are stronger, very much tougher, and more ductile than in their normal condition, but they are not suitable for withstanding wear. Any alloy to withstand wear and at the same time give a low co-efficient of friction must consist of hard particles embodied in a soft matrix, and there must be a considerable difference in hardness between the two constituents. In a bronze alloy there is very little difference in hardness as measured by the Brinell method between a normal and a quenched sample, but there is a great difference in their capacity to resist wear, because in the quenched alloy the difference in hardness between the two constituents has been levelled up, the soft matrix has been hardened, and the hard eutectoid particles have been transformed into the softer beta.

The practice of quenching bronze or gunmetal castings to secure tougher and stronger metal is one which should not be indulged in without the fullest knowledge of the duties imposed on the casting in service. Similar harmful effects may result for the same reasons from the practice of baring the heavy portions of bronze castings immediately they are set and throwing water over them to prevent liquation or bleeding, and in addition the liability to set up severe strains which may result in early failure in service.

Somewhat similar conditions appertain with the question of annealing—heating the castings up to 600 or 700 deg. C. and allowing them to cool slowly. Where the castings have to withstand wear this again is very harmful. Nature has providentially arranged that the rate of cooling which ordinarily obtains in sand castings is the one which gives in bronzes and gunmetals a good structure to resist wear.

The alpha solid solution, containing as it does only 6 or 7 per cent. tin, is comparatively soft and forms a good matrix. The remainder of the tin is present as the valuable eutectoid. If the alloy is annealed, it causes it to assume more nearly its stable structure. That is, the alpha absorbs more tin, becomes harder, and the eutectoid is lost. Figs. 14 and 14A illustrate this point.

Why anyone should want to anneal Admiralty gunmetals and bronzes is something of a mystery. If the strength of such alloys in their normal condition is not adequate and the presence of the eutectoid is not important, why not use an alloy with 5 or 6 per cent. tin and 5 or 6 per cent. zinc.

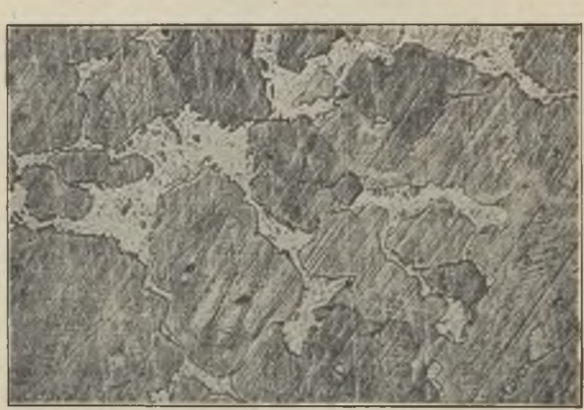

FIG. 15.—HIGH PHOSPHORUS PHOSPHOR BRONZE × 2,000 DIAS.

Phosphor Bronzes.

The primary object of adding phosphorus to a bronze is to ensure freedom from oxide. It should not be assumed, however, that because a bronze contains phosphorus that no oxide can be present, as is generally asserted, because such is definitely not the case. It is extremely doubtful whether phosphorus is capable of reducing tin oxide. If, however, in alloying a bronze the phosphor tin or phosphor copper is added to the molten copper before the tin, the phosphorus combines with cuprous oxide and frees the metal from oxygen. Thus when the tin is added, there is no tin oxide formed. Cuprous oxide is present to some extent in practically all melted copper. Even electrolytic copper, unless melted under very exacting conditions, absorbs some oxygen.

A very small amount of phosphorus is sufficient to accomplish the deoxidation of copper, and if this is the sole desideratum 0.03 per cent. phosphorus will suffice. Phosphorus in excess of this amount appears in the alloy as copper phosphide Cu_3P—a comparatively hard and very brittle substance. If the alloy contains sufficient tin to have an appreciable amount of eutectoid present, this copper phosphide is not easily visible at low magnifications. It is associated with the eutectoid and with it forms a low melting point compound, melting at 620 deg. C.

FIG. 16.—HIGH PHOSPHORUS PHOSPHOR BRONZE × 2,000 DIAS.

One result of the addition of phosphorus is that the period of solidification of the bronze is greatly increased by the formation of this compound, and thus any liability to defects such as liquation is greatly enhanced. Fig. 15 shows the microscopical appearance of a phosphor bronze containing 1 per cent. phosphorus and 11 per cent. tin at low magnification.

Fig. 16 shows a portion of the eutectoid under a magnification of 2,000 diameters with the two constituents copper phosphide and the alpha delta eutectoid. By examining a bronze under high magnification as little as 0.04 per cent. phosphorus can be thus detected. Though it is general for the phosphide to be thus associated with the eutectoid, small patches are met with frequently structurally free. An example of this is shown in Fig. 17.

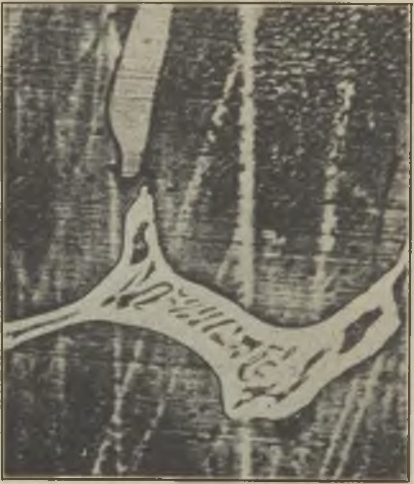

FIG. 17.—COPPER PHOSPHIDE IN PHOSPHOR BRONZE NOT ASSOCIATED WITH EUTECTOID × 2,000 DIAS.

Gun Metals.

The name gun metal is now taken to refer to alloys of copper and tin which contain zinc varying from 1 to 9 or 10 per cent. Perhaps the best known is Admiralty gun metal, which is commonly interpreted to consist of 88 copper, 10 tin, and 2 per cent. of zinc. The addition of zinc to a tin-bronze greatly facilitates casting operations, sound castings being obtained with less trouble, zinc being also a good deoxidant.

The zinc present is not detectable under the microscope as it is present in solution in the alpha constituent. The presence of zinc renders the alpha much harder, and for this reason gun metal is not so valuable as a plain or phosphor bronze for parts to resist abrasive wear as the difference in hardness between the two constituents is smaller.

The gun metals with less tin and more zinc find extensive application in industry, particularly in the manufacture of hydraulic and steam fittings Such alloys, consisting of homogenous solid solutions, are easier to cast than the better-known Admiralty metal, as no eutectoid is present and consequently liquation and segregation troubles are non-existent. Whilst not suitable for withstanding wear, their mechanical properties are excellent.

FIG. 18.—70:30 BRASS, AS CAST × 200 DIAS.

Leaded Bronzes.

In addition to ordinary tin bronzes and phosphor bronzes for wearing duties, bronzes containing appreciable amounts of lead (up to 12 per cent.) find extensive application for bearings. The lead appears as structurally free, metallic lead not entering into solution or combination with the other constituents. The effect of the lead is further to soften the matrix or alpha solid solution portion of the bronze and thus improve the anti-friction properties.

Naturally, it is essential to have the lead as finely divided and uniformly distributed as possible, and to this end the conditions of casting and cooling should be well studied, especially if the lead content is above 8 or 9 per cent.

The Brasses.

Metallographically, the industrial ranges of the brasses, that is from 10 to 50 per cent., are comparatively simple. Up to 35 or 37 per cent. zinc they consist wholly of a solid solution of zinc in copper known as the alpha solid solution. They show the customary dendritic cored structure unless very slowly cooled, and are all comparatively soft and very ductile and can be worked either hot or cold. After about 35 per cent. zinc is passed a new constituent appears which is known as the beta phase. The exact nature of the beta phase is not thoroughly clear, and although it is generally and conveniently regarded as a solid solution, this description may not be strictly accurate.

The beta constituent is much harder and more brittle than the alpha, and consequently the physical properties of brasses in the cast state alter quickly when the limit of solubility of zinc in copper has been passed. After 35 or 37 per cent. zinc is passed the alloy becomes progressively richer in beta until at 48 or 49 per cent. the whole of the alloy consists of the constituent. After 49 per cent. zinc a new constituent makes its appearance which is known as gamma, the slightest traces of which render alloys unsuitable for industrial work, making them extremely fragile and brittle.

The effect of zinc on the microstructure of brasses is illustrated by the photomicrographs in Figs. 18, 19 and 20, which show respectively a 30, 40 and 43 per cent. zinc brasses. The alpha-beta brasses and the beta brasses form an extremely useful series of industrial alloys and one in which large tonnages are cast every week.

Special Brasses.

Most of the alpha-beta and beta brasses which are used for castings are those known as special or high-tensile brasses or, more incorrectly, manganese bronzes. These consist of ordinary brasses to which small amounts of special elements such as aluminium, manganese, nickel, iron or tin are added to improve the physical properties. These elements are soluble to an appreciable extent in brass, and have the effect of replacing zinc in the mixture. That is, a brass containing 65 copper, 34 zinc, and 1 per cent. aluminium would have similar metallographic structure to an alloy containing 40 zinc, 1 per cent. of aluminium being equal to 6 per cent. of zinc.

FIG. 19.—59:40 BRASS, AS CAST × 200 DIAS.

In addition to this zinc-replacing feature, the brasses containing these special elements are considerably tougher and stronger than the corresponding plain brasses, due to the refinement of grain and closer cohesion. Metallography plays an important part in the commercial production of this type of alloy, as the amounts of the alpha and the beta constituents must be carefully regulated for the duties for which the bronze is intended.

The microscope is now also extensively used for controlling the composition during melting. For heavy castings such as propeller blades, the metal is melted in reverberatory furnaces, and, due to oxidation, it is difficult to keep the zinc contents within the necessary narrow limits without control. When the bath is nearly ready for tapping a spoon sample is taken and cast in a chill mould and a specimen rapidly cut off, polished and etched and examined to determine the relative amounts of alpha and beta. With a little practice the amount of each can be gauged to 1 or 2 per cent. equal to gauging the zinc content to 0.5 per cent. From this determination the amount of zinc required to bring the bath to the required composition is calculated. The method is more accurate and reliable than the old procedure of judging the zinc contents from the fracture of chill-cast spoon samples, and cannot be objected to on the score of time, as the whole operation takes only two or three minutes.

Fig. 20.—56:43 Brass, as Cast × 2,000 dias.

Grain Size.

One of the most profitable branches of metallography for the bronze founder is the study of grain size under different casting conditions. Much has been written regarding the best casting temperatures for different classes of alloys, but such information, whilst extremely valuable when applied under similar conditions to which it was obtained,

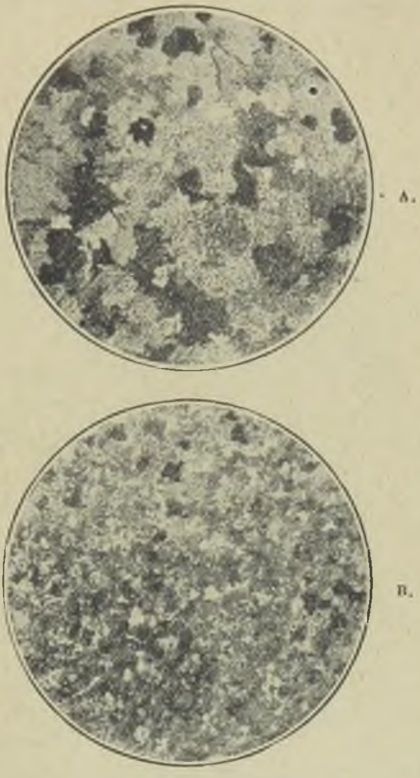

Fig. 21.—Runner End (A) and Riser End (B) of Bronze Test Bar × 2.

is of very little use for the other work and other methods of moulding and running castings.

The underlying idea at the back of all pyrometric control is that the castings shall have a definite grain size known to be associated with the best physical properties for that method of casting.

Such grain size depends upon the period of time over which solidification takes place and to some extent the period of cooling after solidification. Given equal cooling and casting conditions, the higher the casting temperature, the larger will be the grain size, and vice versa. Slow cooling after casting will also give a larger grain size than more

FIG. 22.—RUNNER END (A) AND BAR END (B) OF BRONZE TEST BAR × 2.

rapid cooling, and it is of importance to appreciate these two factors in connection with grain size.

Grain size is very often visible in the machined surfaces of castings when the machining operation has been such as to produce ridges, *i.e.*, planing, shaping or rough turning. Grain size is best studied, however, at low magnifications or visually on ordinary metallographic specimens, which need not be polished with the same extreme care needed

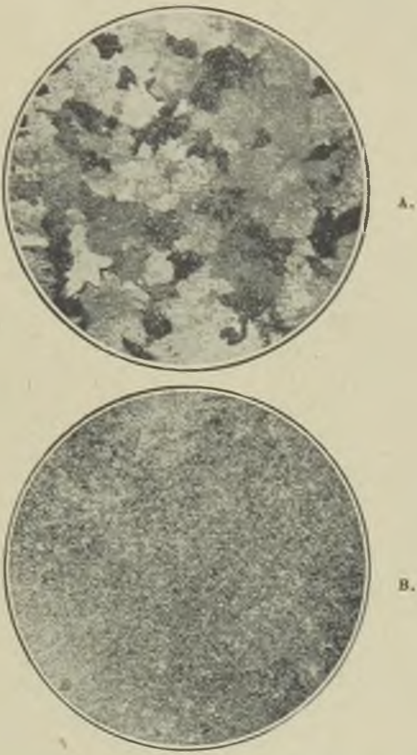

FIG. 23.—MACROSECTION FROM NEAR RUNNER (A) AND FURTHEST POINT FROM RUNNER (B) ON BRONZE RING × 2.

for ordinary microscopic work. Such macrosections give one a good indication of the way the particular casting has solidified and whether the physical properties are likely to be of the best.

Fig. 24.—Similar Sections as 23A and B, but Higher Casting Temperature × 2.

Take, for example, the macrographs in Figs. 21 and 22. Two test bars were moulded 12 in. × 1 in. dia., and both had the same size runner, but one had a riser and the other none. The runner was 1 in. dia. all the way. Both were cast at the same temperature—1,180 deg. C.—with bronze containing approximately 10 per cent. tin. A small section was cut from the runner and riser end of each, and the macro appearance of these are shown in Figs. 21 and 22. It is quite easy to see that the physical properties of the metal at the far end of bars will be quite different from the runner ends of the bar, particularly in the bar cast without riser. Brinell hardness tests taken on the four sections showed :—

	Load 500 *kilos.* 10 *mm. ball*
21A	63
21B	69
22A	65
22B	78

To take another example drawn from actual works practice. A large bronze ring approximately 2 ft. dia. × 4 in. × 2 in. This was cast with a down runner on one side at a predetermined temperature. The macrographs of portions taken near the runner (23A) and diametrically opposite the runner (23B) are shown.

On machining up, blowholes appeared on the opposite side of the ring to the runner. These blowholes were quite rightly attributed to cold metal. The obvious (but incorrect) cure was to raise the casting temperature. As an experiment this was done. The resulting macrographs (taken from similar portions) are shown in Figs. 24A and 24B. This time, whilst the place which formerly was blown was quite sound, the metal was open and porous near the runner, due to the metal being too hot at this section.

The correct remedy was to enlarge the runner so that the mould was filled with metal all at the same temperature or as near this ideal as possible. This is helped, in addition to enlarging the runner, by placing a small riser on the ring diametrically opposite the runner, not to act as a feeder, but so that the coldest metal shall be expelled from the mould. The resulting macrographs are shown in Figs. 25A and 25B, where the grain size both at runner side and opposite side of the casting are as uniform as is possible to obtain. These two examples will serve to indicate the necessity of watching other points beside the temperature of the metal in the ladle. Frequent defects of a similar character are often noticed in a number of castings on a pattern plate. A foundry foreman complained to the author some months ago of the

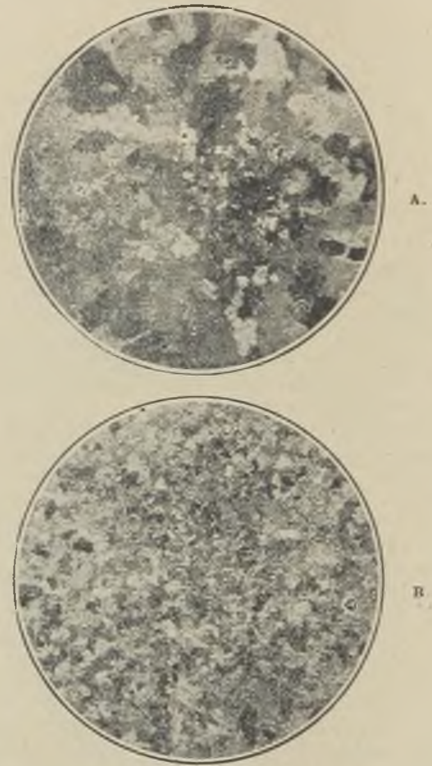

Fig. 25.—Similar Sections as 23 and 24, but Large Runner and Small Riser.

extremely narrow limits of successful casting temperature for a certain type of gunmetal. His opinion was based on the following facts. He was casting a number of small valve bodies either 18 or 20 on plate in a box approximately 30 in. ×

15 in. These were moulded 9 or 10 aside with a common main runner down the middle of the box gating the castings on either side. He found that at a certain casting temperature approximately 90 per cent. of the castings machined up and passed hydraulic test successfully.

If the boxes were cast at a temperature 10 deg. C. higher, nearly 50 per cent. of the castings were porous, and if cast 10 deg. C. lower, similar high percentages of scrap were experienced.

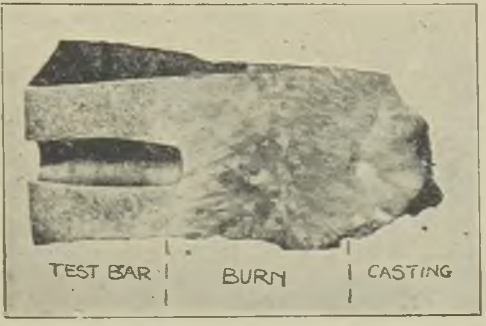

Fig. 26.—Macrograph (Full Size) Runner to Test Bar of Large Bronze Casting.

The author knew that the particular alloy should not be so susceptible in the question of casting temperature and that the casting temperature being used was well on the high side. An investigation of grain size revealed the cause of the narrow limits for casting temperature for this particular job.

The gating was such that the castings near the runner had a much larger grain size than those at the far end of the plate. What was happening was that by the time the castings at the far end of the plate were cast up, the metal had fallen so much in temperature that, unless the metal was poured at a very high temperature (right on the top limit for safety), the castings at the far end of the plate were defective. If this already very high casting temperature was increased by even so small an amount as 10 deg. C., the castings near the runner were defective. By altering the position and size of the runner so that the castings were run all at approximately the same temperature, a much greater latitude was obtained in casting temperature. Another minor application of macrographic specimens is illustrated in Fig. 26. The author had occasion to examine a large bronze casting supplied under specification with test bars cast on the casting.

The casting was received with the test bars cast on. These, when pulled, gave exceptionally good results. A slight discrepancy in the analyses of turnings from the casting and turning from the test bars of the order of 0.2 per cent. in the lead content caused an investigation to be made. The runner connecting the test bar to the casting was sectioned and polished and the macrograph obtained. The cause of the discrepancy in the analyses and the exceptionally good results from the test bars was revealed. The hole on the left-hand side of the piece was one where drillings were taken prior to suspicions being aroused. The evidence of the macrograph is obviously uncontrovertible.

Whilst, perhaps, much of this Paper is platitudinous, the author trusts the importance of the points upon which he has touched are sufficient excuse for their reiteration, and that the practical men of the bronze founding industry (to whom this Paper is addressed) will find some points of interest to themselves and that it will prove some slight incentive to study further the fascinating subject of metallography and confirm or otherwise the personal opinions of the author.

In conclusion, the author would like to express his sincere thanks to the directors of Messrs. David Brown & Sons, Limited, for permission to publish this Paper and, in particular, to their managing director, Mr. Percy Brown, for his kindly interest and stimulating encouragement in all matters pertaining to the application of science to the betterment of industrial products.

ALUMINIUM-ALLOY CASTINGS.

By S. L. Archbutt, F.I.C. (National Physical Laboratory).

It is characteristic of solid solutions to be tough and ductile, and of intermetallic compounds to be hard and brittle. According to the properties desired in castings the metallurgist must choose, therefore, as far as possible the metals he adds with a view to their behaviour on solidification of the alloy. As far as research has progressed up to the present, comparatively few metals which can usefully be added to aluminium have been found to possess any considerable solubility in the solid metal at normal temperature except zinc. Under conditions of equilibrium, zinc dissolves to the extent of approximately 18 per cent. Under similar conditions aluminium will hold approximately 3 per cent. of copper. In castings, however, less than 3 per cent. of copper is sufficient to cause the separation of crystals of a compound of copper and aluminium. With other common metals, *e.g.*, manganese, iron, nickel, the solubility is still less, and still smaller additions cause the separation of hard compounds of the added metal from the solidifying melt.

Another fact restricting the number of other metals which can usefully be added to aluminium is the readiness with which this metal forms definite compounds. Compounds are formed, or appear to be formed, with copper, nickel, manganese, iron, magnesium, to mention common metals only.

The presence of these compounds in the free state in the solid alloy is very effective in producing hardening, but at serious expense in ductility. Moreover, increase in hardness is not necessarily accompanied by increased tenacity. This is illustrated by the binary copper-aluminium alloys, where in both sand and chill castings increase of copper beyond 4 per cent. produces no notable increase in the tenacity at ordinary temperature, but does increase hardness, as, for example:

Copper per cent. ...	4.5	7	8	12
Hardness (Brinell) ...	47	57	60	82

The addition of other metals of low solubility in solid aluminium and which form compounds has a similar general effect.

In view of the above facts, it is not surprising to find that the metals principally called upon to effect the toughening of aluminium in alloys in industrial use to-day are zinc and copper.

Zinc-Aluminium Alloys.

Zinc is one of the cheapest and most satisfactory hardeners for aluminium. Zinc-aluminium alloys are, however, exceptionally weak at high temperature, leading to ready cracking in moulds under contraction stresses. Replacement of part of the zinc by copper has resulted in the development of one of the most serviceable casting alloys we have for general engineering purposes—" L5 " alloy—containing zinc 12.5 to 14.5 and copper 2.5 to 3 per cent., stable in all climates and hardening appreciably with age. This alloy can, moreover, be drop forged. Recent investigations† indicate that although in resistance to atmospheric and sea water corrosion it is inferior to certain other alloys, it is not so bad in this respect as it has been painted.

Copper-Aluminium Alloys.

Binary alloys of copper with aluminium, containing 8 to 12 per cent. copper have proved eminently suitable, particularly for production of castings in metal moulds. They are superior to the zinc alloys in strength at high temperatures, and the alloys containing 8 and 12 per cent. copper, L11 and L8 respectively, have been, and still are, extensively employed for pistons, cylinder-heads, etc., of internal-combustion engines.

Addition of small quantities of tin and/or zinc to this type of alloy with a view to improving casting qualities, *e.g.*, fluidity, is of doubtful wisdom, both these metals having a detrimental effect on strength at high temperatures. On the other hand, addition of manganese (1 per cent.) has been shown materially to improve strength at high temperatures.

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† "Resistance of Various Aluminium Alloys to Salt-water Corrosion," Basch and Sayre, "Mechanical Engineering," Vol. 46, 1924.

"Y"-Alloy.

Employing copper-aluminium as a base, more complex alloys have been developed containing respectively nickel and magnesium and iron and magnesium which possess properties very much superior to those of the plain copper-aluminium alloys, particularly at high temperatures. An alloy of the first-mentioned type known as "Y"-alloy, containing copper 4, nickel 2, magnesium 1.5 per cent., remainder aluminium, has a strength/weight ratio in the untreated cast condition at ordinary temperature considerably superior to that of many other alloys in common use, *e.g.*, L5, L8, L11.

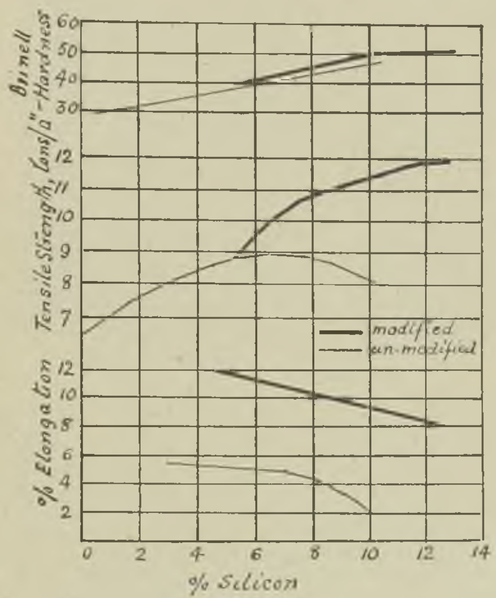

FIG. 1.—MECHANICAL PROPERTIES OF AL-SI ALLOYS.

Although of comparatively recent development, this alloy has been very thoroughly tried out in practice and, coupled with its strength at high temperatures, resistance to corrosion and amenability to heat treatment, has established itself as one of the most valuable casting alloys available.

Duralumin and Alpax.

There is one other element, silicon, more properly classed with the non-metals than the metals, the presence of which in small quantities in all commercial aluminium led to the early development of that remarkable wrought alloy Duralumin, and the addition of which to aluminium in larger quantities has more recently resulted in development of a valuable series of casting alloys. Aluminium and silicon form a simple eutectiferous series, the eutectic containing 10.5 per cent. silicon. In the solid state aluminium will hold in solution at ordinary temperature approximately only half as much silicon as copper, namely, 1.5 per cent. No aluminium-rich compound is, however, formed, and the excess silicon is deposited from the solidifying melt in the form of needles and plates of silicon. A valuable paper dealing with these alloys was presented by Basch and Sayre‡ to the American Foundrymen's Association last year (1924). The variation of tensile properties and hardness of sand-cast test bars with silicon content

FIG. 2.—SILICON-ALUMINIUM ALLOY UNMODIFIED × 150 DIAS.

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‡ "Foundry Treatment and Physical Properties of Silicon-Aluminium Sand Castings."

is shown in Fig. 1. Up to 5 to 6 per cent. addition of silicon produces a comparatively rapid increase in tenacity without, however, so marked a decrease in ductility or increase in hardness as occurs, for example, with copper, so that with 5 per cent. there is available an alloy which, sand-cast, has a tensile strength of the order of 8 tons per sq. in. with elongation of 5 per cent. on 2 ins. From 5 to 8 per cent. silicon, little further accession of strength is obtained in the sand-cast alloy. At this point, however, the remarkable modification process discovered in 1920 by Aladar Pacz, of Cleveland, Ohio, consisting of treatment of the molten alloy with certain fluxes, comes to the rescue whereby the otherwise coarse structure of the high-silicon alloys is rendered fine with great benefit to physical properties. Normal and modified structures are shown in Figs. 2 and 3 respectively.

FIG. 3.—SILICON-ALUMINIUM ALLOY MODIFIED × 150 DIAS.

(This and Figs. 2, 15 and 16 are from Rosenhain and Archbutt's Paper, Light Alloys of Aluminium, to the Empire Mining and Metallurgical Congress, 1924.)

The optimum silicon content for the modified alloy appears to be round about 13 per cent., giving in the sand-cast condition tensile strength of the order of 12 tons with elongation as high as 8 per cent. on a 2-in. gauge length.

This alloy combines high tensile strength and ductility with remarkable casting properties (fluidity, etc.), general soundness and toughness at high temperatures, in a manner at present unapproached by other cast aluminium alloys. In considering the utility of the alloy for highly stressed parts, however, it must be borne in mind that although under shock or repetition stresses its ability to resist actual fracture is high (Basch and Sayre's results indicate that the safe range of stress in fatigue may be as much as 50 per cent. higher than that of L8, L11 or L5 alloys), a comparatively low elastic limit coupled with high ductility leads to distortion, which may readily become objectionable in amount at stresses considerably below those required for actual fracture.

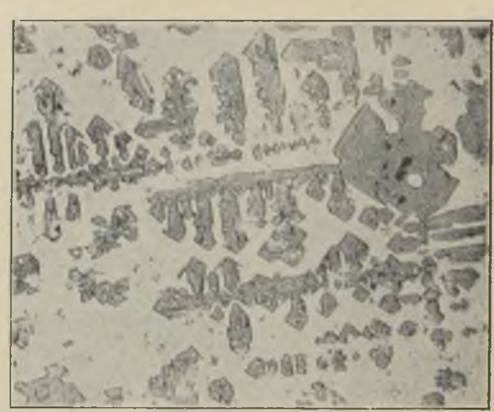

Fig. 4.—Chill Cast Unetched × 150 Dias.
(From J. Inst. Met., 1921, 26, Plate 26.)

The silicon-aluminium alloys are lighter than aluminium itself, and considering tensile strength alone, the strength/weight ratio of the modified 13 per cent. alloy is high, much superior to that of the plain copper-aluminium alloys L8 and L11, and equal, if not superior, to that of "Y" alloy in the unheat-treated condition. Taking elastic limit, however, as the measure of strength, the alloy appears to be no better than the 8 per cent. copper alloy, and is, of course, much inferior to an alloy such as "Y" in the heat-treated condition.

The alloys above mentioned—L5, L8, L11, Si/Al and "Y"—have all been very thoroughly tried out, and are satisfactory and dependable if chosen with due regard to the purpose for which they are required. For high temperatures, *e.g.*, for pistons, cylinder heads, etc., L5 should not be employed, but copper-aluminium (L8, L11), or, better still, "Y"-alloy. So far as actual breaking stress goes, the 13 per cent. silicon alloy, although superior to L8 or L11 at lower temperatures up to about 200 deg. C., appears to be no better than these alloys at higher temperatures, and is inferior to "Y."

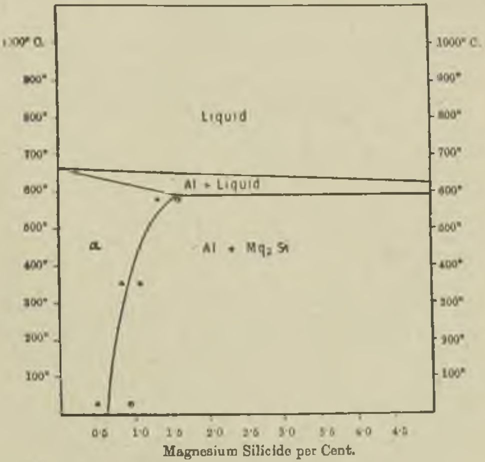

Fig. 5.—Showing Decrease in Solubility of Mg_2Si in Aluminium with Decreasing Temperature.
(From J. Inst. Met., 1921, 26, p. 342.)

For highly stressed castings advantage should be taken of the superior elastic limit and fatigue resistance of heat-treated "Y" alloy wherever possible. L5 alloy can be and is satisfactorily used, however, where stresses are not unduly severe and temperatures are normal, *e.g.*, for many engine crank cases, gear boxes, rear axle casings, etc.

Specifications for L5, L8, L11 and "Y" alloy have been issued by the British Engineering Standards Association.

Heat Treatment.

Considerable attention has been devoted in recent years to the question of improvement of strength of aluminium alloys by heat treatment. Great improvement is possible and has been demonstrated in the case of a number of alloys. The remarkable phenomenon of spontaneous hardening or age-hardening as it is now termed, undergone by certain types of aluminium alloys after quenching from suitable temperatures, was discovered by Wilm about 20 years ago, and as a result the well-known proprietary alloy duralumin was developed.

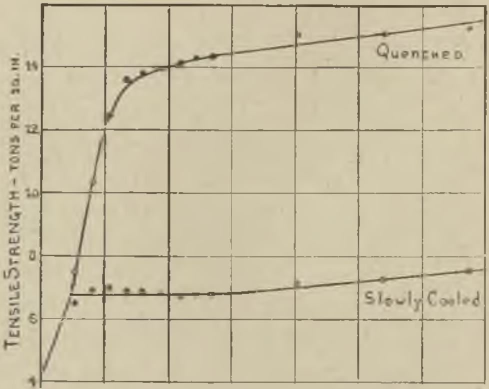

Fig. 6.—Influence of Mg_2Si on the Tensile Strength of Aluminium.
(From J. Inst. Met., 1921, 26, p. 344.)

Wilm's discovery was made on worked material and for many years it was believed that age-hardening was not applicable to cast alloys. Statements that alloys of duralumin-type cannot be employed for castings and that in the cast unworked state they do not exhibit age-hardening appear in authoritative text-books on aluminium alloys, published as recently as 1921.

We now know that age-hardening can be produced in cast alloys as well as wrought, and the reason for early failures to produce age-hardening in castings becomes clear.

Age-Hardening.

The mechanism of age-hardening in aluminium alloys has been very clearly and beautifully demonstrated by Hanson and Gayler* in research at the National Physical Laboratory on alloys of aluminium with magnesium and silicon, which show marked age-hardening. In this system the presence of a definite compound between magnesium and silicon, Mg_2Si, was established. This compound has in polished, unetched sections a beautiful iridescent blue colour. Characteristic forms of it are shown in the photomicrograph (Fig. 4). It is soluble in solid aluminium, and this solubility was found to decrease with temperature in the manner indicated in Fig. 5.

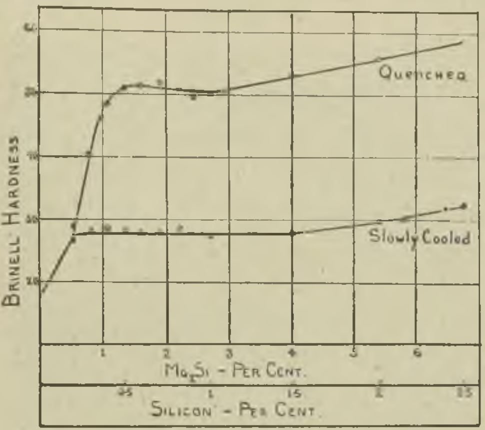

Fig. 7.—Influence of Mg_2Si and Si on the Hardness of Aluminium.
(From J. Inst. Met., 1921, 26, p. 344.)

Slowly cooled alloys did not harden, but quenched alloys did, and the extent of the hardening measured by hardness and tensile tests

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* J. Inst. Met. 1921 (2), pp. 321-355.

increased with the amount of the compound in solid solution at the quenching temperature up to the limit of solubility in the solid alloy at that temperature. This is illustrated in Figs. 6 and 7. On slow cooling Mg_2Si separated as free crystals visible under the microscope, but on quenching no separation was visible. The compound was retained in solid solution.

Such a supersaturated solution at normal temperature is not in equilibrium and tends to deposit the excess Mg_2Si. It was thus established that age-hardening was associated with the formation of this super-saturated solution, and there appeared little doubt that it is caused by the tendency of such a solution to revert to a more stable state by the precipitation of excess compound.

FIG. 8.—CAST, HEAT-TREATED AND AGED "Y" ALLOY TEMPERED AT 250 DEG. C. × 500 DIAS.

The generally accepted theory is that a gradual precipitation of fine particles of the compound takes place subsequent to quenching, and that it is the presence of these hard particles within the crystals of the matrix which causes the hardening. Material confirmation of this is shown in photograph Fig. 8 (500 dias.) of the microstructure of a cast specimen of heat-treated and aged "Y"-alloy which has been held at 250 deg. C. for 12 days. Under such treatment the precipitated particles might be expected to grow and become visible under the microscope. The microstructure indicates large numbers of small needles and rounded particles within the grains.

The explanation of the age-hardening process in certain aluminium alloys thus arrived at leads to the important generalisation that wherever in any alloy a super-saturated solid solution can be formed by quenching, and can subsequently be allowed or caused to revert towards a more stable state by precipitation of minute particles of the dissolved constituent hardening and tempering becomes possible.

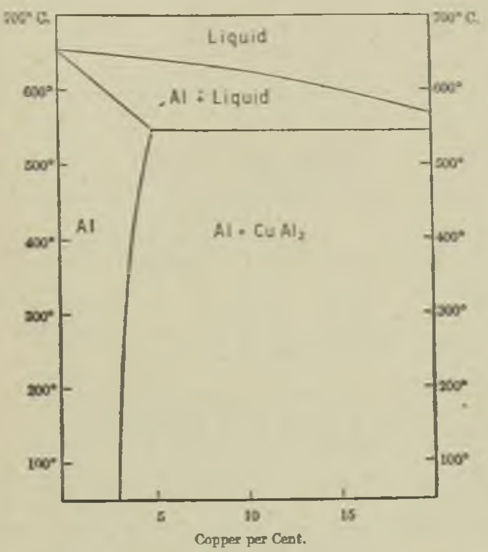

FIG. 9.—ALUMINIUM-COPPER EQUILIBRIUM DIAGRAM.

(From J. Inst. Met., 1923, 29, p. 509.)

Constituents Producing Age-Hardening.

Influence of Composition.—A constituent or constituents may produce age-hardening in an alloy on quenching or rapid cooling, if appreciably soluble in the solid alloy at the quenching temperature and becoming less soluble at lower temperatures. It has been shown that the compound Mg_2Si exhibits such behaviour and produces marked age-hardening.

The compound $CuAl_2$ shows similar behaviour in regard to solubility as illustrated in Fig. 9, where it is seen that the solubility of copper in solid aluminium falls from 5 per cent. at 540 deg. C. to about 3 per cent. at 20 deg. C. Accordingly it might be expected that alloys containing more than 2 to 3 per cent. of copper in solid-solution at, say, 450 deg. would undergo age-hardening on quenching from that temperature. This has been shown to be the case by Hanson and Gayler for both wrought and cast alloys, and will be referred to later. The hardening is illustrated in Fig. 10. Age-hardening has also been demonstrated by the above workers, in the binary zinc-aluminium system, but would appear to be applicable with advantage only to the heavier alloys containing over 20 per cent. zinc.

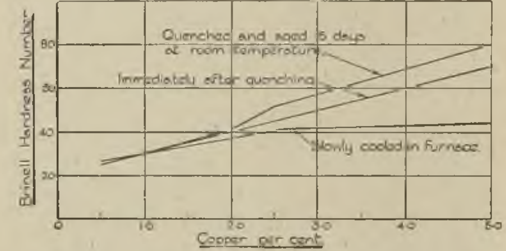

FIG. 10.—HARDNESS OF ALUMINIUM-COPPER ALLOYS AFTER HEAT TREATMENT
(From J. Inst. Met., 1923, 29, p. 495.)

A consideration of vital importance affecting age-hardening is that the addition to a binary solid solution of a second constituent, also soluble in aluminium, will usually affect the solubility of each solute. Addition of an insoluble constituent such as iron will have little if any affect. Thus, in presence of magnesium, copper becomes practically insoluble in aluminium at 400 deg. C., whereas normally it is soluble at this temperature to the extent of 3.7 per cent. The solubility of copper in aluminium at 500 deg. C. is reduced from 4.5 per cent. to 2 per cent. by addition of as little as 0.7 per cent. Mg_2Si.

Again, the solubility of Mg_2Si in aluminium at 580 deg. C. is reduced from 1.6 per cent. to 1.1 per cent. by presence of an excess of less than 1 per cent. of magnesium. The effect of this reduction of solubility in diminishing the hardening effect obtainable on quenching is illustrated in Fig. 11.

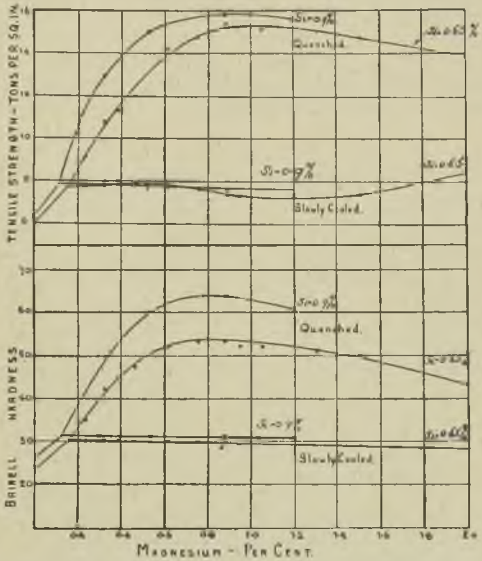

FIG. 11.—INFLUENCE OF MAGNESIUM ON THE PROPERTIES OF AGE-HARDENED ALLOYS OF ALUMINIUM WITH MAGNESIUM AND SILICON.

(From J. Inst. Met., 1921, 26, p. 344.)

It is evident, therefore, that to obtain the best possible results from a heat-treatable alloy, careful control of composition is vital, and that in order to exercise this control intelligently accurate knowledge of the constitution and of the solubility relationship of the constituents in the solid state is essential.

Accelerated Age-hardening.—As already referred to, the process of age-hardening can be hastened by employing temperatures above atmospheric Fig. 12 shows graphs of age-hardening after quenching for an aluminium alloy containing copper 3.74; Mg 1.08; Si 0.30, and Fe 0.52 per cent.

It will be noticed that at 25 deg. C. maximum hardness is reached in about four days, but that at 140 deg. C. an equal degree of hardness is reached in a few hours. The further fact will also be noticed that at 140 deg. hardness continues to increase, approaching a maximum value in about five days, which is approximately 30 per cent. higher than that attained at 25 deg. C. At 200 deg. C. the rate of hardening is still more rapid but is followed by a gradual softening, the alloy eventually becoming softer than when aged at normal temperatures. Increase of hardness above that normally reached at atmospheric temperature may be accompanied by decrease in ductility.

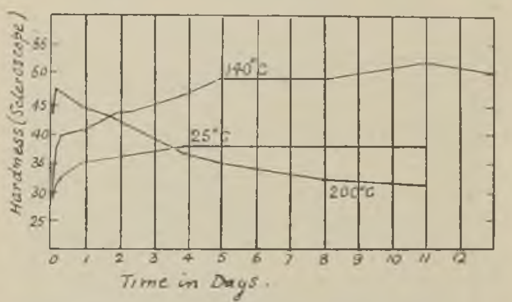

Fig. 12.—Accelerated Age-Hardening of Aluminium Alloy, containing Copper, Magnesium, Silicon and Iron.

It is evident, therefore, that accelerated age-hardening requires careful control to avoid on the one hand attainment of too great hardness at expense of ductility, and on the other hand softening.

Tempering.—In analogous manner to certain quenched steels, age-hardened aluminium alloys can be further hardened by exposure to temperatures above atmospheric; temperatures between 150 to

200 deg. C. are suitable for aluminium alloys. An example of this in the case of binary copper-aluminium alloys has been described by Hanson and Gayler, and is referred to later. Results are illustrated in Fig. 13. Age-hardened alloys containing copper-nickel-magnesium and silicon (*e.g.*, " Y "-alloy) can be similarly further hardened by such treatment.

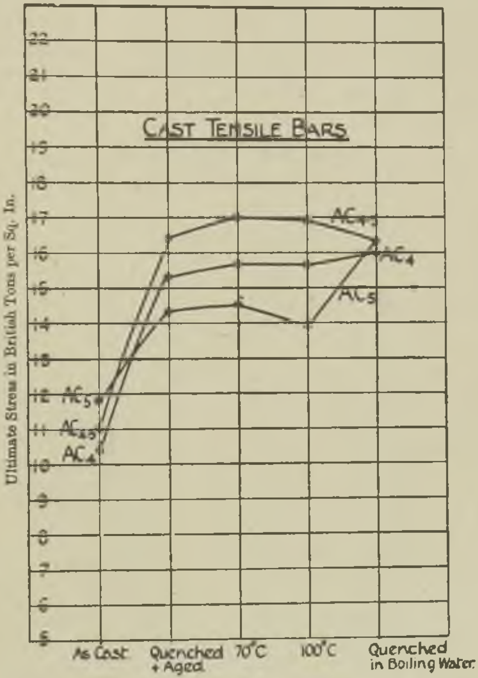

FIG. 13.—INFLUENCE OF TEMPERING ON AGE-HARDENED ON COPPER-ALUMINIUM ALLOYS.
(From J. Inst. Met., 1923, 29, p. 498.)

Cast *v*. Wrought Alloys.

Heat-treatment of Cast Alloys.—It has been shown that to produce age-hardening in an alloy, it is necessary first to have present a constituent or constituents exhibiting differences in solubility at high and low temperatures, and secondly to bring about maximum solution possible at the quenching temperature. The larger the individual crystals of these constituents, the more slowly will they diffuse into the solid alloy and the longer the exposure required at the high temperature before quenching. It is this fact, coupled with ignorance of the true mechanism of age-hardening, to which previous lack of success in producing hardening in cast alloys is attributable.

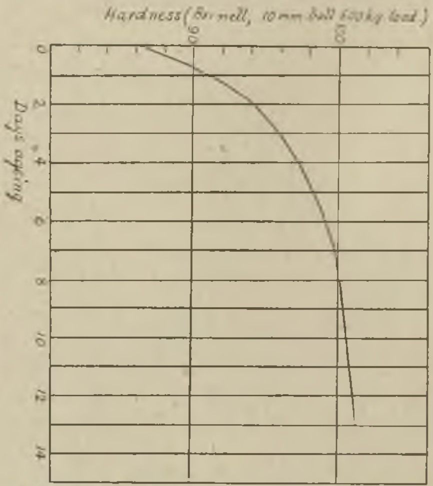

Fig. 14.—Age Hardening of "Y"-alloy.

Hot-working breaks up the crystals of the constituents, disseminates them, and at the same time exposes them to temperatures favourable to solution, so that if sufficient hot work is applied, solution is very effectively brought about at the working temperature, and the actual period of heating at the quenching temperature becomes comparatively unimportant.

Circumstances are very different in the case of castings, however, and the period of heating before quenching is of vital importance. Hours instead of minutes are required, depending upon the coarseness of grain and the maximum temperature which can safely be employed.

Duralumin.—Guillet* has recently demonstrated that by suitable treatment duralumin castings, both sand and chill cast, can be caused to age-harden to an extent comparable to that of the wrought alloy. Examples of his results are given in Table I.

The effect of grain size, period of soaking before quenching, and temperature are clearly shown.

The hardness reached on ageing is comparable with that of the age-hardened wrought-alloy.

Table I.—*Hardness of Duralumin Castings.**

Condition.	Not quenched.		Hardness (Brinell). Immediately after quenching.		Hardness (Brinell). 96 hrs. after quenching.	
	Sand.	Chill.	Sand.	Chill.	Sand.	Chill.
As cast ..	53	60	—	—	—	—
Annealed ..	45	54	—	—	—	—
¼ hr. at 475° C.	—	—	49	59	62	80
1 ,, ..	—	—	57	58	74	84
3 ,, ..	—	—	56	59	73	88
10 ,, ..	—	—	61	69	85	95
10 hrs. at 525°	—	—	—	—	98	104

* Rectangular plates 125 × 100 mm., recessed, thickness varying from 10 mm. to 6 mm.

The shear strength of the chill-cast plates was increased from 9.8 tons per sq. in. as cast, to 14.2 tons per sq. in.

Copper-Aluminium. — The profound improvement in the properties of cast binary copper-aluminium alloys containing 4 to 5 per cent. of copper, which can be obtained by heat-treatment, has been demonstrated by Hanson and Gayler and is illustrated in Fig. 13. In this instance the bars were chill-cast 1-in. dia. and were heated at 500 deg. C. for 24 hours before quenching. The period of ageing at normal temperature was six days. The further improvement obtained on tempering in certain cases is shown. Accelerated ageing by quenching to 100 deg. C. in boiling

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* Revue de Métallurgie, Dec. 1924.

water and holding in the boiling water for one hour produced an equally good effect.

It is seen that in the case of the 4.5 per cent. copper alloy, the tensile strength was raised from 11 tons per sq. in. as cast, to about 17 tons, and elongation from 14 per cent. to 18 to 25 per cent. on 2-in.

A tensile strength of 17 tons per sq. in. in a light aluminium alloy casting is remarkable, and has only been exceeded in the case of the alloy "Y" (copper 4, nickel 2, magnesium 1.5 per cent.).

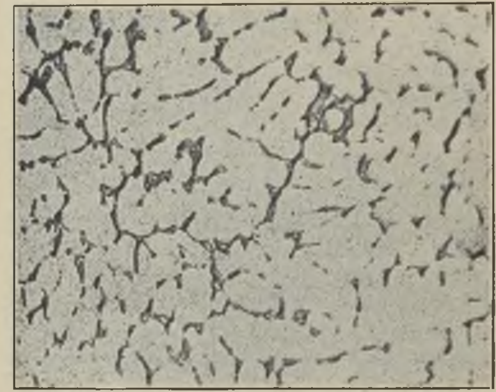

FIG. 15.—"Y"-ALLOY 1-IN. DIA. CHILL × 150 DIAS.

The value of a heat-treated copper-aluminium alloy such as the above will depend on its resistance to deformation under bending, fatigue, etc., stresses. It may be that like the tough but ductile silicon alloys, it will prove too plastic.

It has a strength/weight ratio (ultimate stress in tons per sq. in. divided by specific gravity in grammes per cc.) of 60, second only to heat-treated "Y," the normal value for which under similar conditions is 72.

Preparation and Properties of "Y"-Alloy.

The preparation and properties of this alloy were first described in the 11th Alloys Research Report, Institution of Mechanical Engineers, 1921.

Further information regarding preparation and heat-treatment has been given in subsequent papers to the Institute of Metals.

A remarkable increase in strength is attainable with this alloy by age-hardening treatment. The tensile strength of 1-in. dia. chill-cast bars is raised from about 14 tons per sq. in. as cast to 20 tons and over, with an appreciable improvement in ductility, heat-treated bars giving 4 to 7 per cent. extension on 2-in.

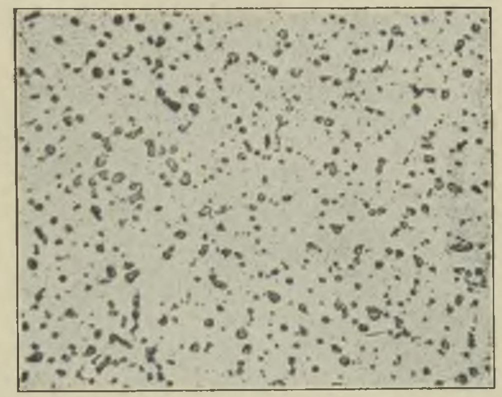

FIG. 16.—" Y "-ALLOY 1-IN. DIA. CHILL, HEAT TREATED × 150 DIAS.

A typical age-hardening graph for a chill-cast bar quenched from 520 deg. C. is shown in Fig. 14. It will be seen that the alloy requires not less than eight days at atmospheric temperature to approach maximum hardness.

The effect of heat-treatment on the microstructure is illustrated in Figs. 15 and 16 at 150 dias.

Age-hardening can be accelerated as in other alloys by employing higher temperatures, and experiments are in hand at the National Physical Laboratory for the purpose of arriving at conditions suitable for application industrially.

The heat-treatment temperature for obtaining maximum strength should approach 520 deg. C. as closely as possible, but not exceed it. One-in. dia.

chill-cast bars require a period of not less than six hours at this temperature before quenching. Sand-cast bars require longer, and large castings may need 24 hours or more, depending on the coarseness of grain, to approach maximum strength.

In the heat-treated conditions the elastic properties and fatigue resistance of this alloy in the cast condition are remarkably high, placing it weight for weight in a class by itself in comparison with other available casting alloys.

Typical properties relating to 1-in. dia. chill-cast bars are given in Table II.

TABLE II.—*Properties of "Y"-alloy.*

	As cast.	Cast, heat-treated.
Density, grammes per cc. ..	2.79	2.79
Elastic limit, tons per sq. in. ..	5.00	7.00
Maximum stress, tons per sq. in.	14.00	20·21
Elongation, per cent. on 2 inches	2	4·7
Safe fatigue range (12 million reversals), tons per sq. inch ..	—	±7.00
Hardness (Brinell, 10 mm. ball, 500 kg. load)	76	105

An admirable description and comparative *résumé* of the properties of various aluminium-base and magnesium - base alloys from the point of view of their use for pistons and connecting rods is given by Aitchison* in a Paper presented to the Institution of Automobile Engineers in 1924. Summing up advantages and disadvantages of the various cast alloys for use for pistons, he suggests the balance of advantages, excluding "Y"-alloy, lies between an 8 per cent. copper-alloy and a magnesium-base alloy containing 6 per cent. aluminium. In regard to "Y"-alloy he says: "On paper 'Y'-alloy is probably the best alloy of all those proposed for pistons, particularly when used in the heat-treated and aged condition. At the present time, however, there appear to be difficulties in carrying out the heat-treatment satisfactorily on

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* "Light Alloys for Pistons and Connecting Rods."

a commercial basis, so that the alloy has to be considered in the as-cast (or cast and annealed) state. Even then it is quite as good as any of the other alloys and rather better than most. If, therefore, the technique of founding is improved, and pistons in 'Y'-alloy can be turned out with the same satisfaction and regularity as in, say, the 8 per cent. copper alloy, it will probably be adopted quite widely."

There is no question that the technique of founding this alloy has now been satisfactorily developed in more than one aluminium foundry of note in this country, and also the heat-treatment of the simpler types of castings, such as pistons. Larger castings, such as the crankcases of high-powered aircraft engines, present greater difficulties, which, however, are in the way of being overcome.

Heat Treating Al-Alloy Castings.

In heat-treating castings of any aluminium alloy, particularly large castings, it must be borne in mind that at high temperatures they are readily distorted, and great care must be taken to handle them in a proper manner during removal from the furnace. For large castings, steel jigs must be used to provide support where necessary in the furnace and for handling during quenching. Provision should be made for a possible slight contraction on quenching in the case of "Y"-alloy.

Preparation.

To reach the best results attainable from aluminium alloy castings, particularly when heat-treatment is to be applied, they must be sound and of fine grain, properties not readily obtained in sand castings.

Cast in sand, aluminium alloys are in general inferior in mechanical properties and general soundness to corresponding castings made in metal or chill moulds.

The slower rate of solidification which occurs in a sand mould produces a coarse grain which is in itself detrimental to mechanical properties. These effects are, however, usually accentuated by general unsoundness commonly of the type known as "pinholing" or "speckling."

The "pin-holes" are small cavities fairly uniformly disseminated through the body of the casting; they are revealed on machining as shown in Fig. 17.

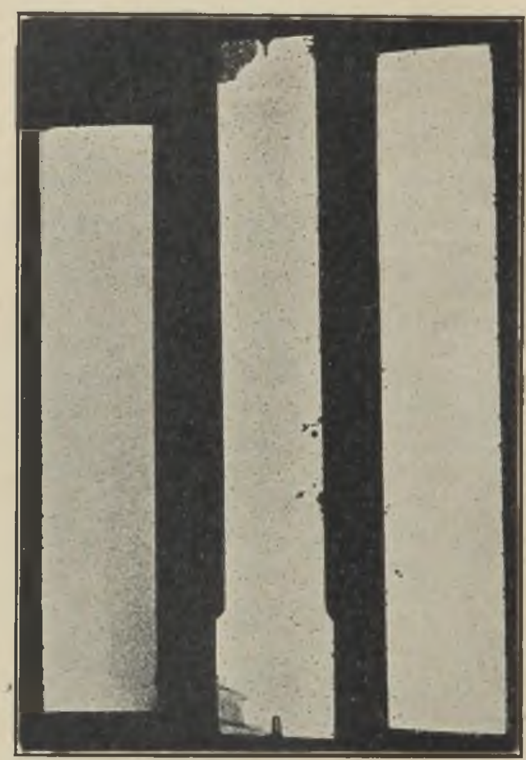

FIG. 17.—LONGITUDINAL AXIAL SECTIONS OF 1-IN. DIA. SAND-CAST BARS, "Y"-ALLOY, MACHINE FINISH, ¾ ACTUAL SIZE. (From J. Inst. Met., 1925 (1), p. 232.)

Coarseness of grain and pinholing are accentuated in sand castings by high pouring temperates; if melting and pouring temperatures are kept low, considerable improvements can be effected in respect of these defects.

In a recent paper to the Institute of Metals* an account was given of some experiments carried out at the National Physical Laboratory for the purpose of determining the cause of "pinholing" or "speckling" and of improving the properties of aluminium alloy castings generally, particularly sand castings. This work forms part of the programme of research on light alloys in progress at the laboratory for the Aeronautical Research Committee, and is carried out under the auspices of the Engineering Research Board of the Department of Scientific and Industrial Research. Permission was given to publish the results, and it is hoped some account of them will not be unwelcome here.

Under the most carefully controlled conditions, employing normal foundry practice and treatment of melts, it has not been found possible at the laboratory to effect more than a certain degree of improvement in soundness of sand castings.

In experiments with "Y"-alloy, using a 1-in. dia. bar as a standard form of casting, dry cold sand moulds, melting temperatures not exceeding 730 deg. C., pouring temperature as low as 650 deg. C., and ample risers and runners, the general order of density of cast bars, unmachined, is 2.735 with an occasional value as high as 2.750. These values are to be compared with 2.780 for corresponding bars cast in metal moulds.

Average tensile properties of these two classes of bar in the cast condition are as follows:—

	Sand moulds.	Metal moulds.
Density with skin on	2.735	2.798
Yield stress (tons per sq. in.)	—	11.4
Ultimate stress ,, ,,	10.5	14.8
Elongation per cent. on 2 in.	0.5	2.5

It is well known at the Laboratory and probably in most aluminium foundries that pin-holing can be eliminated in castings of normal thickness by employing metal moulds.

It is the case, for example, with 1-in. dia. bars of "Y"-alloy and other aluminium alloys.

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* Archbutt, "A Method of Improving the Properties of Aluminium Alloys Castings," Institute of Metals, March Meeting, 1925.

The fact has also been observed at the Laboratory that very slow solidification such as occurs when a melt is allowed to solidify in the pot in the furnace also inhibits pin-holing. In the case of a sand-cast piston in 3L11 alloy sent to the Laboratory for examination, which exhibited profuse pinholing on machined surfaces, a portion was remelted and caused to solidify slowly in a small crucible. A polished section of this ingot was practically free from pin-holing and gave a density of 2.812 compared with 2.769 for material from the piston.

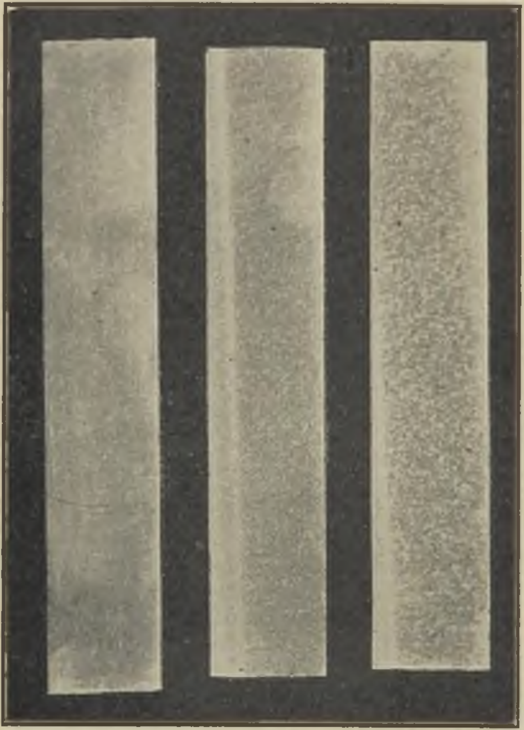

FIG. 18.—LONGITUDINAL AXIAL SECTIONS OF 1-IN. DIA. SAND-CAST BARS. "Y"-ALLOY, MACHINE FINISH. TREATED METALS ¾ ACTUAL SIZE. (From J. Inst. Met., 1925 (1), p. 232.)

It became evident, therefore, that both rapid and very slow solidification inhibited pin-holing, and that some intermediate rate such as occurs in a sand mould is most favourable for its formation. These facts, together with others, led to the conviction that the cause of pin-holing is occluded gas, and particularly that portion of gas which is liberated during the act of solidification.

If solidification is sufficiently rapid as in a metal mould, it would appear that the occluded gases in the melt are not liberated but retained in solution in the solidified alloy. If solidification is sufficiently slow the gas is liberated and enabled to free itself from the solidifying melt, while at intermediate gates it is liberated from solution but entrapped in the form of minute bubbles, causing pin-holing. It seemed probable, therefore, that if a melt were slowly solidified it would largely rid itself of occluded gas, and that castings poured from the remelt would exhibit improved soundness.

Experiments on these lines were immediately successful. The treatment consisted in allowing a melt to solidify slowly in the uncovered crucible (Morgan Salamander) in the furnace. As soon as it was solid, and without further cooling, the crucible was covered, the furnace re-lighted, and the metal re-melted, raised to the required temperature and castings poured. From melts of 10 to 20 lbs. of " Y "-alloy, treated in this way, 1-in. dia. bars cast in sand were obtained, giving without any machining a density of 2.78 and higher. An almost entire absence of pin-holing was observed on light machining, the surface appearance closely resembling that of a chill-cast bar. Very uniform ultimate stress values were obtained from bars from these melts varying from 11.3 to 11.8 tons per sq. in. (as cast), representing an increase in strength of the order of 10 per cent. over that of sand-cast bars from untreated melts.

The improved soundness obtained by the treatment above described is illustrated by bar sections 2030 and 2046 in Fig. 18.

During the above treatment small explosions occasionally occurred at the surface of the melt, suggesting that inflammable gas was being ejected and igniting.

Preliminary ingotting of aluminium alloy melts may therefore be decidedly advantageous, provided the rate of solidification of the ingots is sufficiently slow, but marked improvement is not to be expected from ordinary ingotting in metal moulds.

Further experiments were made with " Y "-alloy in which treatment of melts on the lines indicated above were modified as follows: (1) The slowly solidified and remelted alloy was ingotted in chill and then remelted. A 12-lb. melt was treated in this way, and four 1-in. dia. bars cast in sand. Two of these were tested and gave the following excellent average results: Density machined, 2.774; ultimate stress (tons/sq. in.), 12.20; and elongation per cent. on 2 in., 1.0; (2) slow solidification and remelting was repeated three times on a melt before pouring castings. Unsatisfactory results were obtained from a 10-lb. melt treated in this way; and (3) slow solidification was applied to hardener alloys only. Some excellent results were obtained from melts treated in this manner.

In the majority of the experiments described above, stirring or other disturbance of the melt liable to introduce gas was purposely avoided after remelting subsequent to slow solidification.

Analytical results on small ingots poured before and after the pouring of test bars, indicated some tendency towards concentration of added elements in the lower layers of the remelted alloy. In anticipation of this, a 10-lb. melt was slowly solidified, remelted, and the remelt stirred in a normal manner before pouring. The density, tensile strength, and appearance of machined surfaces of bars from this melt were up to the general standard reached with unstirred melts.

It would appear, therefore, that careful stirring after slow solidification may be employed without detrimental effects.

In all the melts referred to above, notched-bar aluminium of high purity was employed, giving the following analytical results:—

Aluminium " T " per Cent.—Iron, 0.16; silicon, 0.16; copper, trace; and aluminium (diff.), 99.68 per cent.

This metal was tough and ductile under the hammer, and the bars required many reversed bending blows to fracture them at the notches.

In the course of the experiments with this metal, a consignment of aluminium, also in the form of notched bar, was received at the Laboratory. This metal was labelled " Made in Norway," and gave the following results on analysis:—

Aluminium " U " per Cent.—Iron, 0.21; silicon, 0.29; copper, trace; and aluminium (diff.), 99.50 per cent. Aluminium " U " is seen to be of high purity but not equal to aluminium " T " above mentioned.

This metal behaved very differently from the " T " metal under the hammer, breaking quite short in a brittle manner.

Employment of aluminium " U " immediately upset the regular and consistent character of results, as will be seen from Table III:—

TABLE III.—*" Y "-alloy Melts with " U " Aluminium.*

Melt No.	Weight, lbs.	Conditions.	Average density of bars.	Appearance on machining.
YV2015	12	Slowly solidified and remelted.	2.741	Marked unsoundness and pinholing.
YV2018	20	do.	2.729	Serious unsoundness and pinholing.
YV2017	20	Copper hardener only slowly solidified.	2.718	do.
YV2024	12	Ordinarily melted	2.752	Marked pinholing.
YV2030	20	Ingot and scrap from YV2017 remelted and slowly solidified.	2.775*	Slight pinholing.

* A longitudinal section through the axis of one of these bars finished with a fine milling cut, appeared perfectly sound and free from pinholing as illustrated by bar section 2030 in Fig. 18.

It will be seen that on a first application of the slow solidification treatment, very inferior results were obtained from two melts of 12 and 20 lbs. respectively; also from a 20-lb. melt, YV2017, in which the copper hardener only had been treated before use, a method which, when using " T " aluminium, had given good results.

On applying the slow solidification treatment to a remelt of YV2017, excellent density and soundness were obtained from bars poured at 650 deg. It would appear from these results that with certain grades of metal more than one application of the treatment in question may be necessary.

The aluminium in this particular instance was suspected of containing an unusual amount of occluded gas. To obtain evidence in the matter some melts of this metal alone were made and 1-in. dia. bars cast in sand, under conditions similar to those employed with the melts already described. The density of the bars unmachined was determined, and they were then lightly machined and examined for appearance.

Particulars and results of these melts are given in Table IV:—

TABLE IV.—*Experiments on Treatment of "U" Aluminium (1-in. dia. Sand-cast Bars).*

Mark.	Treatment.	Density unmachined.	Appearance after machining.
Made in Norway	Section from notched bar.	2.701 2.694	—
V2020 (1) (2)	Ordinary melting	2.639 2.641	General unsoundness causing poor machine finish.
V2021 (1) (2)	Slow solidification treatment.	2.694 2.695	Greatly improved soundness and machine finish.
V2022 (1) (2)	Treatment repeated on ingots and runners, etc., from V2021.	2.673 2.676	Somewhat inferior to V2021.
V2023 (1) (2)	Do. on ingots and runners from V2022.	2.671 2.667	Markedly inferior to V2021.

The results show that (1) ordinarily melted and cast, this particular aluminium gives sand-cast bars of abnormally low density; (2) on remelting and applying slow solidification treatment, normal density is obtained accompanied by great improvement in the appearance of machined surfaces; (3) repeating the slow solidification treatment appears to be detrimental; and (4) the density of the notched bar as supplied is normal, and illustrates the fact previously pointed out that by rapid solidification occluded gas is retained in solid solution, and has little if any effect on density.

In discussion and consideration of the above results, it was suggested to the author by Dr. Rosenhain that removal of small bubbles of gas liberated and entangled in molten metal or alloy might be facilitated by passing through the melt an inert gas such as nitrogen. The following experiment was therefore made.

Employing "U" aluminium, a melt of 12 lbs. of "Y"-alloy was prepared at about 730 deg. C. The crucible lid was removed and the melt allowed to cool in the furnace. Commencing at 710 deg. C., a stream of nitrogen of ordinary commercial purity from a high-pressure cylinder was passed through the melt by means of an iron tube, coated with a wash of alundum extending to the bottom of the crucible. The passage of nitrogen was sufficiently rapid to produce the effect of moderate ebullition of the melt without ejection of liquid from the crucible. From the commencement of passage of the nitrogen, a gas which took fire and burnt with a blue flame was observed to be escaping from the surface of the melt together with the nitrogen. The melt took approximately 20 minutes to cool from 710 to 650 deg. C., and it was during the first ten minutes or so of this cooling that the inflammable gas was evolved in sufficient quantity to take fire.

The melt was held at 650 deg. C. for 15 minutes and then allowed to solidify and cool to 500 deg. C.; nitrogen was passed continuously until the melt appeared solid.

The crucible was now covered, the contents remelted, and two 1-in. dia. bars poured at 650 deg. C. in sand. These two bars, unmachined, gave the following density values:—

Melt No.	Density
YV 2048 (1)	2.795
YV 2048 (2)	2.794

On machining, these bars were found to be remarkably sound and free from pinholing. A longitudinal section through the axis of test bar 2048 (2) above, finished with a fine milling cut, is shown in Fig. 18 and illustrates the excellent soundness of these bars.

The densities recorded indicate a further marked improvement in soundness over and above the best previously obtained by slow solidification treatment alone. The values are almost equal to the best so far obtained from bars cast in metal moulds.

The experiments described and the results obtained from them indicate the possibilities of a method of treating aluminium and certain of its alloys, which eliminates, at all events, a considerable proportion of dissolved gas and thus reduces unsoundness and to a considerable extent removes pin-holing. The process suggested consists in allowing the molten alloy or metal to cool slowly in the crucible in the furnace until it has just completely solidified; without further cooling it is then remelted—it may then be carefully stirred—raised to the pouring temperature and cast. Ordinary ingotting of aluminium or its alloys is not satisfactory, as the ingots cool too quickly and during remelting are too much exposed to the furnace gases.

Passage of an inert gas through the melt during slow cooling previous to solidification has been found to improve still further the soundness of resulting sand-cast bars.

Slightly anomalous results have been obtained in some cases, and it is not yet clear how far the method is of value in other aluminium alloys. Much further investigation is required. The author learnt, and was authorised to refer to the fact in his Paper, that simultaneously and independently Professor C. A. Edwards and Mr. Prytherk, of Swansea, working on the effect of gases in copper (for the B.N.F.M.R.A.), had discovered a similar effect obtained by solidification in the crucible, in the case of pure copper.

It is evident, therefore, that the facts discovered and the method described may have wider application than in the sphere of cast aluminium alloys alone.

In conclusion, it may well be pointed out that aluminium alloys to-day have received a degree of accurate study and scientific investigation which may well claim to be unequalled in any other branch of the study of materials of construction. They therefore come into the hands of the engineer with credentials of a very high order.

DISCUSSION ON MR. ROWE'S AND MR. ARCHBUTT'S PAPERS.

For the first time in the history of the Institute a special session was held simultaneously with one on grey-iron foundry practice to discuss two Papers on non-ferrous metals. This was presided over by Mr. V. C. Faulkner (Senior Vice-President), who briefly referred to the innovation of holding such a session separately, and although the attendance was small compared with the iron section, he considered that their deliberations would be highly appreciated by at least one-third of the members of the Institute. He hoped that a similar session would be held next year at the London Conference, and expected it would be presided over by a non-ferrous metal expert.

He then called upon the two authors to deliver their papers, so that the discussion could be taken concurrently. Mr. S. L. Archbutt first introduced his Paper on "Aluminium Alloy Castings." Mr. F. W. Rowe then enumerated the chief points in his Paper on "The Application of Metallography in Bronze Founding."

In inviting discussion upon the two Papers, the Chairman referred to the system which had been evolved during the last two years in various irons, so that by altering one variable with relation to another it was possible always to get down to the same results. In "Y" alloy he asked if it was not possible to alter the composition or constitution in the same or opposite direction and always be sure of the same result. In the case of cast iron they had taken the cooling rate with respect to composition, and for "Y" alloy it might be possible to take something in the direction of rapid ageing on the one hand and composition on the other, and always effect the same result by a range of interconnected chemical thermal histories and constitutions, which would be of the highest advantage. He considered it would be an excellent idea if the National Physical Laboratory could study the new system and find out if it could be applied to "Y" alloy and others of the aluminium series and change their composition or heat-treatment so that the two could be compared and so arrive at a series of connected variables which would give the standardised results.

Heat Treatment of Aluminium-Silicon and "Y" Alloy.

In opening the discussion, Mr. J. S. G. Primrose considered Mr. Archbutt had very clearly explained the wonderful result of effecting the change in structure and properties of the silicon-aluminium alloy by the process known as modification by use of a suitable flux. He considered the importance could not be over-estimated of what the author had described as careful scientific control of the delicate operations of modifying silicon-aluminium and accelerating the "age-hardening" of "Y" alloy, and pointed out the extremes of over-hardness with loss of ductility, and, on the other hand, excessive softening which were possible if this careful control of temperature were not exercised. Referring to important discovery of the slow solidification method of removing occluded cases from aluminium alloys followed by a quick remelt and then pouring to eliminate pin-holding, the speaker asked Mr. Archbutt if he did not consider the use of an electric melting furnace would be most useful in which to conduct this process of cooling and then reheating to the proper casting temperature, as the control would be simpler than in, say, a coke-fired crucible furnace in which the fire would have to be drawn and then made up again.

Polishing Media for Bronzes.

Passing to a consideration of Mr. Rowe's Paper, Mr. Primrose next congratulated that author on the work he was doing in broadening the scope of the practical application of microscopical methods to brass foundry procedure. He considered the splendid Reichert outfit he showed in Fig. 1 was not only useful for making photographic records of microstructures, but was also extremely useful in enabling routine work covering several hundred microspecimens daily to be undertaken in minimum time. He doubted the advisability of trusting to wet alumina for the final polishing of some of the softer constituents shown by Mr. Rowe in his photo-micrographs, as usually some of the finer polishing pastes were better. He asked Mr.

Rowe to inform them as to which of the two etching reagents named had been used to develop the structures illustrated and particularly the well-marked coring effects, which appeared to him less marked in the solid solution in Fig. 6 than in the gun metal shown in Fig. 14, illustrating concentric enrichment of the primary constituent. He hoped the author would be a little more explicit in his revised descriptions especially in referring to the several constituents of the phosphor bronzes, *e.g.*, Figs. 16 and 17, as most people were not accustomed to view the copper phosphide at such high magnifications as 2,000 diameters which the author had so successfully achieved with his Reichert outfit.

Annealing of Gunmetal.

In dealing with the question of annealing Admiralty gunmetal at 700 deg. C. as recommended by Mr. H. S. Primrose in 1913, the author had stated that "Why anyone should want to anneal Admiralty gunmetals and bronzes is something of a mystery." There was a very strong financial reason why high pressure castings, often produced at considerable cost, should be annealed after they were found to be leaking from slight porosity due to excessive segregation of the eutectoid, since such treatment made them perfectly water tight, and considerably improved their strength and ductility at the same time. To reduce a wastage of 30 per cent. to 0.3 per cent. in this way was no mean achievement, and the mechanism of the change was no mystery. In view of the difficulty of accurately measuring the temperature of molten metal in the bronze foundry, he asked the author to explain to them the type of thermo-couple or radiation pyrometer which had been used to determine the casting temperatures named in the Paper. He considered the method of using the microscope rapidly to determine the relative amounts of alpha and beta constituents present in a bath of brass already for tapping was a very marked advance upon the old practice of merely judging the fractures of a series of spoon samples.

Micro-etching.

The use made of the examination of the macrostructures of bronze castings to determine when they had been cast at the correct temperature for the work in hand was also an excellent improvement, and was one which should be increasingly adopted for scientific control. He deemed the macrograph in Fig. 26 of the fake in "burning-on" a test bar to a large bronze casting was of the greatest importance in showing the value of this method in bringing home faults to metallurgical wrongdoers.

Segregation of Lead.

MAJOR RHYDDERCH, in referring to Mr. Rowe's paper, asked if the author had found it possible, by the use of nickel, to overcome the difficulty of excessive segregation of lead in the heavily leaded bronzes? He had used nickel to try and stop the very considerable segregation, but when they reached 20 per cent. of lead it became very awkward to obviate getting highly variable results when the castings came to be analysed. He presumed the author must have had similar experiences, although he only mentioned lower lead contents in his paper. He very much regretted the disclosures made by the macrographs of the cast-on test bar, and considered that such things should not be dragged up, for the least said about them the better for the industry.

He expressed great interest in the point mentioned by the former speaker, which was described in Mr. Archbutt's paper as the cooling and then re-heating of aluminium alloys for casting afterwards. He was not quite clear as to the mechanism of this, and would like to know how it is brought about. Did the re-heating not allow the metal to take up gases again? As to the heat-treatment of these aluminium alloys to bring about accelerated age-hardening, especially of castings, it was well known in the steel trade that the structure of castings was very much bigger than in forgings, and to effect a refining at any requisite temperature the time element was the chief consideration. He thought that some such difficulty might arise in connection with the treatment of the aluminium alloy castings, as compared with rolled or forged materials. He thought that there must be some considerable difference between the aluminium ingots "T" and "U" as used to make the "Y" alloys when it behaves so differently. He also asked the author to explain the effect of iron in some of the aluminium alloys named by Anderson in his new book.

Arsenic in Copper.

Mr. A. Logan considered Mr. Rowe's paper would help on considerably the advancement of scientific work in the brass foundry, and regretted that there were only a small number of foundries which spent much time in going into work of this nature. He thought Mr. Rowe did not sufficiently stress the question of oxides in gun metals, as it was one of the chief impurities usually to be found present, and was so important a matter that it counted for most of the difficulties encountered in making castings of this material. In connection with the author's statement that it was easy to determine the amount of oxygen present in copper by means of the microscope, he would like to ask how he would detect or estimate small amounts of oxygen present in copper containing 0.1 or 0.2 per cent. of arsenic, as it was not always desirable to stick to B.S. brands of copper for ordinary brass founding work. Now that the Admiralty gun metal was specified to have 16 tons per sq. in. tensile strength, he considered that it required the very greatest care in working, and, of course, that made the question of oxides present very important. He considered that 0.1 per cent. of oxygen was low compared with what many firms were using in ordinary copper, which required to be very carefully melted to prevent the occluded gases getting to be several times that amount. In regard to the statement in Mr. Rowe's paper that the limit of solubility of tin in copper being between 6 and 7 per cent. depending on the casting and cooling conditions, he considered that in clean gun metal with very low oxygen content, it was possible to get up to 9 per cent. of tin in solid solution in the alpha constituent without any of the delta eutectoid being formed. This hangs on the question of oxide content, as the more burning the metal has had, the bigger the tendency to form delta, and secondly the greater the chance of getting "bleeding," or what is called segregation, and therefore the poorer the quality of the gun metal.

A very practical proposition which had to be fully considered was how to free the gun metal from this excessive oxide, and this made it extremely important to consider the question of adding the tin and the zinc to the copper in their proper order. Mr. Rowe had not mentioned the effect of arsenic upon gun metal, and he asked if the author could give them any information as to the effect of 0.05, 0.1 or 0.2 per cent. of this element when present in gun metal. He was interested in the method described for determining the amount of zinc present in a bath of high tensile brass by means of the micro-structure, but from his own experience in casting a sample from the furnaces into a chill this retarded the formation of the alpha constituent, and unless a series of samples had been prepared in the same condition, he could not see how it was possible to judge the amount of zinc by this method, about which he would like to ask how it was done.

Copper Aluminium Alloys.

Mr. Logan criticised Mr. Archbutt's paper for not containing any reference to the copper-aluminium series of alloy, more especially as the 10 per cent. alloy had been found extremely useful for marine propeller work, for which purpose it might easily supersede manganese brass, as it was highly incorrodible, and in the meantime only possessed the difficulty of obtaining it sound.

Major Rhydderch further contributed to the queries regarding Mr. Archbutt's paper by asking how the molten aluminium alloys were treated. He noticed that the author did not mention what fluxes were used for aluminium alloys, for he considered they might be clarified of objectionable gases by using a suitable covering flux. Referring to the alloy known as Alpax, he believed that there was trouble frequently encountered in effecting good machining, and this was usually an important commercial proposition. Then, again, there was the question of the friction set up by some of these soft alloys. As a good pattern metal some one had quoted an alloy containing 93 per cent. of aluminium, with over 4 per cent. of copper, nearly 2 per cent. of lead, and about 1½ per cent. of silicon, which dragged very badly. He asked if the author could give any practical hint or suggestion as to how this metal could be worked since it was tender when hot and ruptured very easily.

Industrial Application of "Y" Alloy.

Mr. Maybury considered that in spite of all that had been done, very little had been developed practically in regard to utilisation of "Y" alloy commercially. After a paper to the Automobile Association on this metal it appeared that the reception of the information relating to it had not been very enthusiastic. Although they had heard a good deal about "Y" alloy, it did not appear that very many foundries in this country were producing castings of it in any quantity or of any great size. He declared that most of the figures which were given as tests of the "Y" alloy were obtained from test bars of one inch diameter, which had been cast in a chill, and that we had but little knowledge of the physical properties of the "Y" alloy cast under ordinary foundry conditions. He thought Mr. Archbutt might elaborate that point of the physical properties a little more, and also the application of the heat treatment for accelerated ageing upon the castings themselves instead of the test bars, as there was not much scope for handling such fragile materials when hot.

Major Athey said in regard to the question of fluxes raised by Major Rhydderch, he had found that it had been a very difficult proposition effectively to protect molten aluminium alloys from oxidising conditions, but a very useful flux was zinc chloride, although undoubtedly in other countries they had more powerful reagents since they were able to take their refuse and produce aluminium alloys from them.

Mr. Faulkner stated that in regard to the "Y" alloy named in Mr. Archbutt's paper, he thought the N.P.L. had perhaps spent much time and energy needlessly on the question of quick ageing of this material, as they seemed to imagine it was wanted quickly after the castings had been made in the foundry. From what he gathered in the industry, however, they were quite satisfied with the quality of the metal if it acquired its age-hardened properties naturally in about three months' time, which was the period which normally lapsed before the castings were to be put into commission. Another question he raised was in regard to the melting experiments carried out in a neutral atmosphere, because he considered it was more important to have a crucible which would be impermeable by the furnace gases. Much production was spoiled by melting in a clay crucible which was definitely known to be penetrable by sulphur or other gases from the furnace, and he considered that a little research on that line would be difficult, but of great practical value immediately to the industry.

"Y" Alloy Compared with Aluminium-Silicon Alloy.

Mr. F. W. Rowe, like Mr. Maybury, expressed himself as very much interested in the possibilities of the "Y" alloy as distinct from the silicon-aluminium alloy, which required to be modified. His own practical experience pointed to the latter, as he found that it could be produced straightaway without extensive experiments to ensure that the casting conditions were right. Within the 11 to 13 per cent. silicon range, he had found that it was easier to guarantee results than with the "Y" alloy, which took much experimenting to get right. He found that the silicon alloy was extremely simple to make, as the molten metal poured like water, the shrinkage and porosity troubles were very slight, and in addition the machining operation of the solidified castings was very easy and regular. He knew that about 100 tons of this alloy were being produced per week for such varied purposes as motor 'bus wheels, motor-car back axle cases, underground railway carriage doors, etc., and he had not heard of any such wide application of the "Y" alloy. He concluded by asking Mr. Archbutt to give his candid opinion as to which he thought of the two alloys held out the greater commercial proposition.

Mr. Archbutt, replying first to the discussion, stated to Mr. Faulkner that the suggestion to vary the composition and adjust the heat treatment to suit was not feasible, as in order to get the best results it was essential to adhere very closely to the composition specified for the aluminium alloys. Of course, it was possible by modification of the heat treatment to get widely varying physical test results. In "Y" alloy, tempering makes it very much harder, and also by suitable higher temperatures it could be made very soft. Thus a tensile strength of 20 tons per sq. in. with only 3 per cent. of elongation could be altered to 10 tons with 13 per cent. elongation. The question of quick ageing of "Y" alloy had been raised by the Engineering Standards Association, whose committee had been dealing with a suitable specification for the material. They had asked if it would be possible to quicken the period taken normally to harden, and thus the usual eight days had been found, on using 100 to 120 deg. C., to be reduced to as many hours. The neutral atmosphere used was that of nitrogen, and it was selected because it was practically insoluble in the aluminium alloys. The author thanked Mr. Primrose for referring to the slight errata and omission, which would be rectified. In regard to the type of furnace used, it had been found possible simply to withdraw the crucible from the furnace, allow it to fall in temperature to about 500 deg. C. very slowly, and then replace in the furnace in order to melt up the contents quickly before much or any gas was reabsorbed. It was also a remarkable fact that in addition to very slow cooling, very quick solidification also overcame the trouble of pin-holing. He explained the mechanism of this change to Major Rhydderch as being that in the slow cooling the gases were thrown out of solution, and were able to escape, due to the metal solidifying sufficiently slowly to permit of this, whereas by the quick cooling, as in chill casting, the gases in solution were not alloyed to fall out, and thus there was again no pin-holing. It was the intermediate rate of cooling, such as obtained in making ordinary sand castings, which caused the trouble of pin-holing, which allowed the gases to fall out of solution, but not sufficiently slowly to allow them to get out of entanglement in the metal. He believed the addition of zinc to some of the American aluminium alloys was intended to increase the ductility of the metal, whereas it was usual to consider that the iron increased the strength, particularly at high temperatures, but to exceed the limit of 1 per cent. only increased the founding difficulties very considerably. Complex alloys like that quoted were often used in the United States of America, but he considered it very doubtful if they were any improvement on the straight alloys of simpler composition as used here.

Fluxing Aluminium.

On the question of fluxes he claimed that it was not possible to reduce metallic aluminium from alumina, but only to flux it off. For this purpose zinc chloride was advocated, but it only removed the oxides at the surface, and then there was the danger of getting it into the alloy. To effect a modification of the silicon alloy it was possible to use metallic sodium to do this without the use of the usual flux. In regard to the difficulty of machining Alpax, he believed it was not so great as some people imagined, as they had found no difficulty in machining test bars for their physical test purposes. He believed its ductility was not so good as the "Y" alloy when the latter was properly heat-treated. In regard to the complex pattern metal named, with the low copper and about 2 per cent. of lead, he would prefer to recommend the alloy of silicon with aluminium as simpler and less liable to break. Even with the L5 alloy containing higher copper than the alloy named, it would be possible to make a satisfactory job.

In reply to Mr. Maybury, he contended that he held no brief for "Y" alloy, but merely advised its use in suitable cases because of its excellent possibilities when rightly treated, even if it was not quite so inexpensive an alloy as some others. He declared that it was well known that it was not usually possible to get from castings exactly the tensile or other results obtained from test bars, but there was usually a very good indication of what to expect from the one when the value of the other was known. He instanced a crank case which gave in "Y" alloy an actual tensile strength of 15 tons per sq. in., whereas in L5 alloy the casting only gave about 3 tons per sq. in. As to the suggestion that the castings of complicated shape would lose their shape during heat treatment, it was a simple matter to protect them from distortion by use of a steel jig. Any suggestions as to bettering this would be valued.

The author did not think that there would be much good accruing from the attempt to smelt aluminium out of the aluminium drosses, as it was very difficult except in an electric furnace to reduce the oxide to metal again. Of course, there were fluxes which are of value in melting the skimmings in order to let the finely divided particles of aluminium or alloy coalesce and separate out from the flux, and then this can be melted down into ingot form. Mr. Rowe had suggested that he preferred the aluminium-silicon alloy, and whilst he had to admit that it was an excellent alloy, the question to be considered first was its application, that is, to what purpose was the casting to be put. If the aluminium-silicon alloy was judged on the tensile strength alone it was second only to "Y" alloy, but the best way was to consider the strength to weight ratio, and, moreover, they found that the elastic limit of the silicon alloy was very low, so much so that there is very great distortion at such very low loading as is very frequently applied, and this was a serious objection, so that he did not think they would retain their shape as did "Y" alloy castings. "Y" alloy was not deemed to be a particularly expensive alloy, being only about one penny per pound dearer than the usual run of aluminium alloys, and the possibilities it possessed in its physical properties, more particularly when the necessary care was taken to melt it and further cool it in such a way that the gases were removed before casting. As to Mr. Rowe's objection in regard to sand castings, he considered that the higher temperature of pouring required for "Y" alloy undoubtedly gave rise to greater shrinkage, but that was a matter which could be overcome without much difficulty.

Admiralty Gunmetal.

Mr. Rowe, in reply to the discussion of his Paper, expressed his indebtedness for the kind remarks which had been passed upon it. He usually preferred the magnesium oxide to that of aluminium to effect his final polishing, as he had found dimantine to be very coarse and irregular in recent deliveries. As to the question of etching raised by Mr. Primrose, the majority of the figures reproduced had been got by etching the specimen with acidulated solution of ferric chloride, although the ammonium persulphate was useful in bringing out the coring effect, often very well marked in the phosphor bronzes. He quite appreciated the reasons advanced for annealing Admiralty gun metal, but he brought up the question because this alloy was not fundamentally a good one with which to make hydraulic castings, as it possessed no advantage on the question of strength over alloys which were basically a solid solution. It was best for this purpose to keep the tin content low and have also present sufficient lead to be able to fill up any interstices which might allow of water leakages. The only real reason for annealing Admiralty gun metal he supposed was to ensure better hydraulic tests, and from previous Papers he thought writers had been making too much of annealing to raise the tensile strength and ductility. For temperature control he made use of thermo-couples of two types. The base metal ones for direct immersion in the molten metal, and also the platinum against platinum-rhodium couple for higher temperatures, and, of course, these were provided with a protective sheath.

Major Rhydderch had raised the question of segregation of the leaded bronzes, but he had never had any trouble with the usual run of 8 to 9 per cent. If it were necessary to have more than that very careful control was needed to effect an equal distribution of the lead. He thought 9 per cent. was a maximum used in cases where good anti-friction properties were desired, and even then some care had to be taken in regard to the pouring temperature in order to get good, sound castings. If the temperature fell below 1,020 deg. C. it was often possible to get harmful blow-holes, especially in green sand castings. Above 9 per cent. of lead he knew that nickel was often advocated to ensure uniform distribution of the separated particles, but he had not found so much success with that as with either lead or molybdenum sulphide which had enabled him to get to 18 or 20 per cent. of entangled lead into bronzes. The reason he attributed to his want of success with nickel was that in order to get the nickel into the bronze it might be stewed in the process, as it was difficult to get the nickel completely into solution.

He was pleased to have Mr. Logan's criticism regarding the question of oxides, and fully agreed with him that quite 90 per cent. of the troubles connected with cast gun metals and bronzes were directly traceable to this cause. Zinc and phosphorus added after this impurity had been formed did not remove it completely. Even re-melting did not remove the oxygen, and in fact very few castings were completely free from some traces of oxide, and it was a very easy matter to detect them microscopically in what were considered quite good test bars. He agreed that it was not easy to detect oxygen in copper which also contained small amounts of arsenic. He had no experience of the effect of this impurity upon the properties of gun metal. Especially in melting gun metal in reverberatory furnaces it was important to add the zinc before the tin to ensure that the least possible amount of oxygen was left in the melt. It was an easy matter to allow for the rapid cooling in estimating the amount of zinc in brasses which had to be examined microscopically for their zinc content before tapping, as the effect of retarding the formation of one constituent was quite a regular function.

Solubility of Tin in Copper.

The other point in regard to the solubility of tin in copper was one in which he differed from Mr. Logan, as he had always found even when working with pure tin and copper in the absence of oxygen, that he invariably got some delta separation whenever he passed the 5½ per cent. composition. He quite agreed, however, that oxygen present had a great effect in promoting the separation of eutectoid from the alpha solution, and also the delta was made to separate more completely.

Scottish Branch.

PRESIDENTIAL ADDRESS.

Mr. Affleck, on assuming the chairmanship of the Branch, delivered his presidential address as follows:—

In looking over the list of my predecessors in the honourable position of President of the Scottish Branch of our Institute, I find the names of many distinguished foundrymen, names which are more or less household words in the foundry trade. You will, therefore, readily appreciate that I accepted the position with some degree of trepidation. At the same time I think I may safely say that although all my predecessors may surpass me in talent and abilities, I am quite certain that none will exceed me in gratitude and appreciation of the honour you have done me in electing me to this chair, and I assure you that my very best efforts will be devoted to the interests and the prosperity of our Institution.

In an Association such as ours, in which the membership is composed of iron, brass and steel founders, it is, I think, desirable that the subject of a presidential address should be of general rather than of purely technical interest, and with this in view I propose to place before you a few thoughts on one or two subjects which influence, more or less, all branches of foundry activity.

Suggested Improvement.

Mr. Henry Ford, the celebrated American motor manufacturer, in his recent book describing his life and work, says, in speaking generally of the development of industry: "The progress has been wonderful enough, but when we compare what we have done with what there is to do, then our past accomplishments are as nothing." While I cannot help feeling that Mr. Ford's modesty regarding his own accomplishments is perhaps excessive, and certainly most unusual in an American manufacturer, I am certain that what he says is profoundly true of the foundry industry to-day. We all feel that a vast and ever-growing field lies before us, and that great advances in foundry technology and in foundry practice will be made, and, in fact, must be made, to meet the demands of allied industries. It is my purpose this afternoon to indicate briefly one or two of the factors which may influence progress, one or two avenues along which suggestions for improvement might be made.

Effect of Cheap Power in Foundry Developments.

It is unfortunately the case that the commercial conditions in most branches of the foundry industry at the present time, although improving, are still very unsatisfactory. Costs are high, prices are low and extremely competitive. In very few businesses is the margin of profit sufficiently great to enable the management even to consider any serious scheme of improvement or re-organisation. In this respect I do not think I am far wrong in saying that 90 per cent. of British foundries have during the last few years been absolutely marking time as regards serious expenditure on development work. At the same time I am quite certain that British foundrymen in general, and Scottish foundrymen in particular, have not by any means been asleep, and that many of them have, by an intensive study of their present plant and processes, effected most striking economies in production, and more or less prepared themselves for that wonderful boom in trade which has been so long foretold, but which, like Royal Charlie, is very long in coming.

How Railway Electrification Would Help.

Looking over the industrial field of Great Britain from the broadest point of view, we find there are one or two national questions in which the foundry industry, along with other industries, is specially concerned. Perhaps the most important is that of the supply of cheap power, particularly in the form of electric energy. Certain schemes are now afoot, supported by national funds, for the supply of electricity in bulk to various districts. In some cases the source of energy is found by the harnessing of water power, in others by the unification of existing electric supply schemes. Severe pressure is also being exerted on the railway companies to electrify their systems, and, if this were carried out, as it may be in the not too distant future, it would, in my opinion, produce an almost revolutionary effect on industry. The electrification of the railways would mean that electric cables and an electricity supply would be carried with the railways into every corner of the country. Uniform load conditions, the lack of which is now the bugbear of all electric supply schemes, would be secured by the continuous railway traffic, and a large surplus supply at cheap rates could be arranged for industrial purposes.

Brass Foundries and Electric Melting.

These schemes no doubt seem far removed from the everyday interests of foundrymen, but I think, nevertheless, that they deserve more than passing attention on account of the important developments they may bring in their train. I refer particularly to the possibility, if a cheap supply of power were available, of the greatly extended use of electricity in foundry practice, particularly for melting operations. At the present stage of development, if really cheap electric power were available, the greatest benefits would probably be gained in steel and brass foundries, and would be associated with the use of electric furnaces. The great advantages resulting from the use of electricity in steel melting generally, and particularly in the manufacture of special alloy steels, have been generally recognised, but I do not think the corresponding advantages and possibilities of this method have been appreciated to the same extent by brass and iron founders.

In many brass foundries, even very large foundries, the melting methods are still in the mediæval stage, and the ordinary pot furnace reigns supreme. There is no doubt that, where small heats are the rule and where a number of different mixtures are in use, this type of furnace offers distinct advantages, but where comparatively large amounts of metal are required, the foundry conditions become very arduous, unhealthy, and uneconomical. In more modern foundries, where a considerable amount of non-ferrous metal is melted, the pot furnace has been superseded by the crucible tilting furnace and the air furnace, but to my mind the ideal is certainly the electric furnace. This is particularly the case where brasses of high zinc content are being handled, and where, consequently, the metal losses by oxidation and volatilisation using the ordinary methods of melting would tend to be very high. With a good type of electric furnace these losses may be kept very low indeed. Further advantages are high-quality metal and very accurate temperature control. Labour charges are also considerably less, there is no fuel to charge and no ashes to cart away. Last, but not least, the atmosphere, working and other conditions affecting the health, comfort and safety of the worker are greatly improved. From the financial point of view also, an important aspect in these hard times, the balance-sheet compares favourably with that of other types of furnace, providing one condition is favourable, namely, the cost of electric energy. A cheap supply of electricity would no doubt lead to the wide adoption of electric furnaces in this country, as in the U.S.A., where some foundries have as many as 80 electric furnaces installed under one roof.

Cupola *v.* Electric Furnace.

But while the most favourable sphere of operation of electric furnaces would appear to be meantime in brass and steel work, there is also a certain field even in iron foundry work, and this field is gradually extending. The great god of the iron foundry meantime is, of course, the cupola, and the cupola is undoubtedly a wonderful tool, which, in the hands of experienced foundrymen, gives results of marvellous consistency. For certain classes of work, and particularly for very heavy work, it is doubtful if the cupola will ever be superseded by any type of furnace. It is well, however, in dealing with the possibility of evolutionary changes in furnace or melting practice to look at the matter as far as possible from the broadest point of view. The function of the foundry industry is to supply the demands of the engineering and other industries as regards castings, and accordingly it naturally follows that the foundry industry must react to and may be vitally affected by technical developments of all kinds in other industries. Generally speaking, the present-day tendency in machinery is to reduce weight to a minimum. This, of course, implies stronger and superior material to closer specification and analysis. There is a great and growing field for irons of very special quality. The Diesel engine industry, for example, which is developing with extraordinary rapidity, demands irons of characteristic properties and strengths, and, as the weight of Diesel engines per horse-power at the present time is extremely high, there is not the slightest doubt that Diesel engineers, in the near future, will be demanding still stronger irons with a view to reduction of weight. In steam engineering, also, the tendency is to use higher and higher steam pressures, and plants are now being designed to operate at steam pressures as high as 1,200 lbs. per sq. in. These pressures are associated with very high steam temperatures and demand very special metals. In fact, in all branches of mechanical industry the demand is insistent for stronger and more reliable materials carefully selected and specially adapted for the particular work they may have to perform, and foundrymen must be prepared to anticipate these demands and to adapt their organisations and resources to meet them. How far and for how long the cupola will be able to meet the growing demands for irons of very special quality remains yet to be seen, but, meantime, if electric supply conditions are favourable, the electric furnace is certainly capable of acting as an efficient adjunct and possibly as an ultimate successor to the cupola. The easy control, accurate temperature regulation and synthetic building up of accurate compositions which are possible with electric melting, not to mention other incidental advantages, such as speed in melting and improved labour conditions, should make the proposition attractive to most foundrymen. Here again, however, it appears to me that the controlling factor must ultimately be the cost of electricity in bulk supply, which will depend to a great extent on the successful development of these national schemes for power distribution to which I have already referred.

Technical Status of the Industry.

There is another matter of general interest to which I may, I think, fittingly refer on this occasion, and that is the present technical status of the foundry industry. There is a suspicion abroad at the present time that, technically speaking, all is not well with the foundry trade in this country. Considerable discussion has taken place over the action of one or two prominent firms engaged in large Diesel work who have recently ordered iron castings from foreign firms without even offering the work in the home market. While these firms may have the best of reasons, from certain points of view, for this procedure, it appears to me, from the broad standpoint, to be rather a short-sighted policy. It is certainly very discouraging to British foundrymen, and shows an alarming lack of confidence in the ability of the home industry successfully to handle new problems and conditions, a lack of confidence which I think is hardly justified by the past record of British ironfounding. The question then arises—is this lack of confidence justified by present-day conditions? I cannot speak from personal knowledge in this case, but in the arena of commercial life one sometimes strikes against hard and disturbing facts, and I might mention a recent personal experience in another sphere of foundry practice of rather a disquieting character. The castings required were of steel, and weighed in the rough about 15 cwts. The job was undoubtedly a difficult one, as the structure of the castings was somewhat complicated, and the designed metal thickness only $\frac{3}{8}$ in., lightness being of great importance in the particular machines in view. Patterns of the highest class were provided, and these castings were offered to various steel founders throughout this country, also to certain Continental firms of repute. While on the one hand the foreigners all readily offered for the job, quoted reasonable prices, and displayed eagerness to get the work, on the other hand the greater number of the British firms who were approached simply declined to undertake the work; a few quoted conditionally on the thickness of the casting being doubled; and one or two, who obviously did not want the job, quoted absurdly high prices. The procuring of these castings became a source of worry and anxiety to all concerned, and for some time it appeared as if it would be necessary to place the order abroad. It is incidents like this which tend to shake the confidence of clients in the home market, and raise doubts as to the technical resources of the home firms. Many steel foundries have possibly not the equipment for work of this nature, as I am convinced that electric steel is necessary to make a really first-class job of castings of this kind, but the whole circumstances do not reflect much credit on the steel-casting industry generally in this country, and show, or at least appear to show, a striking lack of that ability, courage and enterprise which we usually associate with British manufacturers. I am happy to say that the problem was finally tackled, and looks like being solved, by a Scottish firm not 100 miles from Glasgow.' There is little doubt that in the next few years we shall be called upon to face the severe competition, in the world's markets, of Germany, not militarist Germany, but "deep-thinking, patient, laborious Germany," and possibly, before very long, the competition also of powerful Franco-German combinations with immense resources in plant and finance. Some people may regard this as a misfortune, but it seems to me that it may prove a blessing in disguise as it may awake us from our apathy and evolve that inherent characteristic of our race, that "dourness" which has carried us over so many obstacles in the past. Character alone, however, will not carry us through difficulties of this nature; we must take advantage of all the means of grace in foundry technique. Signs are not wanting that important advances in foundry practice which have only been partially disclosed, have taken place on the Continent, and if our commercial success is to be assured, it is incumbent on every progressive foundryman to take stock of, and to overhaul his equipment from both the mechanical and scientific points of view.

If foundry practice is considered from the standpoint of an art or handicraft, I believe that British foundrymen can defy the world, but I have grave doubts as to our position with regard to mechanical equipment and scientific methods, particularly the latter. A great deal has been spoken and written about the place of science in the foundry, and for years the technical press has been deluged with a roaring cataract of articles, mainly on metallurgical science. Many of these articles have been of great interest and importance, but a large number of them I would venture to say, deal with abstruse and research aspects of metallurgy which have little interest to the average foundryman, simply because he sees no way of making any practical use of the information given.

The Gulf between Theory and Practice.

The skilled chemist and metallurgist may place before the foundrymen the most minute details regarding the micro-structure of any given metal. He may define very concisely its physical and chemical constitutions and characteristics; he may state its properties under varying temperatures or other conditions, but he may be still very far from making any serious addition to actual foundry knowledge of the metal, any addition to that information which the foundryman requires to enable him to make a sound casting corresponding to the metal described. No person interested in foundry practice can read the technical literature associated with foundry work without feeling how singularly ineffective some of it is in respect of the enlightenment or solution of some of the most serious foundry problems. To the foundryman, a great many of, I might say the bulk of current scientific articles, and I am afraid even some of our Institution lectures, appear to be of the treadmill variety, and so far as practical work is concerned, to end where they begin. From the nature of current scientific literature it would appear that many of our metallurgists appear to have no desire for the serious study and attack of some of the most obvious everyday problems of the foundry, they evidently prefer to patrol the high grounds of research. From certain points of view, of course, their attitude may be completely justified. From the other point of view many foundrymen find themselves separated from the developments of metallurgical science by a wall of more or less obscure technicalities which they have neither the time nor the inclination to surmount. The ideal condition, as expressed by the motto of our Institute, "Science hand in hand with labour," seems still to be far removed from the realities of work-a-day life. I feel strongly that this gulf which exists between theory and practice is a reality and must be bridged in some way before our industry is on a proper basis. The inherent reason lies, of course, on the one hand, in the comparative inexperience of many scientific workers of foundry processes, problems, and difficulties, and on the other hand, in the inability of many foundry workers to appreciate and give practical application to scientific facts and principles; the remedy seems to be that the scientist must become more of a foundryman, and the foundryman more of a scientist. It is my experience that when hard scientific facts are available in the proper form, no class of man is more enthusiastic in applying them to practical work than the foundryman. As an illustration of this, I might refer to one of the most interesting examples of practical technical instruction in foundry matters, namely, the "McLain" system as developed in the U.S.A. As applied to the manufacture of semi-steel in the cupola, this system has been studied and successfully operated all over the world, and McLain graduates are to be found in all countries. It is a combination of technical and practical information such as I have already referred to, and in such a form that it can be directly applied to industry. Investigation of the actual system seems to show that, so far as the theoretical part of the instruction is concerned, the information given is not new; the facts and principles enunciated have been well known to metallurgists for years; the success of the system is due to the practical application of these facts and principles. The information given is such as to enable the practical man successfully to run semi-steel and, so far as the foundryman is concerned, this appears to me to be the vital matter. I may say I hold no brief for the McLain system: I have never been a student of the system; I merely mention it as an illustration of the power and interest of applied as distinct from purely academic science.

As a further illustration of what I mean, I might mention the technical position regarding that material which is now exciting interest in foundry circles, namely, the so-called pearlitic cast iron. This material, which is being put forward to replace cast steel and malleable cast iron, is a low silicon, low carbon iron of great strength, and is reputed to show minimum growth under repeated heating and cooling. When cast at the correct temperature into a heated mould, also at the correct temperature, the metal requires no feeding heads, due probably to its short freezing range, and the casting may be readily machined and worked. The properties of the material are, in fact, such as to excite the envy and curiosity of all ironfounders, particularly those engaged on special work. If cast in the ordinary way, however, the normal impracticable white iron structure would be produced. The constitution and structure of so-called pearlitic cast iron are well known to metallurgists, and can undoubtedly be reproduced under laboratory conditions, but when we enter the realm of the commercial production of castings, the problem becomes much more acute. When the ironfounder sets out to make a casting of this material, who can tell him what should be the exact composition and temperature of the mould, or parts of the mould, to give the required structure and properties? This is the vital information for the founder, and constitutes one of these problems in applied as distinct from pure science, which, in my opinion, can only be solved by the active co-operation of the scientist and the practical man.

The Value of the Research Worker.

But while the immediate concern of the foundryman lies in practical applications or applied science, we must not fail to appreciate the great importance of research along the line of what is usually termed pure science. The worker in pure science, the man who devotes himself to the intensive study of natural phenomena from pure love of the subject is, in my opinion, one of "the salt of the earth." He works in a realm far removed from that of ordinary commercial cupidity and hustle, a realm of "toil unsevered from tranquillity," and while his financial reward is often relatively very meagre, his value to the community is sometimes immeasurably great. In fact, some of the most important industrial developments of modern times have been the outcome of the work of men of this class. It is rarely that the results of their labour become immediately absorbed into practical affairs. The records of their work may slumber for years on the dusty shelves of laboratories, but in the course of time very often simple researches have far-reaching results in industrial life. Who can estimate the profound effect on the iron and steel industry of the pioneer work of men like Turner, Stead and other research workers? In another sphere, that of electrical engineering, we find that about 18 years ago Mr. W. Dunwoody discovered experimentally that a carborundum crystal or silicon carbide possessed the property of transmitting oscillatory electric currents more easily in one direction than the other. Further research then showed this property to be more or less common to all crystals. Who could have predicted that this obscure research, and the discovery of this peculiar property, would to-day make possible by the simplest and cheapest means the wireless reception of entertainment and instruction by millions of people, that it would lead to the foundation of a great new industry, that it may ultimately be utilised to enable the voice of a single human being to be heard all over the world.

It is gratifying to note that the great importance of iron foundry research has been recognised in this country, and has led to the formation of the British Cast Iron Research Association. This Association, which is assisted in a moderate degree by public funds, is designed to effect, as far as possible, that co-operation between pure and applied science which is of such vital importance in industry. The Association now possesses a scientific laboratory for experimental research, and arrangements have also been made for extensive experiments on a commercial scale in the works of certain of its members. During its comparatively short life most important practical results have already been obtained and communicated to its members. Other researches on outstanding problems are now in progress. In spite of this somewhat extraordinary record, it is a remarkable fact that the great possibilities and value of an Institution of this kind in solving industrial problems do not appear to have been realised by the majority of ironfounders in this country, as the percentage who have actively interested themselves in the Association is relatively small. It is difficult to account for this appalling apathy in the face of modern conditions and foreign competition, although financial stress is at the root of some of it, and it is to be sincerely hoped that before long the greater number of the ironfounders will have realised their responsibilities and extended their support to the scheme. For commercial success we dare not leave any stone unturned in our efforts to bridge the gulf between science and practice, we dare not spare any effort to obtain for foundry work wherever possible that mechanical precision and accurate control of process which makes for the highest efficiency. Membership of the Research Association is one of the most direct means to this end, and the united labours of scientists and practical men provide in the Association a reservoir of important information which is the business of the Association to transmit to its members.

The Education of the Worker.

But there is another important element in foundry work which must not be neglected, and that is the human element. Some of us are convinced by experience that this is perhaps the most important element of all. Although the use of machinery is gradually extending in foundry practice, particularly in repetition work, the industry as a whole is still very far from the purely mechanical stage—founding is still an art requiring very special qualities of knowledge, initiative and practical skill, qualities which depend to a very large degree on the experience and training of the workers of all grades in the industry. This brings us to what one might call the "hardy annual" of presidential addresses, the subject of the education of foundrymen. A great deal has been written on this subject, particularly on the education of apprentices, and many elaborate schemes and syllabuses have been put forward. The scheme recently adopted by the French Foundry Employers' Association is extremely interesting, including as it does the direct tuition of apprentices in both practical and technical work, and opening as it does a direct path for apprentices to graduate from elementary classes in the foundries and evening schools to the Technical High School in Paris, where training may be obtained for the very highest positions in the industry. We have no co-ordinated scheme of this kind in action in this country whereby classes are carried on by employers, although the provisions of the new Scottish Education Act, when it comes into operation, will make the attendance of young employees compulsory on part time day continuation classes which may be of a technical nature. So far as I am aware, however, only one or two firms in Scotland have organised works classes for foundry apprentices in co-operation with the Education Authorities, and in anticipation of the Act and in the present depressed condition of the industry it is, I suppose, unreasonable to expect any general move in this direction. A number of firms, however, have appointed special men for training apprentices in practical work on the foundry floor as recommended in the French scheme. This scheme, although supported by Government funds, does not appear to be compulsory in any way, the initiative evidently being left in the hands of local associations of employers. Generally, one cannot help gaining the unpleasant impression that, so far as the organisation of technical education for foundry workers is concerned, the Frenchmen have been more enterprising, and are distinctly in advance of this country. It appears to me, however, that, while organisation of this kind is of importance, the central and everlasting problem of foundry education, as of all kinds of education, is the problem of really awakening the interest of the person concerned in the subject of study. I have had some personal experience of this aspect of the problem in a foundry with which I was associated for some years, and in which classes in foundry subjects for apprentice moulders were carried on during working hours.

It was found that while many of the apprentices were keen, others were apparently entirely indifferent. A few were even actively hostile, and methods bordering on "Prussianism" had sometimes to be used to induce them to attend at the "seat of learning." In cases such as this, where interest in the subject of study is lacking, it is extremely doubtful if the youth really profits by the time spent in the class-room. Certainly I can sincerely sympathise with him in sitting out lectures on subjects which bore him to the back-bone. No doubt he learns to look on the works school as another of the many discomforts associated with foundry work. The problem of interest is undoubtedly a difficult one. It is affected by factors over which the employer, manager, foreman, or teacher has little or no control—by factors such as physique, health, home life, natural aptitude, and most directly, by primary education. In this connection it appears to me that the far-reaching influence of the primary school teacher is not sufficiently recognised by those engaged in industrial work. He it is who handles the raw human material in its most plastic condition. He has at once the responsibility and the opportunity of implanting those ideals of public service, of fair dealing, of thoroughness, of pride in a good job for its own sake, which affect so profoundly the mental attitude of the boy towards his work, and which mean so much more than mere learning in the making of the master craftsman. If these ideals were instilled in the early stages of life, if boys were taught to respect and admire skill in handicraft as they now learn to admire skill in games, if work were presented to them, not as a penance, but as an interesting vocation, then I think the problem of the technical education of the boy for his selected trade would be moving towards solution. The actual course of instruction should, I think, even in the early stages, have a strong practical bias. In teaching simple scientific principles it is surely not difficult to obtain illuminating examples from the workshop itself. No attempt should be made, however, to make scientific experts of youth who wish only to be competent moulders or to cram them with facts having little or no bearing on their daily work. Those of us who have been through what I might call the "valley of the shadow" of modern education know only too well its weakness in this last respect. Great stress is laid nowadays by teachers, education authorities, and others on what they call cultural education. Its value cannot be denied, and it undoubtedly adds to the pleasures of life. But, after all, a knowledge of Latin prose composition or Greek poetry does not carry much weight in the iron foundry, and the education and training which enables a youth to earn his living and serve the community in an efficient manner must, after all, take first place. These matters are worthy, I think, of our serious attention, because I feel certain that, sooner or later, the foundry industry in this country will require to organise the education of its workers, young and old, and that we, as an institution and as individuals, will require to face and solve every aspect of the education problem.

The Importance of Educating the Adult.

And the problem of education does not end with the youths or adolescents, who are, after all, only foundrymen in embryo. It extends also to the adults in the industry, to those foundry workers often of ripe practical experience, who take, or appear to take, no interest in the technical side of their vocation. It seems to me that the field here is of equal importance, and the difficulties equally as great, as in the case of the youth. The youth in industry must always be an uncertain factor as regards his future possibilities and his career. In the case of the adult we are on surer ground, as he usually possesses in a large degree the vital practical experience and training which may be amplified and enriched by technical knowledge. The Prime Minister, Mr. Ramsay MacDonald, in a message to the Adult Education Conference, said recently:—

> "We are only beginning to understand the importance of adult education. Unless we keep our adults in contact with those influences which make mature minds, and keep them ripening into an ever richer fullness, our people will suffer from arrested development, and the education they get in their youth will be largely wasted."

No better justification for the existence of our Institute could, I think, be obtained than is contained in this statement. I think we must recognise it to be profoundly true, even in the more or less restricted sphere of technical education. Facilities for adult education are necessary not only to assist the present generation of foundrymen, but to ensure that our efforts for the rising generation will really bear fruit. In providing these facilities, our Institute must surely play a prominent part. The obstacles in the way of adult education are, of course, of the same general nature as in the education of apprentices, the main trouble being one of diffidence, and the most serious problem being the awakening of interest. If we can arouse one-tenth of the discussion and excitement over our Institution Papers and meetings as we find taking place week by week over the Scottish Football League Competition or in "spotting the winner," this room will hardly hold us, and our foundries will be speedily transformed. The awakening of this interest must depend very greatly on the keenness and enthusiasm of the members of our Institute, each one of whom goes forth as an ambassador to the foundry, to the laboratory, or to the pattern shop, which form our recruiting ground. On our personal efforts in these fields will depend our success or failure. By gaining in this way, as far as possible, the personal interest of every craftsman in the industry in our Institute, we shall take the most direct means of broadening its influence; we shall avoid the disaster which has befallen other societies like our own, of becoming merely a happy hunting ground for the managerial and employing classes; we shall take the most effective step towards increasing its power and prestige in the community.

The Attraction of the Foundry.

In closing what I feel has been a somewhat discursive address, I do not think I am exaggerating when I say that, although the environment and amenities of foundry work may not be comparable with some other branches of industry, although on occasion foundry work implies both difficulty and discomfort, it nevertheless offers a field and a career, particularly for young men, which is excelled by no branch of engineering or mechanical art. In the foundry, as in no other branch of the metal industry, men are confronted with the raw forces of nature, including, at times, human nature, in their crudest form. The conflict with these forces tends to develop the best type of character, as revealed in those qualities of courage, hardihood, and skill often exhibited by moulders under the most trying conditions as part of their daily work. The present-day technical problems of the foundry are of such a nature also as to test the most acute brains and the most cunning handicraft. Fame and fortune wait on the solution of some of these problems. In fact, I know of no trade or profession which offers superior attractions in this respect, no field in which men of ability and enterprise have more scope. The fact that the founding of metals consists so largely of art and handicraft is, in my opinion, one of its chief attractions as contrasted with the more or less mechanical processes of other branches of the metal industry. During the Great War a distinguished author was commissioned by the British Government for propaganda work, and for this purpose toured the country inspecting engineering and munition works. During his visit to one of the large engineering establishments in this district he was conducted over the works by a personal friend of my own, who noticed that he showed unmistakable signs of acute boredom, and exhibited only the most languid interest in machine-shop processes generally. In view of this, it occurred to the guide to take his visitor into the foundry. The effect was instantaneous. The man was transformed, and exhibited the most intense interest in every process to the extent that it became a matter of some difficulty to get him out of the foundry again. He had obviously never been in a foundry before, and expressed his delight and charm at the delicate processes and manual skill involved in the working of the sand. In spite of the dust, the smoke, and the grime of the foundry, kin drew to kin, and the true artist in literature was instinctively attracted by the work of the artist in sand. It is desirable, I think, for us not to lose sight of the artistic aspects of the craft, although these are very often obscured by the vile conditions under which work is carried on. Sentiment and enthusiasm are powerful influences in life, and sometimes transform the drudge into the willing worker. Mr. Rudyard Kipling, in his poem entitled "McAndrew's Hymn," depicts the emotions of an old Scotch sea-going chief engineer as he stands by his engines on watch at sea and listens to their rhythmic beat. His romantic vision endows the engine with life, and feeling his inability, as a mere practical man, to express his experiences and emotions, he exclaims in a moment of esctasy, "Lord, send a man like Robbie Burns to sing the Song o' Steam." When we consider the life-long labour and enthusiastic devotion of some of the members of our Branch, past and present, in the interests of the craft, we cannot help feeling that they must have been inspired by similar sentiments, and, like McAndrew, have sighed for a poet to express their emotions and to sing the Song of the Foundry.

It is a sad fact, however, that in far too many foundries at the present day the working conditions are such as to provoke not poetry, but profanity, and there is no doubt that these conditions must be swept away before the foundry industry can attain its rightful dignity and status in the community. Our ancient craft has been the handmaid of humanity from the dawn of history to the present day; the moulder has done as much for civilisation as all the philosophers, and infinitely more than all the politicians As an Institute we have inherited great traditions of service of which we may be justly proud. We have also an heritage of responsibility to the past and to the future, which we cannot ignore, and which should inspire us to greater and greater efforts towards the advancement and honour of the profession to which we have the privilege to belong.

Sheffield Branch.

PRESIDENTIAL ADDRESS.

By Prof. Cecil H. Desch, F.R.S.

The Improvement of Cast Iron.

It is encouraging to notice that the metallurgy of cast iron, a subject which has been strangely neglected, is now receiving a greater meed of attention, although its position is still low in comparison with that of other branches of metallurgy. Research into the properties of cast iron is particularly active in Germany, and it is from that country that we hear of the most interesting innovations, although America shows much activity, on less scientific lines. It must be admitted that few opportunities have been provided for scientific instruction in the principles of foundry practice, and that the subject has been unduly neglected by teachers and by students. Steps are now being taken to remedy this evil, and progress has been made, in spite of certain grave difficulties inherent in the nature of the foundry industry. An inquiry by the Board of Education, in which the speaker was privileged to take part, revealed some of the difficulties in the way of providing technical instruction for apprentices in foundries, but also proved that in some of the most important foundry centres there is a real desire to afford facilities for such instruction. A report on the problem has been issued by the Board, containing suggestions as to the courses to be established and the measures to be adopted in order to provide training for apprentices, so that foundry workers may have the means of obtaining instruction similar to those possessed by fitters, patternmakers and others. Sheffield did not wait for these recommendations, but decided to act immediately, thus presenting an example to other centres. A committee on which foundry employers, trade union officials, welfare workers, the local Education Committee, the University, and the technical societies, including our own, were represented, sat for some time to consider the possibilities of establishing systematic training courses, and especally of overcoming the known reluctance of the foundry apprentice to attend the usual evening classes in technical subjects. As the result of the sittings of this committee a scheme has been adopted, leading up to a Foundry Trades Technical Certificate, to be gained by those who have successfully passed through a systematic course of instruction. The scheme, details of which may be had, provides for two years' work in an evening continuation school, beginning when the boy enters on his apprenticeship, and intended to improve his general education. This is followed by two years in a central evening school, where training in chemistry, mechanical drawing, and other subjects bearing on the work in the foundry is given. The last three years are occupied by evening instruction in the principles of foundry work, given in the Metallurgical Department of the University of Sheffield, success in which will be recognised by the award of the certificate mentioned above. It is hoped that this scheme, which has already been put in operation, will result in the provision, in the course of the next few years, of a supply of adequately trained foundry workers. Steps have been taken to provide technical instruction for men already employed in the industry, but too old to begin at the beginning of the course here outlined.

Pearlitic Cast Iron.

Turning to the problems which interest our skilled foundrymen and managers, we may consider the question of improving the quality of cast iron, and so further increasing its usefulness as an engineering material. Looked at from the point of view of the scientific metallurgist, cast iron is essentially a variety of steel, having its continuity interrupted by flakes of graphite and by patches of the hard phosphide. These constituents may be regarded as foreign inclusions, weakening the metal, although the phosphide, by its hardness, exerts a favourable influence for some purposes. The graphite is present because the carbon lowers the melting point of iron, and makes it possible to melt and cast at a temperature far below that required for steel, thus furnishing a cheaper and more convenient material. Moreover, the expansion which occurs, not during solidification but immediately afterwards, due to the liberation of graphite from the decomposing carbide, enables the metal to take a sharp impression of the mould instead of shrinking away from it. Evidently, the strength and toughness of the iron are properties of the matrix, that is of the steel in which the graphite is embedded. Attempts to improve cast iron have therefore to provide for the formation of a matrix of maximum strength and toughness, and for the minimum interruption of that matrix by graphite plates. In other words, neglecting the phosphide for the present, the best cast iron is likely to consist of a strong steel, containing graphite crystals of such small size and so grouped as to produce the least weakening effect. The toughest steel has the composition of pearlite, containing 0.89 per cent. of carbon. There has recently been much talk of "pearlitic cast iron," a product of such composition, and cast under such conditions, as to consist when cold of a mass of pearlite broken only by groups of small crystals of graphite. How far the process of manufacture is novel is a matter for experts. It is, however, worth mentioning that within the speaker's knowledge excellent small castings were made in quantity during the war by casting a suitable iron in red-hot iron moulds, ejecting immediately the metal was solid, and turning out into a mass of smouldering sawdust for slow cooling. The iron so produced was wonderfully soft to machine, and had excellent mechanical properties. A recent paper by Emmel, of the August-Thyssen-Hütte, gives the following figures as representing suitable compositions for pearlitic cast iron, if cast under proper conditions.

	Total C.	Graphite.	Comb C.	Si.	Mn.	P.	S.
1	3.46	2.54	0.92	1.08	0.96	0.40	0.090
2	3.48	2.66	0.82	0.98	1.02	0.32	0.088
3	3.32	2.35	0.97	1.10	0.62	0.47	0.137
4	3.20	2.14	1.06	1.14	0.70	0.48	0.155

The combined carbon in the irons shown in the table is always near to the composition of pearlite. Another series of irons is mentioned by the same author, containing 1.5 to 1.9 per cent. of silicon and only 0.03 per cent. of sulphur, this proportion being lower than can be obtained in the cupola so that an oil furnace has to be used. The high silicon, which however must not exceed 1.9, makes it possible to machine the iron without heat treatment.

If a product of this kind is to be obtained with regularity, so that its uniformity approaches that of steel, it will probably be necessary to introduce improved methods of melting. The cupola, useful though it is, is a comparatively crude appliance, and oil-fired furnaces have to be considered. Improvements in the cupola have also been attempted, and some of these we may hear further during the present session. Another direction in which improvement is to be looked for is in the manufacture of permanent moulds. Iron moulds have their disadvantages when used for long periods at high temperatures, and it will be necessary, either to improve the iron considerably, perhaps by the addition of alloying elements, or to find a satisfactory substitute. The great progress now being made in our knowledge of refractory materials may help in this direction.

There are many reasons why cast iron of close grain, with minute particles of graphite held in a pearlitic ground-mass, is desirable, apart from its strength and machining qualities. Chemical attack, such as the destruction of acid tanks by sulphuric acid, is associated with an open grain. The acid penetrates into the metal by way of the large graphite plates, and crystals of ferrous sulphate being formed in the cavities, their outward thrust disintegrates the iron. The speaker has met with striking instances of this action. Similar considerations apply to irons which are to be subjected to high temperatures and to the action of oxidising gases. It has been shown by Carpenter and others that "growth" only occurs in graphitic irons, and is particularly marked in irons containing a high proportion of silicon. The action advances along the surface of the large plates of graphite.

The scientific evidence goes to show that all cast iron is white, that is, it contains all its carbon in the combined state, when it first solidifies. Graphite is formed after solidification, by the decomposition of the carbide. The formation of large crystals of graphite may therefore be prevented by chilling rapidly, and then decomposing the carbide by a carefully regulated heat treatment. This is the method for the manufacture of malleable castings by the blackheart process, but it need not be carried so far as complete softening. The method of centrifugal casting has been developed largely, especially in America. By this means, using hot metal, a close structure is obtained, and the relative proportions of graphite and combined carbon are adjusted by a subsequent heat treatment. The rate of cooling through the lower critical point is of importance in determining the properties of the iron.

If we are to aim at the production of cast iron of a quality superior to that obtained by ordinary methods, it will be necessary to assimilate the practice of the iron foundry to that of the steel works. Among other things, close attention to the temperature of casting is most important, and this involves the use of the pyrometer in a systematic way. It is usually stated that for the production of pearlitic cast iron a higher casting temperature than usual is required, and means of measuring that temperature must be at hand. It may be noted, also, that graphical methods of determining cupola compositions, and of representing the relation between composition of metal and rate of cooling when a given structure is required, are being increasingly used in Germany, and it would be well for foundry experts to become acquainted with such methods, which greatly facilitate accurate and uniform work.

Lastly, a reference may be made to the vexed question of the occurrence of oxygen in cast iron. In an important paper read to the 1921 conference by our late President, Mr. Shaw, this matter was reviewed, and its importance in relation to the properties of the iron was indicated. At first sight, the presence of oxide in a material containing so large a quantity of deoxidisers, such as carbon and silicon, appears to be unnatural. There is, however, some evidence that these elements may co-exist. The native iron of Ovifak, in Greenland, may be regarded as a natural steel, produced in all probability by the reduction of a basalt rich in iron by some carbonaceous substance at a depth below the surface of the earth. Benedicks examined the structure of this iron, and found, in addition to the usual constituents of a steel, a peculiar eutectic, the two constituents of which were the carbide and oxide of iron. This "oxide-pearlite," so called from its appearance, had been formed in the original mass, and was not a product of subsequent alteration. No doubt, under the conditions of reduction, a high pressure prevailed, so that the usual reaction between carbide and oxide, leading to the production of gaseous oxides of carbon, would be inhibited, and the two solids would be able to co-exist. The pressure under which ordinary cast iron is formed is close to that of the atmosphere, so that the same explanation will not hold good, but the Ovifak iron may only be an extreme instance, and an equilibrium between the two constituents may occur even under low pressures. Some support for this view is furnished by the interesting work of Carpenter on the carburisation of iron at low temperatures, in which he found that a complex product, containing both carbon and oxygen, could be produced and recognised. It is evident that this field of research calls for further exploration.

The reorganisation of the Cast Iron Research Association under the directorship of Mr. J. G. Pearce leads us to hope that systematic research into the properties of cast iron will now receive increased attention in this country. There is no lack of problems, and there is every hope that when this material has received only a small fraction of the scientific attention which has been given to steel it may be possible to improve its quality to such an extent as to enlarge very considerably its sphere of usefulness.

London Branch.

NOTES ON PEARLITIC CAST IRON.

By J. E. Hurst.

The term pearlitic cast iron applied to what is presumably a new type of cast iron was brought to the notice of the foundrymen in this country within the last year or so by the translation of an article by Professor Bauer describing the work of Diefenthaler at the Lanz Foundry, Germany. This article appeared in THE FOUNDRY TRADE JOURNAL, June 7, 1923.

In a further letter to THE FOUNDRY TRADE JOURNAL,[1] Professor Bauer gives a more concise definition of pearlitic cast iron. He considers pearlitic cast iron to be the product of a certain special and novel process for the production of cast-iron castings, and he defines it as follows:—

"By the 'pearlitic casting process' it is possible to produce a grey iron on solidification from a pig-iron low in carbon, phosphorus and silicon, which under ordinary circumstances would solidify white, and that at the same time, due to the low total carbon content, a microstructure is produced which consists of a pearlitic matrix with enclosures of free graphite."

This definiton is more or less confirmed[2] by the remarks of H. T. Meyer, one of the departmental heads of the Lanz Foundry, who states that the iron "when cast normally" should show "a white fracture when cold." This state of affairs is presumably brought about by the use of irons with low silicon content; but in addition it is evident from a further article[3] that a low content of both carbon, manganese, and phosphorus is also desirable. For some reason or other various writers have laid considerable stress on the fact that it is immaterial whether the irons have a high sulphur content or not.

The information available on the method in which castings are produced to comply with the

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[1] F. T. J., December 13, 1923.

[2] F. T. J., August 14, 1924.

[3] F. T. J., August 30, 1923.

requirements of the foregoing definition of pearlitic cast iron is outlined in the British Patent Specification of Diefenthaler. This is to be found in abstract in THE FOUNDRY TRADE JOURNAL,[4] and states " that the invention can be carried into effect satisfactorily by bringing the mould preliminarily to a definite temperature. It has been found, for example, in the case of an iron of the following composition:—Tot. C. 3.00, Gr. 2.15, C.C. 0.85, Si. 1.00, Mn. 0.70; S. 0.10, P. 0.40, and Fe. 94.80 per cent., that the mould should be reheated to a temperature according to the thickness of the section of the casting as follows:

" Thickness of section, about 10 mm. to about 200 deg. C.; thickness of section, about 20 mm. to about 150 deg. C.; thickness of section, about 30 mm. to about 100 deg. C.

" If the composition is different; for example, if it is of the following composition:—Tot. C. 2.80, Gr. 1.95, C.C. 0.85, and Si. 0.80 per cent., the preliminary temperature of the mould should be selected about 40 to 50 deg. C. higher, that is to say:—

"Thickness of section, about 10 mm. to about 240 deg. C.; thickness of section, about 20 mm. to about 195 deg. C.; thickness of section, about 30 mm. to about 145 deg. C.

" It may be seen from these examples that it is a comparatively simple matter to prepare scales or curves for a particular composition from which without further trouble the necessary temperature of the mould can be read for a particular thickness of material."

Alternative methods of carrying out the process to produce the lamellar pearlitic structure consist of:—(1) Heating the mould by inserting the mould after casting in a heated chamber; (2) heating the metal to a higher initial temperature.

This is broadly all the information available on pearlitic cast iron and the process whereby it is produced, and the whole of this may be conveniently summarised again in the following words:

Pearlitic cast iron is a cast iron having essentially a low silicon and low total carbon content. This cast iron, when cast normally, would have

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[4] F. T. J., August 30, 1923, page 186.

a white fracture, but when cast in warm moulds or cooled slowly in the mould under special conditions has a structure consisting solely of pearlite and graphite. The composition and rate of cooling are varied to comply with these conditions for any particular thickness.

In endeavouring to consider pearlitic cast iron privately, let alone discuss it in a Paper of this nature with a view to forming some opinion as to the nature and value of this material, there is at once evident a serious difficulty of the lack of essential information.

The first question arising is, what is the difference between pearlitic cast iron and ordinary castings containing an all pearlite-graphite structure of which many hundreds of tons of castings must have been made in the ordinary course of foundry practice daily? This question is at once answered by the definition, and it is important to be clear on this point. By the definition it is stated that pearlitic cast iron is essentially of such a composition that for any given thickness of section when cast under the ordinary rules of sand casting the finished casting would have a hard, white fracture. This fact at once differentiates between an ordinary cast iron of a pearlite-graphite structure and the product now known as pearlitic cast iron. There has evidently been some confusion on this point, and the Editor of THE FOUNDRY TRADE JOURNAL has suggested the special term of Lanz pearlitic cast iron to be used to cover the product of the Diefenthaler patent. This modification in the title is, apart from anything else, an act of courtesy justifiable under these circumstances. The very scanty information available on the Lanz pearlitic cast iron has already been mentioned as a difficulty in profitably discussing this subject. The writer proposes to discuss such information as he has been able to obtain both as regards the production and properties of this material, and to discuss generally some of the principles which might be considered to underlie the idea of pearlitic cast iron.

Before doing this, the writer feels it to be his duty to call attention to the considerable amount of looseness met with in the technical writings concerning this material. For example, it appears redundant to specify a content of combined carbon in the description of a cast iron in the text of a patent which is concerned with ensuring that cast iron shall have an all pearlite-graphite structure. Such statements as the production of a casting " according to the rules of the iron-carbon crystallisation doctrine, and conducting its cooling in such a way . . . etc.," are extremely loose and without meaning. Such looseness of expression is apt to give the impression of quackery and certainly tends to lower the subject in the estimation of the thinking foundrymen.

Properties of Pearlitic Cast Iron.

The properties claimed for pearlitic cast iron produced according to the Lanz process are summarised as follows:—(1) High tensile, transverse strength and toughness; (2) high resistance to impact stresses; (3) moderate hardness when properly treated; (4) only a slight tendency to the formation of pipe; (5) great resistance to sliding friction (abrasion); (6) fine dense structure, the structure being unaffected by temperature changes, and (7) a certain amount of ductility, viz.: (0.8 per cent. elongation) is claimed, and in several places it is mentioned that pearlitic cast iron is replacing malleable castings for many parts.

The first six of the above items are abstracted from Professor Bauer's Paper already referred to, whilst the last item will be found mentioned on several occasions in the various articles relative to pearlitic cast iron which have appeared in The Foundry Trade Journal.

Professor Bauer gives a series of test figures obtained on Lanz pearlitic cast iron. The tensile strength and hardness determination converted into English units are given below:—

Tensile Strength.—" A," 22.23 tons per sq. inch. " B " 24.1 tons per sq. inch.

Hardness (Brinell).—" A," 152. " B," 155.

These determinations were obtained on test bars turned from dry sand castings approximately $1\frac{1}{4}$ in. and $1\frac{5}{8}$ in. dia. respectively by $29\frac{1}{2}$ in. long. The composition of the pearlitic cast iron was as follows:—Tot.C. 3.25, Gr. 2.41, C.C. 0.85, Si 1.11, Mn 0.79, S 0.154, and P 0.40 per cent.

These test figures are undoubtedly remarkable, and whilst equally as high strength figures have been often obtained, there is as yet no definite method to be followed which will ensure regularly obtaining such values from test bars of such dimensions. A further striking fact is, that these high tensile strength values are accompanied by a comparatively low Brinell hardness figure.

The highest recorded authoritative value for the tensile strength of cast iron of which the author is aware is that of the synthetically produced cast iron described by Keller.* This cast iron is recorded as having a tensile strength of 50 Kg. per sq/mm. or 31.7 tons per sq. in. Unfortunately, the complete composition of this is not available, but another recorded case is added in Table I. This is a sample of Swedish pig-iron recorded by Dr. Swinden in 1909.

TABLE I.—*Compositions of High Tensile Strengths Cast Iron.*

	"A"	"B"	"C'
Tensile strength	19.2 Tons per sq. in.	31.7 Tons.	24 Tons.
Tot. C. ..	2.60	2.90	3.25
Gr.	2.40	—	2.41
C.C.	0.20	—	0.85
Si.	2.80	1.75	1.11
Mn.	0.60	0.50	0.79
S.	0.15	traces.	0.154
P.	0.50	0.50	0.40

"A"—Swinden, 1909. "B"—Keller, 1919.
"C"—Pearlitic Cast Iron.

The comparative figures given in Table I serve to show the remarkable feature of the high tensile strength of pearlitic cast iron. Contrary to what we should have expected we find that the total carbon contents are quite normal, and in this respect the pearlitic sample differs from the other samples recorded.

In spite of the high tensile strength of the pearlitic sample there are one or two disappointing features in connection with this and also Professor Bauer's comparison of test results. Firstly, it has been shown that the composition of the pearlitic sample is not strictly in accordance with either the Patent Specification or the opinions of the authorities who have written or

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* J. I. S. I., No. 2, 1919.

this subject. The total carbon figure is higher than would have been expected in view of the emphatic declaration on this point above. The same remarks apply to the silicon content, and it is certain that a cast iron of this composition cast into dry sand moulds, into test bars 1¼ in. dia., would not of necessity have had a white fracture. These considerations at once upset our ideas of pearlitic iron gained from the definition which has been made so emphatically by the authorities on this subject.

Professor Bauer's results would have been of much more value and would have given more striking evidence of the value of the pearlitic process if he had published a comparison of the test results on the pearlitic iron cast according to the method of the pearlitic process and the same iron cast in the ordinary way.

Further, these results would have been of far more value than the comparison he gives with other cast irons, the composition of which have nothing in common with the pearlitic sample, nor can they pretend to be typical examples of the best practice in this class of work they are supposed to represent.

In connection with this, the writer turned up the analyses of two different makes of gas-engine cylinder liners. These analyses were made about the end of 1915 from three liners which came under the writer's notice as having given extraordinary satisfaction in life and service in the engine. Samples Nos. 1 and 3 are by the same maker, and sample No. 2 by a different maker. No. 4 is the composition of Bauer's sample of pearlitic cast iron.

The combined carbon contents of No. 1 and No. 2 are not so high as recommended for pearlitic cast iron. Sample No. 3 more closely approaches the composition of Professor Bauer's sample No. 4, and only differs seriously in the sulphur, manganese, and phosphorus contents. Neither the tensile strength or hardness value coincide with those of Professor Bauer's pearlitic cast iron. It is important to bear this difference in mind, and it is proposed to discuss this more fully later. Incidentally, these samples, which were taken from cylinder liners in no case more than 1-in. thick, serve to confirm the fact that

TABLE II.

No.		Tot. C.	C.C.	Gr.	Si.	Mn.	S.	P.	Tensile. Tons.	Brinell.
1.	Mouth End	3.25	0.59	2.66	1.16	0.80	0.072	1.00	17.9	228
	Exp.: End	3.38	0.64	2.74	1.23	0.89	0.071	0.93	—	207
2.	Mouth End	3.39	0.71	2.68	0.96	1.04	0.080	0.93	18.1	228
	Exp.: End	3.32	0.68	2.64	0.93	0.95	0.073	1.18	—	228
3.	Mouth End	3.33	0.87	2.46	0.98	1.10	0.09	0.89	18.25	228
	Exp.: End	3.34	0.90	2.44	0.98	1.13	0.08	0.81	—	228
4.	——	3.25	0.85	2.41	1.11	0.79	0.154	0.40	24	155

such low silicon irons cast in the ordinary way need not necessarily be white irons.

Professor Bauer gives a complete list of the physical properties, including transverse and impact tests, all of which are in keeping with the high tensile strength value recorded above.

The resistance to wear of pearlitic cast iron is claimed to be one of the outstanding properties. In this connection it must always be borne in mind that wear is a relative property, and must strictly be considered in conjunction with the conditions under which the wearing part is operating and with the wearing body itself. Many curious cases of resistance to wear can be quoted in irons which have anything but a pearlitic matrix. In spite of these, however, it is, generally speaking, well known that an all-pearlitic structure is advisable for the best general resistance to wear.

Ductility.

It has already been mentioned that it is claimed to be possible to substitute pearlitic cast iron for malleable castings. This claim must be considered very carefully, and unless this is done it is liable to be a gross misstatement. The high tensile strength results alone would not justify this material replacing malleable castings, and even 0.8 per cent. elongation is hardly sufficient to allow of the claim that pearlitic cast iron is an efficient substitute for malleable castings. It is not certain how the 0.8 per cent. elongation was measured, nor is there available the composition of the sample on which this result was obtained. It is a higher value than generally met with in cast iron, which may be taken as showing an elongation of 0.0131 to 0.0215 in. on 8 in., or 0.163 per cent. and 0.27 per cent. respectively. These values are given by Dr. Unwin.

Chemical Composition.

Two features in the chemical composition of pearlitic cast iron are repeatedly stressed in the writings on this subject. These features are the necessity for a low total carbon and low silicon content. In an article* translated from "Die

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* F. T. J., August 2, 1924, page 96.

Gieserei" it is stated that the total carbon content "must definitely be between 3.0 and 3.1 per cent., and the silicon and manganese contents are specified as being in the region of 1.5 per cent. and between 0.7 per cent. and 0.8 per cent. respectively. It is important to note the emphatic way in which the total carbon content is specified.

Further examples quoted in an article previously referred to give total carbon contents of 3.00 and 2.8 per cent. respectively, and the condition of low total carbon and silicon contents are again pointed out. These latter are low values from regular cupola melting practice, and in this connection the author has been verbally informed that the inventors consider the use of open-hearth furnace melting as desirable, in fact, almost a necessity.

The manganese content is specified in the former case, but from the articles which have been available to the author, he is not sure that sufficient importance has been attached to either this constituent or the phosphorus constituent. Any attempt to secure a constant pearlitic structure amounts to the same thing as attempting to obtain a constant combined carbon. If all other things are equal, any variation of the manganese and phosphorus contents will have an effect on the amount of combined carbon, and consequently the amount of the pearlitic constituent present in the final iron. An increase in both these constituents, other things being equal, tends to lower the amount of combined carbon present. The necessity for specifying the limits of these constituents is at once apparent.

It is also stated, as an advantage of the pearlitic process, that a higher sulphur content can be used without detriment. This is probably quite true, but again it is obviously important that some limits should be specified for particular conditions, otherwise it appears impossible to guarantee the production of a correct all-pearlitic structure.

When these instructions are taken into consideration along with Professor Bauer's experiments on the strength properties, in which test bars were cast of $1\frac{3}{8}$-in. dia., it is somewhat disappointing to find that they hardly appear to comply with the conditions stated in our definition. Our definition appears to be correct, as it is taken direct from Professor Bauer's writings, yet the compositions above specified and actually used by Bauer would certainly be grey when cast in the ordinary manner in test bars 1⅜-in. dia. Cast in a thinner section, say about ¼ in., in a monobloc motor-cylinder casting, it is probable that this composition would have a white fracture, which leads us to one of the serious omissions in the information available of the Diefenthaler process—that is, that the limits of chemical composition have not been specified for the different sections of castings.

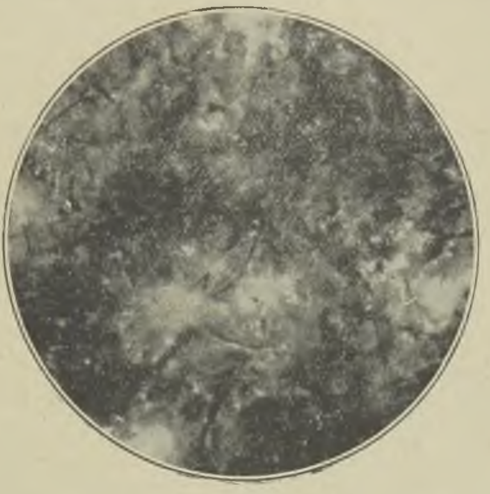

FIG. 1.—CAST IRON HEAT-TREATED, SHOWING PLATES OF PRIMARY GRAPHITE AND NODULES OF SECONDARY GRAPHITE. MAGNIFICATION 100 DIAS. ETCHED HNO_3.

To illustrate this point, if one imagines an exceptionally thick casting, say a roll casting, of some 6 in. thick. If this were cast in the composition mentioned in the Diefenthaler patent, it would follow, if the extrapolation of the temperature thickness of section data in a linear manner is legitimate, that this should be cast in a mould of a temperature somewhat below zero. This is obviously not intended, and the correct procedure would be to adopt new limits of composition for the thicker sections of castings.

Sufficient has been said to illustrate how seriously the lack of essential information and the difficulty of correlating what published data is available, affects us in forming a definite opinion on the nature and advantages of the alleged pearlitic casting process. Before discussing certain general aspects arising out of this discussion, it is of advantage briefly to summarise the position we have arrived at. *Firstly*, the definition of pearlitic cast iron, the product of the pearlitic cast-iron process as designed by Diefenthaler, is perfectly clear, but the examples quoted do not appear to comply strictly with the terms of this definition, or with perfectly clear and ostensibly authoritative instructions given by certain writers on the subject. *Secondly*, it is to be regretted that the perfectly clear and obvious method of demonstrating the advantage of the pearlitic casting process, by comparing the physical test results on the same cast iron before and after the pearlitic casting process has not been adopted, at least in any published writings which have been available to the author.

There are, however, quite a number of points arising out of this discussion which are worthy of consideration, and the writer has selected what appear to him to be the most important to be dealt with here.

The first point which is of immediate importance to foundrymen in general is the fact that the pearlitic cast-iron sample of Professor Bauer's is a high tensile strength iron, and if regularity can be ensured in the production of such high tensile strengths in cast iron by this process, then this process is worthy of very serious attention. A most important additional point is that this high tensile strength is secured with a comparatively low Brinell hardness. Cast iron is very commonly produced to-day by ordinary foundry methods of cupola melting and sand casting, having a tensile strength in the neighbourhood of 20 tons per sq. in. It cannot be said yet, however, that regularity of such results can be guaranteed, in confirmation of which it might be said that no foundryman would agree to a specification embodying a tensile strength of 20 tons per sq. in., particularly when determined on a sand-cast bar of $1\frac{3}{8}$-in. dia. Such results when they are obtained are the direct result of careful attention to a number of details so far as they are known to influence the tensile strength result.

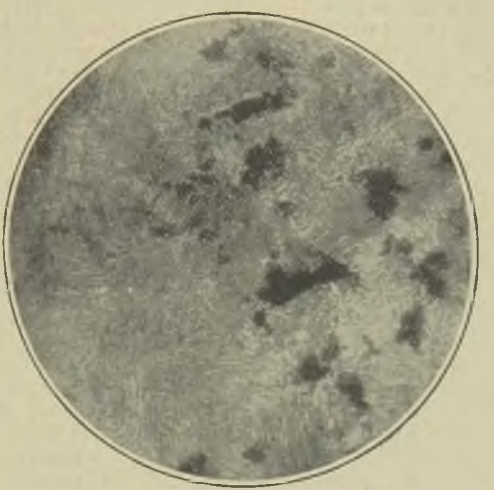

Fig. 2.—Cast Iron Heat-treated, showing Secondary Graphite Formation. Magnification 500 dias. Etched HNO_3.

For example, foundrymen generally commence to lower the silicon, total carbon, and phosphorus contents either individually or as a whole. Special care is taken with the casting temperature within the limits of cupola melting practice, and it should be mentioned that a considerable amount of information is available on the influence of casting temperature both within and outside the range of cupola melting practice. These are now fairly well-known general methods of attacking the problem of producing high-strength cast irons, and as far as is clear to us, the pearlitic casting process uses these general methods, in addition to making an attempt to control the rate of cooling. Whilst, broadly speaking, foundry metallurgists are well aware of the influence of rate of cooling on the constitution of cast iron, none of us has been aware of the fact that the rate of cooling could be modified in the manner proposed in the pearlitic cast-iron process, and for such a modification to be accompanied by such gratifying results.

The inference which should be carefully guarded against is that the superior properties are entirely due to the pearlitic structure and is open to quite a number of objections. In the first place, the writer has quoted a single case already in Table I of an iron having a pearlitic structure giving lower results than the authentic pearlitic cast iron. Other similar cases can be readily quoted, and, conversely, cast irons having quite a large quantity of free ferrite or excess cementite, giving equally as high results as pearlitic cast iron, can be readily quoted, but we may conclude at once that the pearlitic structure is not solely responsible for the high strength figures. The analogy drawn between the strength of cast iron and steel of increasing pearlite content is not legitimate, as the overwhelming influence of free graphite in the mechanical properties of cast iron is well known. The size, quantity, and distribution of the graphite, and, what is not necessarily the same thing, the grain size, are the important features in determining the mechanical strength of any given cast iron, and the writer believes that were the subject of pearlitic cast iron possible of rigid investigation, it would be shown that these were still the controlling factors.

It must not be lost sight of in this connection that, if the definition of pearlitic cast iron is correct, the least thing the inventors of the pearlitic process can do is to obtain a pearlitic structure as being the only structure which could be reasonably machined.

The definition of pearlitic cast iron is particularly intriguing to certain sections of the iron-founding industry. One of these—the motor-car cylinder founder—will surely be interested in the possibility of reducing his silicon content to such a low figure, and still obtain a machinable casting without any apparent increase in his casting difficulties. At the other end of the scale the roll founder and heavy casting manufacturer will be delighted at the possibility of ensuring at least a uniform pearlitic structure throughout the whole cross section of the very heavy castings with which he is called upon to deal.

In the former case at least two other properties in addition to machinability, high tensile strength and good casting qualities are desired. These are resistance to wear and resistance to distortion under heat influences.

Fig. 3.—Head from Large Column Castings. Magnification 84 dias., showing Large Graphite and Crystal Boundaries. Etched HNO_3.

The writer has already indicated the difficulty of discussing the question of resistance to wear. This difficulty is that it cannot be discussed with reference to one component only of the wearing conditions. The writer's present opinion on this subject is that, generally speaking, in engine cylinder practice where cast iron is working in contact with cast iron, the best practice, at least so far as sand castings is concerned, is to use cast iron free from free ferrite and having the smallest grain size. That is to say that an all pearlitic matrix (apart from the phosphide and sulphide constituents) is the best practice.

Further, it is the writer's experience with many cylinder problems of recent years that the lower the silicon content apart from any consideration of the combined carbon or pearlite content, the better the resistance to wear under almost all conditions appertaining in engine cylinder work, internal-combustion engine or otherwise. From these points of view the pearlitic cast iron structure and the underlying features of the Lanz pearlitic cast iron as defined, in the author's opinion, fully justify their claims regarding resistance to wear. Although the writer is not yet in a position to express a really authoritative opinion, it should be pointed out that the low silicon and all pearlitic structure accompanied by the low Brinell hardness, are a set of conditions that might be expected to

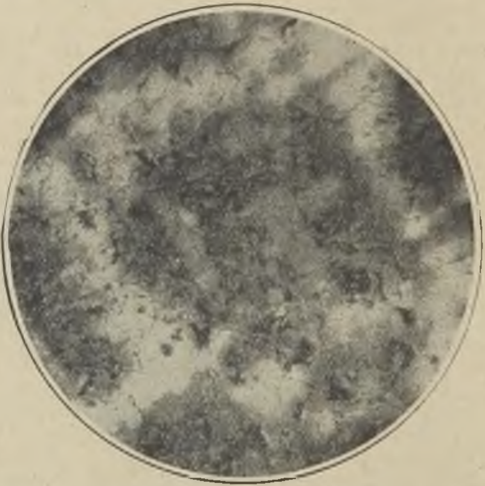

FIG. 4.—LOW PHOSPHORUS CAST IRON. ETCHED STEAD'S REAGENT, SHOWING NETWORK FORMATION OF "THE LAST TO SOLIDIFY" PORTIONS OF THE CAST IRON.

give better results than the same conditions only with a high Brinell hardness.

The distortion of cast iron under heat influences in the engine cylinder is another complex phenomenon, and the writer has already shown that this is in part due to the gradual decomposition of the pearlite constituent yielding free graphite even at the comparatively low temperatures prevailing in engine cylinders.* It was shown here, and has since been confirmed by other investigators (Donaldson) that the lower the silicon content the greater the resistance of the pearlite constituent to decomposition under these circumstances. It is the writer's opinion that a low silicon and all-pearlitic structure such as accompanies pearlitic cast iron are desirable conditions to obtain the best resistance to distortion arising from the above-mentioned causes.

There is now finally to discuss several points arising out of the method adopted by Diefenthaler in obtaining the pearlitic structure. The writer approaches this portion of the subject with considerable diffidence. As already pointed out so much essential data is lacking, and what experimental data the writer has found available leaves one in doubt as to whether the method of casting into heated moulds is really necessary.

Formation of Pearlite.

The pearlite constituent is formed in the pure iron carbon alloys from the solid solution known as austenite, by the resolution of the austenite into a two component constituent—pearlite—at the temperature of the arrest on the cooling curve known as Ar_3—about 760 deg. C. The amount of pearlite formed depends in some manner on the austenite solid solution, and it is easy to see that there are several important differences between the formation of pearlite in cast iron and steel. In steels below 0.9 per cent. carbon the amount of pearlite formed depends upon the amount of combined carbon present or the concentration of the austenite solid solution. Above 0.9 per cent. carbon the amount of pearlite formed is a constant amount, in fact all the matrix of the pure alloys will be pearlite unless the solid solution undergoes

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* J. E. Hurst, "Engineering," July 4, 1919.

any changes in cooling down prior to reaching the temperature of the Ar_3 point, which reduces its concentration to a value below 0.9 per cent. This is what actually happens in commercial cast iron. Long enough before the temperature of the Ar_1 point is reached, in fact at temperatures round about the final solidification temperature, graphite is formed. It does not matter for present purposes how this graphite is formed. It is sufficient to note that if the carbon exists in the cást iron as free graphite at these temperatures it cannot exist in the solid solution. Therefore the solid solution is reduced in concentration according to the amount of graphite formed, and according to the reduction in concentration of the solid solution so the amount of pearlite is affected later on at the temperature of resolution of the solid solution. This at once leads us to the important conclusion that the amount of pearlite in cast iron is governed by the conditions of the formation of the graphite at the range of temperatures at which the graphite is formed, and that any attempt to control the amount of pearlite present is practically the same thing as controlling the amount of graphite present.

In commercial cast iron containing silicon a certain proportion of the graphite present is undoubtedly formed during that period of the cooling between the final solidification temperature and the temperature of the resolution of the solid solution. That is to say, after the principal proportion of the graphite has been formed. The extent of this, which has been called the secondary graphite formation, is governed by the rate of cooling and the amount of silicon present. In low silicon irons with the ordinary rates of cooling in castings the extent of this secondary formation is not large unless the rate of cooling during this range is so slow as to almost be the equivalent of an annealing process. Even in thick castings in which the structure of the central mass is usually one of free ferrite and graphite, the whole of the graphite is principally of the primary formation, and the ferrite graphite structures are the result of the rate of cooling being sufficiently slow at the tempeatures round about the solidification point as to result in practically the whole of the graphite being precipitated at this temperature. The writer is of the opinion that the so-called secondary graphite is not so common as is frequently imagined, which is somewhat contrary to the general views held on this matter. Evidence of the correctness of the writer's view is to be had from the microphotograph Figs. 1 and 2, which show the general appearance of primary and secondary graphite. The secondary graphite in this example has been artificially produced by heat treating the sample. It has the distinct appearance of the free carbon in malleable castings, and is of a type very rarely met with in slow cooled samples from the molten state, an example of which is to be found in Fig. 3. This is a microphotograph of a specimen taken from the centre of a large feeder head on a vertically cast hydraulic ram. This photograph has been kindly loaned to the writer by Mr. J. A. Gardner, chief metallurgist to Glenfield & Kennedy, Limited, Kilmarnock. No evidence of secondary graphite is to be seen but on the contrary huge plates of primary graphite embedded in crystals of ferrite. It

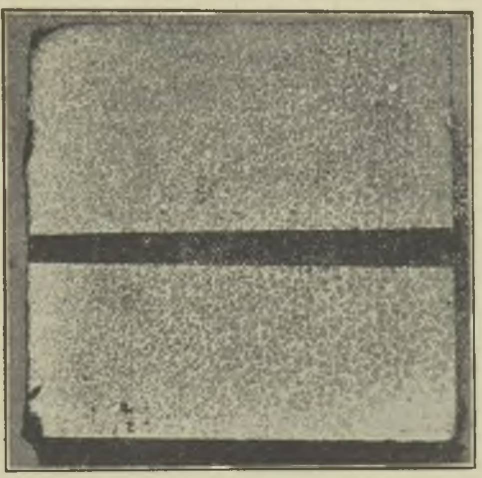

FIG. 5.—NETWORK STRUCTURE OF PHOSPHIDE CONSTITUENT MACROSCOPIC STRUCTURE.

will also be noticed that the composition of the cast iron in this particular case is fairly high in silicon.

Border Line Compositions.

In an iron of a given chemical composition it is a well known fact that the rate of cooling is a vital feature in determining the extent of the graphite formation. The extent of the graphite formation, however, we know from experiment is not a linear function of the rate of cooling over all possible rates of cooling. In any event, other things being equal, there must be a rate of cooling below or above which graphite is or is not formed. In a like manner, other things being equal, and with cast irons of the chemical compositions met with in ordinary practice, it is possible to conceive of certain chemical compositions which would invariably be white irons and others which would be invariably grey irons under the particular conditions. This being the case, there must be an intermediate series of chemical composition which with small variations in the other conditions—principally the rate of cooling—would be either white or grey according to the direction of variation of these conditions. There are, of course, a large number of possible chemical compositions falling within this intermediate zone according to whether these elements, which are known to exert an influence on graphitisation, are considered singly or combined. In this connection something of the order of a critical percentage of certain elements, other features of the chemical composition being equal, and for a given rate of cooling, has long been suspected above or below that which graphitisation is or is not effected.

Traces of such a point are to be found in the standard investigations on the influence of silicon on cast iron. In the classical experiments of Turner* on the influence of silicon, we do not find that the graphite contents gradually increase with increasing silicon content, but we pass a point where a comparatively small increase in silicon content brings about a large increase in the graphite formed. In a like manner in the experiments of Hatfield† — in which much care was taken to ensure that all the conditions of casting were

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* Journal Chem. Soc., Vols. XLVII and XLIX.

† J. I. S. I., No. 2, 1906.

comparable. These experiments were conducted on thinner bars (viz., 1 in. × $\frac{3}{8}$ in.) than in Turner's experiments and a similar point was noticed. In a second series of similar experiments conducted at higher casting temperatures than the former the existence of a similar point was confirmed. A further series of experiments undertaken by Haigh and Turner* show a somewhat similar result.

The figures illustrating this point are abstracted and tabulated below from the various experiments, and show sufficient evidence of the existence of a critical composition, in these cases a percentage of silicon, at which there is a rapid formation of graphite. This percentage of silicon lies between 1.0 and 2.0 per cent. for the particular compositions, and mean rates of cooling conditions in the above experiments.

There are certain further observations which can be made from the above experiments, which are worthy of notice. The first one which was pointed out by Hatfield in the original experiments is that with a higher casting temperature, the critical silicon percentage has a higher value. This is tantamount to saying that with a higher casting temperature there is a tendency for the prevention of graphite formation and the irons would consequently be harder. This was further demonstrated by Hatfield, who showed that in an iron containing 1.10 per cent. silicon the bar cast at a temperature 180 deg. C. higher than the other was mottled white in fracture, whilst the lower casting temperature bar was found to be grey.

The second point to be noticed is that the extent of graphitisation is slightly influenced in these experiments by the total carbon contents, for it will be noticed that with a total carbon content of 2.53 per cent., silicon 1.72 per cent. is necessary to bring about approximately the same condition as 1.96 per cent. brings about in Turner's experiments. It is perhaps hardly fair to compare these experiments in this fashion, and this has been done here only to show that these experiments confirm the general opinion more or less.

It will be quite clear from the definition of pearlitic cast iron that it is intended to belong to the class of irons which have been described as border-

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* J. I. S. I., No. 2, 1910.

line compositions, and we may expect that this being the case it would be extremely sensitive to the effect of the rate of cooling.

Grain Size.

The importance of grain size has only been partially dealt with in the consideration of the strength properties of cast iron. The importance of the graphite size has been fully realised, but it does not appear to be clear that the grain size, apart from the graphite, is of some importance, and is not necessarily in accordance with the graphite size. It appears to be generally imagined that the free graphite in cast iron exists round the crystal boundaries, and a little reflection will show at once that this cannot be strictly correct. If it is assumed that the primary graphite is formed over a range of temperature round about the solidus line, probably partly above and partly below, we at once appreciate that the crystalline structure of the alloy has already been established and the graphite formation is actually an internal change in the crystal grain. It may, however, take place to a sufficiently large extent to break up the crystal grain structure, and in this manner it may be said that the graphite exists round some crystal boundaries. In this case the graphite is existing strictly at the crystal boundaries of its own making due to the rupture of the various crystals in which it is formed. This is clearly shown in Fig. 3 already referred to in which is found the crystals of ferrite with large graphite plates passing through them.

In the majority of commercial samples of cast iron where the structure is a complex mixture of numerous constituents, it has not yet been found possible to show up the crystal boundaries under the microscope. In this connection it is the author's opinion that the now well-known network structure, the significance of which in the strength properties of cast iron was first shown by Cook and Hailstone, is synonymous with the grain size. The actual cause of this network structure of the phosphide constituent has never been satisfactorily explained before. Two illustrations of the network structure are given in Figs. 4 and 5. Fig. 5 is particularly interesting in revealing the segregation of the last to solidify mother liquor in a cast iron containing an extremely small quantity of phosphorus.

The influence of crystal boundaries on the strength properties of metals is well known, and it will be readily appreciated that in cast iron the influence of the crystal boundaries will become more and more predominant as the size and consequently the influence of the graphite is decreased.

The importance of the grain size as independent from the graphite size is not sufficiently well realised, and it is quite an easy state of affairs to imagine cast irons having the same graphite size and different grain sizes and *vice versa.* We have here another peg on which to hang explanations for those frequent anomalies in strength properties which are the bone of contention of many foundrymen.

The grain size is determined at an earlier period of the cooling of cast iron, and within limits is seriously altered by the rate of cooling conditions.

Rate of Cooling.

The object of discussing these features—the composition, structure and the grain size—is to show that they are well known to be fundamentally controlled by the rate of cooling conditions.

The feature of the Lanz pearlitic cast iron process so far as we know it is the use of heated moulds. This feature has the direct result of altering the rate of cooling conditions from those under which cast iron cools when normally cast into sand moulds.

Another difficulty which again presents itself in discussing this aspect of the subject is the lack of any specified casting temperature data. It is impossible to ensure comparable rate of cooling conditions unless this temperature is specified. This is equally as important as the specification of the initial temperature of the mould.

Broadly speaking, if the casting temperatures are maintained as in normal foundry practice, we should expect the provision of heated moulds would retard the mean rate of cooling, and it would appear that Diefenthaler's object of using heated moulds is to secure conditions such that

TABLE III.

Turner's Experiments. J.C.S.				Hatfield. Series " A "				Hatfield. Series " B "				Haigh & Turner.			
Tot. C.	CC.	Gr.	Si.	Tot. C.	CC.	Gr.	Si.	Tot. C.	CC.	Gr.	Si.	Tot. C.	CC.	Gr.	Si.
1.98	1.60	0.38	0.19	2.9	—	trace	0.66	3.00	3.00	trace	1.51	2.71	2.55	0.16	0.03
2.00	1.90	0.10	0.45	2.9	—	,,	0.88	3.00	3.00	,,	1.71	2.61	2.44	0.17	0.23
2.09	1.85	0.24	0.96	2.9	—	,,	0.99	3.00	2.90	0.10	1.73	2.95	2.82	0.13	0.66
2.21	1.71	0.50	1.37	3.0	—	,,	1.10	3.02	2.91	0.11	1.80	2.56	2.33	0.23	0.97
2.18	0.56	1.62	1.96	2.98	2.70	0.28	1.43	2.98	1.78	1.20	1.95	2.70	1.38	1.32	1.19
—	*	—	—	2.95	2.30	0.65	1.68	2.97	1.50	1.47	1.97	2.48	1.19	1.29	1.50
—	—	—	—	2.53	0.6	2.47	1.72	3.12	0.62	2.50	2.05	2.47	0.97	1.50	1.95

* In view of the later work of Haigh and Turner, the degraphitisation in this case may have been due to the increase in manganese content which increased from 0.26 to 0.60 per cent. between the third and the fifth samples.

when casting compositions of the borderline type, it is primarily certain that they are going to be on the soft grey and machinable side of the borderline. This appears to be the most important feature of the process.

Conclusions.

In summing up these notes and considerations it must be borne in mind that the writer's knowledge of the subject is secured from the technical data which has appeared in the Press and which is so scanty as to prohibit any definite statements as to the merits or otherwise of the pearlitic casting process.

The merits of the process would have been demonstrated with more certainty if Professor Bauer had given us the comparative data on his samples before and after treatment by the pearlitic casting process.

In its conception the use of irons of borderline composition and utilising hot moulds to ensure a pearlitic structure, or at least a machinable structure, for a given thickness of casting attracts to the author as a method of obtaining better mechanical properties, particularly in those thin castings in which it is necessary to use a higher silicon content to ensure machinability.

The influence of the pearlitic structure in itself is considerably overstressed, and it is undoubtedly due to the size, arrangement and distribution of the graphite and the crystals that the strength properties are due. The pearlitic structure in itself is undoubtedly a distinct advantage from the point of view of resistance to wear and to certain distortion under heat influences.

Finally, there is no doubt that pearlitic cast iron and the pearlitic casting process, in so far as it complies with the fundamental definition, is a subject worthy of the serious consideration of foundrymen. It is to be hoped that the authorities connected with this material will take an early opportunity of putting before us the plain, simple information necessary to convince us that their actual practice is in accordance with the terms of their definition and to demonstrate conclusively the superior properties which they claim for pearlitic cast iron.

DISCUSSION.

THE BRANCH-PRESIDENT (Mr. V. C. Faulkner), in opening the proceedings, said it was usual to call upon the Secretary to read the minutes of the last meeting, but, unfortunately, Mr. H. G. Sommerfield (the Branch-Secretary) was very ill indeed, and was not at all likely to be able to take any part in the proceedings of the Institute for many months. He (the Branch-President) was sorry to have to give the members this news, but he was sure they would allow him to convey to Mr. Sommerfield their best wishes for his recovery.

Presentation of Diplomas.

Continuing, the Branch-President said that his next duty was a very pleasant one, because it fell to his lot to present diplomas which had been granted by the General Council of the Institute to two members of the Branch. The first was to their Past-President and very good friend, Mr. A. R. Bartlett, for his Paper on "A Day at the Cupola." (Applause.) Mr. Bartlett was the very best friend the Institute had ever had. He must have travelled thousands of miles on their business, especially during the war, when travelling facilities were poor; also, whenever the Branch had been short of a lecturer, Mr. Bartlett had invariably stepped in. In addition to his administrative work, his Papers had been of very definite interest; they were always of a good, practical and technical character.

The diploma was then presented, amid applause.

MR. A. R. BARTLETT expressed his thanks to the Branch-President for his kind remarks, and to the members for the manner in which they had responded to them.

THE BRANCH-PRESIDENT said the second diploma was to Mr. J. W. Gardom, who was an ideal member. The first time he had attended a meeting of the Branch he had made some very constructive remarks, and since then had been one of the very best members. He had read an excellent paper, and at every meeting they could look forward to some remarks from him, which carried the subject under discussion a little further, which they all appreciated.

The diploma was presented to Mr. Gardom, also to the accompaniment of applause from the members.

Mr. Gardom expressed his thanks.

Lanz Pearlitic Cast Iron.

The Branch-President then introduced the lecturer, Mr. Hurst. He (the Branch-President) was responsible for the subject of Mr. Hurst's Paper, which was one of very definite interest to all cast-iron foundry people. The least one could say about it was that, if it did nothing else, it would resurrect the interest of the British foundry trades as to what was the best composition for cast iron, and what was the best test one could expect to get out of it. The members were to be told that evening, he understood, exactly what the Lanz pearlitic cast iron was, and how it differed from the pearlitic cast iron which had been made in this country for a considerable period in large quantities.

The Branch-President, in opening the discussion, said it would be agreed that they had had a most interesting Paper, but, unfortunately, they were still left in the air, inasmuch as Mr. Hurst had been unable to say exactly whether they must regard the Lanz pearlitic cast iron as a serious product or as a quack material. He gathered, however, that, providing certain factors were regulated, then it was a material worthy of the serious attention of foundrymen. Although the moulds were heated up to a certain temperature, apparently the patentees were not taking mass effect into consideration. By that he meant that, if the wall of the mould were only ½ in. thick, it would not have the same effect as if the wall of the mould were 2 in. thick, because the rate of cooling would vary with the thickness of the mould, although it was heated to the same definite temperature. Some of the members of the Branch would remember that, at an exhibition at Olympia, they were taking test pieces of about 1 in. diameter of electrically-melted iron made by Summerson, of Darlington, and those test pieces regularly gave about 19.9 tons per sq. in., so that the figures given for the Lanz product were roughly 4 tons per sq. in. better than the best normal material they could get from British manufacturers.

Continuing, the Branch-President said he had had a note from Mr. J. G. Pearce (director of the British Cast Iron Research Association), who had had to leave the meeting before the conclusion of the lecture. Mr. Pearce had prepared a confidential document, which had been issued to the members of the British Cast Iron Research Association, and, generally speaking, his views coincided fairly well with those of Mr. Hurst, namely, that more information was needed in regard to this material. There seemed to be something in it; everybody agreed that the patentees were proceeding on the right lines, but there were certain factors which were still wanted.

Insufficient Details Available.

Mr. F. A. Melmoth said the lecturer had laid considerable stress on the fact that very little definite information was available, and he agreed that to all intents and purposes our knowledge of the subject was limited to what had been published in the technical Press. He himself was very interested in the constitution of cast iron, and he would like to know whether the lecturer considered there was anything in the following theory bearing on the reasons for the Lanz pearlitic cast iron possessing certain unusual properties. He tentatively suggested that the pearlitic condition in what would be, when normally cooled, a white iron was caused by the retarding action of the hot mould slowing down the cooling to such an extent as to cause the partial or complete decomposition of the normally-formed massive cementite. He would take, for example, a white iron of a composition used for producing American black heart malleable. Its composition was somewhat similar to that mentioned by Mr. Hurst, being, total carbon, about 2.5; silicon, 0.7 to 0.9 (depending on the thickness of the sections required); manganese, 0.3 to 0.4; sulphur, 0.05; and phosphorus, 0.2 per cent. The actual micro-structure of such an iron, if cooled in the ordinary way, would consist of massive cementite in a matrix of pearlite.

In this case, looking at the cooling curve drawn by Mr. Hurst, it would pass through the solidus line, and below that point would form massive cementite, the pearlite being formed at a lower temperature, approximately 760 deg. C., or perhaps a little lower than that. If, however, any retarding influence were placed upon the cooling of that iron, so that it passed through the middle range, say, between 1,150 and 760 deg. C., at a much slower rate, the possible tendency would be towards the decomposition of the already-formed cementite with the production of secondary graphite. Taking the same alloy, and subjecting it to sufficient temperature with quite a short treatment, the result obtained would be a pearlitic structure containing small scattered amounts of graphite.

It appeared possible to him, therefore, that the Lanz process being based on the retarding of the cooling during the period between 1,150 and 760 deg. C., allowed, therefore, a sufficient time for the formed cementite to commence to decompose or entirely decompose. It had been asked by the Branch-President whether the Lanz process was to be considered as a quack process or a something which would become really valuable. Personally, he did not think at the moment that ordinary works conditions could so co-ordinate composition and temperature of mould that such a matter as this could become a definitely practical proposition. As an instance of this, Mr. Melmoth asked how many castings came their way in which one definite thickness of the casting could be relied upon right through. In very many cases they were asked to produce castings which were ¼ in. thick in one place and 2 in. thick in another. In such a case were they to alter the composition for any one part, or the rate of cooling for any one part, or the local heat to which they subjected the moulds? If it were possible to do none of these, would they, with this particular reaction, the possible decomposition of cementite—assuming it to be that—obtain equal structures in the 2-in. and ¼-in. sections? He doubted it. Therefore, it seemed that ordinary foundry practice would only be adapted to the conditions necessary to produce pearlitic cast iron with extreme difficulty.

Old Cannon show Pearlitic Structure.

Mr. Wesley Lambert (Past Branch-President) congratulated Mr. Hurst upon his lecture, in which had been brought out a great deal of matter of considerable interest. When a man could lecture for an hour and a-half on a subject with regard to which he had admitted there was little information available, all would agree that he had done remarkably well. The high tensile figures which Mr. Hurst had given for cast iron reminded him (Mr. Lambert) of a number of thin-wall cannon which were broken up as scrap some thirty years ago. The members would probably have in mind cast-iron cannon with rather thick walls, but in those days there were quite a number of old cannon having comparatively thin walls—anything from 2½ in. at the breech to 1 in. at the muzzle. At the time these cannon were broken up under the steam-hammer, he had secured some pieces for test purposes, and it was not an uncommon occurrence to get round about 20 tons tensile from that cast iron. He had examined the metal under the microscope, and found that it possessed a structure which to-day would be regarded as of a pearlitic character. Mr. Hurst, in the course of his lecture, had spoken of grain size, and that had a very important bearing on the tensile strength of the iron, as also had the character and distribution of the graphite. If large flakes of graphite segregate out, one must not expect to get very high tensile figures. In the particular iron secured thirty years ago which he had examined, the graphite certainly was in a very fine state of division Mr. Hurst had said that graphite does not necessarily follow the boundaries of the crystals. From that it might be gathered that he wished to infer that the graphite was present as a component part of the actual crystals, but he (Mr. Lambert) was not of that opinion. In every instance in which he had examined the metal the graphite was merely entangled amidst the crystals of pearlitic iron which go to make up a grain. One should differentiate between a crystal and a grain. The actual crystals of iron of a pearlitic character contained, so far as he was able to ascertain, no graphite whatever, but amidst the conglomerate of the crystals of pearlitic iron forming a grain, the graphite is found entangled between the boundaries of adjacent crystallites.

With reference to the iron carbon diagram, it should be distinctly understood that it was an iron-carbon diagram. *i.e.*, a diagram of the two elements, iron and carbon. There was no doubt that it could be modified by the other constituents present in cast iron, and, although they looked upon pearlite as requiring 0.89 per cent. combined carbon, it was just possible, and not at all unlikely, that the other elements in commercial cast iron may exert an influence, and that it may be possible to get an almost wholly pearlitic structure, if not a true pearlitic structure with a content of combined carbon of less than 0.89 per cent. He regarded the iron-carbon diagram in much the same way as he did the ordinary copper-zinc diagram. There were certain co-efficients for use when other elements were introduced into a copper-zinc mixing in the making of the complex brasses, and by a series of simple calculations the modification in the micro-structure caused by the introduction of such elements can be anticipated. He believed that in course of time the full influence will become known of the other elements additional to the essential iron plus carbon constituents of commercial cast iron. The iron-carbon diagram will be further elaborated, and the manufacture of commercial pearlitic cast iron may possibly be arrived at in more ways than one.

Commercial Aspect of Pearlitic Cast Iron.

Mr. J. A. Smeeton (a visitor) said that Mr. Hurst had spoken in a most enlightening manner for an hour and a half on a modicum of information which he had said he had gathered from an ancient patent and various articles in technical journals. The Diefenthaler patent, said Mr. Smeeton, was somewhat old, and, since Diefenthaler had joined the Lanz Company, that Company had spent many years on experiment and research. He was informed that, as a result, there were three later patents, the provisional applications for which were passing through the Patent Office, and would be published shortly. They would probably throw a great deal of light upon the methods by which the Lanz Company claimed to produce consistently pearlitic structure castings. He himself was only interested in the production of pearlitic castings from the point of view of giving English foundries something which would enable them to turn out a superior product, with more lasting efficiencies, and he was of opinion that, considering the lack of available knowledge of the Lanz process, it could only be assumed, from the fact that the Lanz Company were selling licences to some of the most important foundries in Europe and other parts of the world, that they must have arrived at something more or less definite. Mr. Hurst had mentioned that there was no data given in regard to the pouring temperatures of metals, or the degree of heat which must be applied to moulds for castings with walls of variable thickness, or any definite information with regard to the cooling-down period. He (Mr. Smeeton) believed they would find, when they inquired further into the Lanz process—which, after all, appeared to be a defined method of producing consistently pearlitic structure castings—that all these factors had actually been arrived at, and that the information would be placed at the disposal of founders who were seriously inquiring into the methods of manufacture; any founder who was sufficiently interested to become a licensee of the Lanz process would have all this information placed at his disposal, so that he would be able to manufacture these castings, which, apparently, had some advantage. Recently, said Mr. Smeeton, he had made a tour of England, and, wherever he went, he had the claims of this Lanz pearlitic iron process thrown at him for discussion. He had happened to become associated with the Lanz process—knowing nothing at all about cast iron or foundry work generally, and being a mechanical engineer of certain ability—and he was accused of trying to force on the market some process which was going to upset everyone's existing ideas and practice; he was threatened with all sorts of dire punishment for endeavouring to tread on the corns of investigators in this country, though there was no reason for him to be accused of doing anything of the sort. His view of the position was this: Had the Lanz Company obtained a patent which was of value? Did their patent enable any individual foundryman to produce a casting which was superior to a normal casting, which would economise machining costs, which would give a higher tensile strength, some ductility, and all the other advantages claimed by the Lanz concern for castings produced by their method? Apparently the Company had been able to convince some 18 of the most important engine builders and other specialised manufacturers in Europe. They had not yet convinced anyone in England, although recently quite a number of foundrymen had been in Germany investigating the process, and their reports would eventually be published, if not to the public, at least to their boards of directors. To set his (Mr. Smeeton's) mind at rest, he had thought the best thing to do was to ask the Branch-President (Mr. Faulkner) to go to the Continent personally to investigate the question, not only in the Lanz works, but in the works of some of the most important licensees. Then he would perhaps be able to say whether the Lanz process was quack, as mentioned, or whether it was real. Mr. Smeeton suggested that, considering the small amount of real practical knowledge available, they should leave the matter over until the Branch-President was in a position to address the members of the Branch and place before them the results of his investigations, and his real opinion as to whether the claims of the Lanz Company were justified, and whether the process was of any value to them all, as foundrymen and engineers interested in the economic production of high-class castings.

Heat Treatment of Moulds not New.

Mr. A. R. Bartlett (Past Branch-President) spoke of the difficulty of getting a mould to such a temperature that would give an even rate of cooling over the whole mass of a casting, through the thickness of the casting being varied. It was quite common practice, he believed—at any rate, it was so far as he was concerned—to make test bars in a dry-sand mould, and to keep that mould in the stove until the last moment of cooling. The metal was cast as hot as they could get it, and, after casting, the mould was taken back to the stove and left until it was practically cold. Under those circumstances, it seemed to him that the Lanz process was somewhat the same as that followed in order to fake the test bars. (Laughter.) It was not a true reading of what the actual casting would be. As to the analysis given by Professor Bauer, he (Mr. Bartlett) would take that to be quite a good analysis for the heavy type of cylinder casting, and the figures Mr. Hurst had given corroborated that.

Cost of Process.

Mr. H. O. Slater (Past Branch-President) said that he looked at the matter from the practical point of view, as had Mr. Bartlett, and it seemed that the lecturer had dealt with it rather from the scientific aspect. With regard to the heating of the mould to a particular temperature to suit a particular section, this would be, in his opinion, a very costly proposition.

The Branch-President said it increased the cost by 15 per cent., according to the German investigators.

Mr. Slater pointed out that it would be rather difficult to heat a fair-size loam mould to a particular temperature, and it would be an expensive operation. It all came back to the question of annealing. He had in mind some small boxes made for electrical apparatus. When cast in ordinary iron it certainly solidified much whiter than they had anticipated. They thought it best to follow common practice and put them in a muffle, cover them with sand, and anneal them for a few hours on similar lines as they would malleable iron, only in sand instead of iron ore; that was successful. He believed the German process was not altogether new, because many old foundrymen knew the value of annealing or holding back the cooling of iron, in order to get a soft and ductile machining iron. Were pearlitic cast-iron castings made by this process sand cast, or cast in a permanent mould or chill?

Mr. Smeeton said they could be cast in any form.

Mr. Slater, although he reiterated his point that the heating of a mould to a particular temperature involved considerable expense, agreed that if the material would do all that the patentees claimed for it, it would be very acceptable to the motor industry; he himself, as an amateur motorist, would very much appreciate a better cylinder.

Low-Silicon Iron.

Mr. J. W. Gardom, after commenting on the instructive nature of the lecture, said that he was particularly interested in low-silicon iron. Without considering, at the moment, whether or not it was possible to produce iron with the properties mentioned by Mr. Hurst by means of the Lanz process—though really he believed it was possible—he could not see that it was going to be a commercial proposition. In his own particular class of work he had produced grey iron, or what should have been grey, but which had turned out white iron, and that was rather trying. With a normal composition iron, with 2½ per cent. silicon, in a section 1-in. thick, he had obtained white iron. Another, containing 1 per cent. of silicon, turned out to be mottled. That sort of thing was very trying, and made them wonder whether it would be commercially possible to bring all the varying factors down to such fine limits as to enable them to produce exactly what they wanted every time. He knew, for instance, that given an iron containing 3 per cent. total carbon, 1 per cent. silicon, 0.7 per cent. manganese, and 0.1 per cent. sulphur, if they raised the sulphur content from 0.1 to 0.15 per cent. they could get a serious variation in the appearance of the castings, though they were of the same size. It was possible, in an ordinary sand casting, with a 1-in. section, to produce a mottled effect, and, in a 2½ per cent. silicon iron—the ordinary grey iron—by taking it to a temperature of about 920 deg. and quenching it in water, they produced, of course, a white iron; by annealing that for from half an hour to an hour above 700 deg. they produced an almost entirely pearlitic iron. They usually found many cracks in it, however, and, if they did produce pearlitic iron, they were bound to get that result. Pearlite would naturally give a higher tensile strength, greater resistance to wear, etc., but he considered that the difficulties to be overcome were almost insurmountable.

Mr. Wesley Lambert, referring again to the old cannon he had mentioned previously, said that pictures showing the method by which they were cast were in existence. Iron moulds, presumably lined with a thin coating of loam, were employed, and a wood fire was lighted around the outside of the mould to make it hot at the time the metal was being poured.

THE AUTHOR'S REPLY.

Mr. Hurst expressed gratification at the lengthy discussion his Paper had provoked. Dealing with the matter generally (as he understood it) he said that the position in regard to pearlitic cast iron at the present time was that the definition given by Prof. Bauer—the definition as laid out in the only existing patent specification of the Lanz process, was an extremely good one, and was of considerable interest to foundrymen, as offering a possibility of getting, in many cases, a better iron than they are able to produce at present. Whether pearlitic cast iron would be universally applicable to all types, shapes, sizes and conditions of casting was another matter. If reference were made to Prof. Bauer's Paper, and to some of the other articles published with regard to pearlitic cast iron, it would be found that there was a tendency to adhere strictly to cylindrical castings, such as cylinder liners and piston ring drums. If they considered the matter from the point of view of the making of cylindrical castings, many difficulties would be overcome, and Mr. Hurst considered it a mistake to endeavour to interpret the definition in the terms of all the shapes, sizes and conditions of casting that occurred in modern practice. He did not think Lanz would like to claim that. The only point was that, so far as the information derived from the published patent specification and published articles went, the definition itself held out promises of an extremely useful invention. The unfortunate part was that none of the examples quoted up to the present time complied strictly with the terms of the definition itself held out promises of an extremely useall in. Where were they? When the examples of Prof. Bauer—an authority on cast iron in Germany—did not comply strictly with the definition, and when he avoided (whether intentionally or otherwise Mr. Hurst did not know) the direct issue of comparing his iron, cast by pearlitic method and cast normally, it made it extremely difficult for them to consider the subject of pearlitic cast iron, and to attach any importance to it. None of them was asking the inventors to give any information which was of commercial value, and which they would, naturally, expect to be paid for; all they asked for was information which would enable them to gauge the value of the pearlitic process. That information could be supplied quite easily, and he (Mr. Hurst) suggested to Mr. Smeeton—who was, he understood, a representative of the Lanz process in this country—that he should urge his principals to give the results of tests on a $1\frac{3}{8}$ in. dia. test bar, cast according to the pearlitic method and according to ordinary sand-casting methods.

Mr. Smeeton pointed out that the Branch-President would be able to do that when in Germany.

Mr. Hurst said that would prove conclusively whether or not there was any merit in the process. The question was quite capable of simple proof, and it would set their minds at rest at once. If the Branch-President were satisfied that the results claimed could be regularly obtained, then that would at once demonstrate the commercial value of the process.

Dealing with Mr. Melmoth's suggestion as to what he considered were the features underlying the pearlitic cast iron process, Mr. Hurst pointed out, in the first place, that Mr. Melmoth mentioned a silicon content, which was lower than those mentioned in any of the writings connected with pearlitic cast iron. Mr. Melmoth had mentioned 0.7 and 0.9 per cent. silicon contents with which the difficulty of getting graphite in the structure with any normal rate of cooling, as apart from annealing, was well known. From what he (Mr. Hurst) could gather, after reading the published matter on pearlitic cast iron, the rate of cooling was not very much longer than it would be in normal grey iron foundry practice. In any case, there was no semblance of any annealing, except in the alternative methods which were suggested, but which were not described. Secondly, if Mr. Melmoth would refer to the micro-photographs in Prof. Bauer's Paper, he would see at once that the free carbon deposited in pearlitic cast iron was not of the type which would have been expected from the secondary formation of graphite during an annealing process. That would be of the type similar to that which appeared in micro-photographs of malleable castings. In Prof. Bauer's photographs large flakes of graphite, indicating that it was a primary graphite formation were to be seen.

Pearlitic Structure to be where most Needed.

Mr. Hurst, replying to the Branch-President, said that the mass of sand would not have very much influence on the process; the sand had such an extremely low thermal conductivity that the difference between $\frac{1}{2}$ in. and 2 in. thickness of sand, in the time taken to produce the casting, would have very little effect indeed, providing it was all at a constant temperature, which, presumably, Lanz desired. He believed the Branch-President had in mind a motor car cylinder, with a cylinder wall, say, $\frac{1}{4}$ in. thick and a holding-down flange about 1 in. thick. If Lanz desired a temperature of 200 deg. C. for his mould wall in one place, then, if they adhered strictly to the patent, they would expect a mould wall temperature of 100 deg. C. in another place. The practical difficulties of getting those differences of temperature in one sand mould were enormous, and he did not think Lanz seriously intended that there should be any attempt to do that. In considering a motor car cylinder he would probably reason that the most important part of the cylinder was the cylinder wall, and that was where the high resistance to wear was wanted. Therefore, if the conditions obtained were such that they had an all-pearlitic structure in the cylinder wall, that was as much as could be expected practically. Thus, he would arrange his average mould temperature at 200 deg. C. Whether he obtained an all pearlitic structure in the flange did not matter to him very much. That, after all, was not so very different from the line of reasoning in ordinary foundry practice. They would say, for instance, that in a $\frac{1}{4}$-in. section it would be necessary to have a silicon content of 2.5 per cent., and that in a 1-in. section a silicon content of 1.75 per cent. But they could not do that in practice, of course, so they adopted for the whole casting, a silicon content of 2 per cent., that is the proper silicon content to ensure a good cylinder wall, regardless of what happened to the flange.

A Voice: Or chill it.

Mr. Hurst replied that even chilling was not so generally resorted to as all that. However, in all fairness, they should not attribute too wide a scope to the pearlitic process, and that was why he had refrained from dealing with mass effect. Incidentally, there had been no suggestion of it in any of the writings, and that was another point on which the patentees might easily have been more clear without disclosing any essential information.

Crystals and Grains.

Coming to Mr. Lambert's remarks, Mr. Hurst said he disagreed strongly as to the position of the graphite in the crystal boundaries, as suggested by Mr. Lambert. It was impossible for the graphite to exist at the crystal boundaries, unless they adopted Mr. Adamson's theories that it existed in the free state in molten iron, which he could assure them it did not. There was no free graphite in molten iron. If Mr. Lambert would reflect that the crystal boundaries were formed long before the graphite was formed, then how was it possible for the latter to exist at the crystal boundaries? He was afraid Mr. Lambert could not produce any evidence of crystal boundaries in cast iron unless in a sample of a slowly-cooled cast iron in which the whole matrix was ferrite. In such a sample the boundaries could be shown by etching. He (Mr. Hurst) suggested that the reason they could not show the crystal boundaries was because they were all hidden by the phosphide eutectic, and that was the constituent which segregated out at the crystal boundaries. The manner in which the last portions of the liquid metal to solidify occupy a position at the crystal boundaries will be found described in any text book. Those last portions were the phosphide eutectic. Therefore, he suggested that Mr. Cook's network structure was the same thing as the crystal structure.

Mr. Lambert: Are you speaking of " crystals " or " grains "?

Mr. Hurst: They are one and the same thing.

Mr. Lambert: I am afraid I cannot agree.

Mr. Hurst said that Mr. Cook's network structure was all round the crystal boundaries, and the graphite was in the midst of it.

Mr. Lambert said he had a single grain, about 2¾ in. in dia., which had been examined by Prof. Desch, who had confirmed that it was a single grain, because the crystals in that grain had the same orientation throughout. They must differentiate between crystallites and the grain. He believed the graphite occurred round the grains, and not in the individual crystals that went to build up the grain.

Mr. Hurst replied that the graphite did not occur round the grain. It was a fundamental property of crystals that they could be broken up into an indefinite number of smaller crystals, all of which had the true habit of the original crystal from which they were broken up. If graphite existed inside that crystal grain, it must, of necessity, exist around the boundaries of those tiny cleavage planes which, when broken up, constituted the smaller crystals.

Mr. Lambert agreed.

Mr. Hurst continued that the graphite did not exist round the crystal grain formed during the solidification of the cast iron, but inside the crystal grain. He had taken the trouble to make the point clear because, so far as he knew, it never had been made clear.

Internal Chill Castings.

Replying to Mr. Gardom's question as to why an iron was white at one time and grey at another, Mr. Hurst said that in an article in The Foundry Trade Journal for February 1, 1923, page 85, he would find a very plausible explanation. The title of the article was "Internal Chill in Castings." To deal with the matter properly would require another Paper. It all depended on a true conception of the rate of cooling, which was set forth in the article referred to. Whilst it did not deal with the specific point raised by Mr. Gardom, the whole of the underlying theory was outlined.

Finally, Mr. Hurst said they would all be delighted if the Branch-President, when in Germany, could persuade the authorities connected with pearlitic cast iron to demonstrate its value by the very simple test already indicated. The results of such a test would enable them at once to conclude whether pearlitic cast iron was a material worth their consideration or whether it was not.

Vote of Thanks.

Mr. Shillitoe, in proposing a vote of thanks to Mr. Hurst for his Paper, said that the discussion had reminded him of the tests carried out in 1910 by Mr. Neufang, of the Gasmotoren Fabrik Deutz, Cologne, and Diefenthaler, before a patent was thought of. They were working with raw material which was a re-melt of pig-iron and steel made in a small Siemens furnace, and which had an analysis practically the same as that used by Prof. Bauer.

Mr. J. Ellis (Past-President) seconded the vote of thanks, which was cordially accorded.

Lancashire Branch.

MODERN PATTERN MAKING.

By J. A. Stevenson.

In the preparation of this Paper it is not the intention to set up a theoretical idea in respect to pattern construction, but to give in a most concise manner the experience gained by the reader in general engineering. There is no branch in connection with the engineering industry which offers such attractive attention, or exercises the mental power or perspective faculty as does the building of a pattern, the more difficult and intricate the better.

It is in the pattern shop that the part to be constructed assumes the correct form, and always gives the precise outline, which in many instances is not easily or readily seen on the print, and presents to the designer the opportunity to remedy or modify any imperfection in detail not apparent on his drawing.

The advance made in general engineering and machine construction has also made itself noticeable in the pattern room, and a wide gulf exists between present-day pattern-making and that of, say, 40 years ago, but not in respect to make any allusion to ability.

Rapid production in the first place has brought about the sectionalising of trades, and also compelled the introduction of labour-saving machinery. New and more modern plant has enabled the patternmaker to produce many things his forefathers never had occasion to think about, and the new order has made demands for patterns of much greater intricacy, calling for higher skill and greater ingenuity on the part of the department. It is recent history to many readers that when serving their apprenticeship the only tools to be found in the pattern room were a very decrepit circular saw (no band saw or planer), and a lathe in similar condition, and the employer in those days considered these the only tools necessary for the production of his patterns.

To-day no pattern shop worthy of the name is complete without up-to-date wood-working machinery; good planers, saws of various types, practical pattern-making machines, and the indispensable sand-paperer.

These have made all the difference between what in the past obtained and that which is in vogue to-day; the trade has been improved beyond conception, and gives a production vastly in excess of that which previously obtained.

Pattern-making is generally considerd a somewhat expensive trade, principally on account of the cost of material, but probably more so from the fact that the pattern bears no share in the profits of the completed machine or part, other than that it gave it form.

Because of the cost, it is necessary to construct on the cheapest possible lines, except when making a standard pattern for repetition work, when the very best in material and labour must be put in, which ultimately would also prove to be the cheapest. For the purpose of reaching a common understanding in respect to the acceptance of cheaper patterns, it becomes necessary to have frequent consultations with the foundry.

There never was a time when close touch with the foundry was more necessary than the present, because of the intricacies, sub-dividing and coring are such to-day, which make it advisable for the patternmaker to consult with the moulding department, so that the best results be obtained.

Personal experience has proved that many economies are effected thereby, and, in addition, a better feeling results. The two sections are so interdependent that it is imperative this feeling should exist if good results are to obtain. For instance, suppose a job of the breakdown character comes along, and assume it is a part not likely to be repeated in the near future, no one would consider it justifiable to construct anything other than that which would economically produce the casting required. It is in cases where one or only a few castings are required that the patternmaker has to use that judgment in the construction of his pattern which will make it a profitable one, and yet give satisfaction to the moulder.

This in a large number of cases is a most difficult problem, because of the inborn desire and pride on the part of the patternmaker to produce a high-class job, and who cannot see how futile it is, from a productive standpoint, for the pattern to cost as much, and, in some instances, more than the value of the casting.

Of course, cases arise where the cheapening is almost an impossibilty, but these are the exceptions, and in dealing only with the general aspect of pattern-making they will be ignored.

Plate Patterns.

Many and varied methods of pattern construction are in vogue to-day, and for multiple production of repetition work the plate is the recognised method. Each foundry foreman considers the type under his supervision the best and simplest, consequently this point must be left for the moulder.

There are many firms who do not possess a machine and still resort to the old method of plate moulding by hand, with very satisfactory results. Where the draw is not so fine this could very easily obtain, but in making moulds with very straight and numerous sides, such as spur gears of very fine pitches, the machine cannot be supplanted.

Patterns for Oil-Sand Cores.

The author has within the past two years had occasion, in order to cheapen the ultimate cost of production, to resort to, which for the want of a better name, is known as the sectional-core mould method. As an illustration, a bearing bracket of the ring-oiling variety, and used universally on motor-driven pumps having a centrifugal action, can be cited. It is half-cylindrical in form, with an overhung flanged base and joint, with various preparations on the circular body. To have constructed it in the usual way, the joint flanges, where overhung, would have had to be left loose, as also would the preparations on the body, which in all probability would have necessitated the use of a middle part. On one end only was there freedom of draw. The nuisance of loose pieces, with the possibility of getting out of position, is well known, and in this case the centres were so fine and the bosses so small in diameter and well projecting, that the risk was increased. Instead of so doing, a master block was made, which acted as a pattern of the mould, elongated in shape, with a margin of 2½ in. in excess of the casting on each of the four sides, but correct to size in depth. Upon this block, top and bottom, were placed all the necessary shapes, prints for internal cores, and facings. Next the design was split up into four sections, and each placed in its special core box. These cores, when dried, were placed in position in the mould, and gave a perfect outline of the casting required. The cores, made in oil sand, were quickly produced; in fact, the whole of the cores, including the internal cores, were made in 1½ hours, and the whole job completed and ready for the metal in under 6 hours. This job under ordinary circumstances could not have been moulded under 12 hours. The cost of patternmaking was slightly higher, the moulding considerably lower, and considering that the bracket is a standard pattern and will constantly be in use for its own size of pump, the author feels satisfied that a simple yet sound method has been adopted. This casting weighs with the cap exactly 1 cwt. This method has been adopted for much larger and heavier castings, save that the oil sand was replaced by ordinary core sand.

The author has introduced what many would consider freak methods of moulding since more generally adopting oil-sand cores. Quite a number of patterns have been prepared that eliminate the need for a top or any other box part.

Flanged Couplings.

Take, for instance, an ordinary flanged coupling. Here the pattern was turned on an overhung circular print with taper sides. A core box was built up and turned to correspond exactly with the print. All necessary facings, which ordinarily would have been on the pattern, were placed in the box along with the guide print for centre core and also the gates. The pattern was moulded in the floor, and, after blocking and centre coring, the mould was closed by the covering core, and when weighted, was ready for the metal. This was usually a boy's job, and he could give from this method a very satisfactory output—many more per day than if the usual box-ramming method had been in operation. Again, where the job has been convenient, the pattern has been placed in a core box, and covered with another core made to fit and containing the gate. This, when closed, is put in floor, rammed round, and cast.

Ring-Oiling Pedestals.

A very neat and serviceable ring-oiling pedestal is being made on a Ronceray machine, which is so well known as not to require description. The patterns of body, cap and steps are first made in wood, and afterwards cast in white metal, and fixed with the necessary stripping plates to suit the mechanism. The core for the pedestal body is most intricate, and entirely self-contained. It consists of two cradles for the reception of the brass bearing, which are tunnelled for the passage of the oil from one end, well to the other, and also contains preparations for the Tee-headed cap-bolts.

This box is made in hardwood. First, an outside shell with the bottom attached is prepared so as to give an allowance of $\frac{3}{4}$-in. taper on each of the four sides. The internal parts are prepared in sections, with abnormal positive and negative taper for draw. These are then secured to two pieces running lengthwise of the box and which take out all unnecessary box-taper, after which the completed internal parts are cut in two for drawing-off purposes.

After the core has been made, it is turned over on a specially-prepared perforated plate. The outside shell is lifted off, then the sides are drawn away, leaving a most perfect oil-sand core, which takes less than five minutes to make.

This is one of the most perfect core boxes the author has yet made, because of its simplicity and the saving of time owing to elimination of loose and separate bolt and drain cores.

Pinion Housings.

The call for cheaper production has introduced to the trade methods which would not have received a moment's consideration years ago, and there not being that beauty of outline to display as upon a finished pattern, the uninitiated naturally assume that little skill is required. Considerable thought and ingenuity is very often brought to bear when constructing some large pattern for a heavy and important casting with just a frame, as, for instance, the construction of a pinion housing for rolling-mill plant. These are usually built up in four parts; the lower or base part frequently weighs more than 20 tons.

This portion is a rectangular casting having its two ends set at 90 deg. and the sides tapering off from a 4-in. deep facing at top at an angle of approximately 30 deg. to a 8-in. deep base, with the necessary radius where the lines bisect. There are, in addition, four large taper bosses for holding-down purposes on each side, and run the full depth, which often reach 3 ft.

The frame for this is made correct to length and depth, so that all the necessary prints and facings can be placed in position. The width is made 12-in. wider in order that the outside cores can have substantial support at the edge. All that is now necessary to form the mould is one outside box, designed to the correct shape, with two bosses attached, which make the cores for opposite ends, and after adjustment by the pattern-maker, the box is ready for the two remaining cores. When dried and inserted along the sides of the mould, they are tried up for size, and, after securing, the necessary hollowing is done preparatory to drying the mould. The internal coring is done in just the ordinary way as would have obtained if the pattern had been a shaped one. The saving in pattern-making alone is considerable, for instead of a full-shaped pattern with eight expensive bosses attached, there were only prepared a frame and one core box with two bosses attached to make the completed mould. This was completed in less time than would have obtained under ordinary circumstances.

Moulds of base plates, 23 ft. long, 10 ft. wide, and 20 in. deep, have been made with a simple frame pattern. In this case one is compelled to camber the sides owing to the excessive length and section. Being a box section divided into 30 compartments, it was cast plate down with the cores bolted to top part. At first, doubt existed as to the necessity of cambering the job, because it was thought six sides 23 ft. long and 18 in. deep would be sufficient to keep the casting straight. After due consideration, an allowance of $1\frac{3}{4}$ in. was made, which proved to be correct, for the casting was comparatively straight.

Pipe Patterns.

In general engineering shops, and indeed, jobbing shops also, the cost of preparing pipe-patterns is an all-important one. Most engine pipe ranges have quite a number of special shaped pipes, which require special treatment, and unless some cheap method of preparation is adopted, much labour may be spent upon their construction.

For all pipes not convenient to be made in skeleton form, the loam pattern is found to be expeditious, satisfactory, and cheap. The core is formed, if not for a straight pipe, on a couple of plates, and, when dry, jointed and trimmed off. Afterwards the thickness representing the metal is put on, and again dried off, after which it is ready to receive either flanges, socket ends, or other preparation. These, when placed in position, give a pattern in loam complete in every detail. Both S and bend pipes up to 26-in. bore for socket end and flange have been made by this method and found to be satisfactory. The full pattern correct to shape is, of course, most desirable, but these special circumstances constantly arise, and must receive special treatment.

If the pipe under treatment is of small bore, the jointed plate with semi-circular pieces to make up the circle of the diameter placed on each side is very accommodating. These pieces need not be placed too closely together, and can either be filled by the moulder with black sand or left as they are. The moulder gets an excellent outline, and readily cleans out all unnecessary sand.

This is a far better method than the putting on and stopping off process, which not only entails risk of bad jointing, with its weakening effect on the casting, but gives very little satisfaction to the moulder for his labour. The pipe core is always made from the plate, if not straight, and on the barrel if so. Unless the pipe be of very small bore, or in frequent demand, a core box is unnecessary.

Grooved Rope Pulleys.

Another and important point for consideration is the manufacture of grooved rope pulleys. For pulleys up to, say, 48-in. dia. and with a groove to accommodate from one to six ropes of from 1 in. to 1⅛ in. dia., no system has been found so expeditious as the using of a belt pulley rim to form the inside diameter. This is placed in position and levelled, with top of rim representing top of casting. It is rammed inside sufficiently deeply to centre the loose S arms and outside to the joint. After the arms have been secured and jointed, it is rammed up with the lifting plates in exactly similar manner to an ordinary belt pulley. After removing the top part and lifting out the centre portion to liberate arms and, of course, to finish, the outside is strickled down to the necessary depth for reception of groove cores. These are made correct in depth and segmented in length. After finishing, they are inserted and securely rammed on the back side, thus completing the mould, which is then ready for closing.

If the pulleys are of a larger and heavier type, say from 6 to 20 ft. dia., and with a groove width to accommodate up to 25 ropes of 1¾-in. dia., a different method of necessity is resorted to. The groove cores are made in exactly the same manner as smaller pulleys, but the arms are prepared in core form, divided on the centre, so that two cores form the mould of one arm.

They are made in a parallel box sufficiently wide to take in the web of the centre boss. Between these cores, when laid out in position, are put what are termed inside cores, which complete the continuity of the circle of the pulley, if cast in one piece, or half-circle if in two parts.

These pulleys are built up entirely in core-form from a struck bed, and covered either with a plate, loam-daubed, or a rammed top-part. If the pulley is to be in two parts and not larger, say, than 10 ft. dia., the two parts are made at one and the same time, by the use of an elliptical bracket on the spindle, which gives a throw on either side of 2 in., enabling the insertion of a 3½-in. parting core. This, of course, entirely divides the mould, and yet gives the necessary machining on each joint.

Large Fly Wheels.

Large fly wheels have been made upon similar lines, though these, owing to their size and weight, were made in separate quarters, each of which weighs approximately 32 tons. Belt pulleys are made under conditions very similar in every shop, large quantities of standard sizes being manufactured on the machine. Still many shops are without such an apparatus, consequently resort to the only alternative of hand moulding.

Weaving-Shed Pulleys.

For the manufacture of small weaving-shed pulleys of from 11- to 14-in. dia. the adoption of an old method (the turnover plate), but slightly improved, is very satisfactory. For this a base or ramming table is prepared, and in its centre is secured a circular piece, fitting easily in the rim of pulley and deep enough to meet the centre of the arms. Upon this, again, are placed four pieces shaped and tapered with a guide peg to fit inside the arms, with sufficient allowance all round to represent the lifting plate. The box is placed in position on the table, and when rammed made the top joint, and also inside joint to centre of arms. The lifting plates are actually cast from the patterns on the central block, and thus there is the satisfaction of knowing they will drop into the impression to receive them without difficulty. This method has proved ideal for production, and has much simplified the work in foundry. Circular work is produced whenever possible with the use of the strickle board. Personally, the author prefers, where practicable, the jointed box as used in connection with machine-moulded wheels for the making of a circular mould. It gives a better outline than if the top part was rammed from a negative, and also in the case of urgency the use of the two parts at the same time. In the event of castings requiring additions, such as feet, bosses or flanges, which are undercut, the difficulty is overcome by inserting a block or blocks in the required position and putting on the addition in core form.

The pulley rim, as a handy method, is useful and economical in many instances, and frequently gives all the outline necessary, in such cases as block pistons for engine work and many other straight-faced circular castings.

Importance of the Strickle.

Many expensive and delicate castings are thus made with the strickle board. The cost of patternmaking is lower, probably moulding a little higher in some instances, but there is certainly a net gain on the job.

There are many who would consider the placing of any addition on a strickled surface rather risky and inaccurate; but within personal experience the work produced has been as accurate and satisfactory as though it had been fixed upon a solid pattern.

Whilst many complete circular patterns are made, which, on account of size and quantity of, are found to be more convenient, there are many castings of a larger type, even though of a standard character, which are, apart from the temporary ones, made with strickles.

Cores, also, in many cases can be made for circular work by the use of the strickle, and various methods are used. Some cores of rather an ornamental character are made with the strickle, worked from a wood central pillar attached to the base board, and frequently is the evergreen pulley-rim called upon to do the work in the case of emergency. These methods make a great saving in the cost of core boxes, and produce work equally good.

Loam Moulds for Engine Cylinders.

Many firms who produce loam castings in smaller or larger quantities adopt different methods. Quite a number still prefer to build up to a solid block, either in wood pattern or black-sand form, and the author fails to appreciate the advantage to be gained where the body is circular and could much more readily be struck up. An ordinary engine cylinder provides an excellent example, whether it be a Corliss, slide, or drop-valve type. The cylindrical portion, including belts, flanges, with and without header, is struck up with the board, which is marked off with strips for all the necessary data lines of the additions to be cast on the cylinder, and as the mould progresses these are set to the required position. At the author's works there have been made hundreds of these and similar castings, and they have as yet found no method so simple and yet so accurate. This is proved in the casting, and the works claim to produce loam castings without superior.

In the building of turbines, especially those of high power, considerable labour is spent upon the patterns, most of which is unavoidable. Some firms build up full patterns for all the work, including the steam and exhaust casings, yet they would, upon full consideration, find the strickle board extremely satisfactory for the purpose.

Exhaust Casings.

An exhaust casing being the most difficult, in that it is not completely circular in form, can be usefully cited. In two parts, it is jointed by flanges very similar to a letter B, and gradually runs off from this shape to a semi-circle in the top portion to a tapering body in the bottom portion, terminating in a completely circular branch. When making the top portion the bed is struck, and the B-shaped flange is placed in position at right angles to the bed, and then the core is struck up. This is facilitated by the use of a circular runway behind the spindle, which assists to give the shape from a larger to a smaller diameter, and strickles from the flange complete the remainder. Next the thickness is placed on, after which, of course, the moulding is proceeded with in the usual way. The lower portion is made in a manner somewhat similar. If patterns had been made it will readily be realised, especially by those conversant with turbine work, the heavy cost of patterns and core boxes likely to be incurred. These were in every case eliminated, and the firm saved considerably in pattern-making, material and the all-important storage.

Skeleton Patterns.

The skeleton method of pattern-making is frequently adopted in the making of the patterns for marine turbine and engine work. The pattern is correct to shape in every detail, and constructed so as to give the exact thicknesses of metal required. These patterns entail a considerable amount of labour, because by being built up in ribbed or strip form much time is of necessity taken. There is the advantage in this type that core boxes are unnecessary, jointing and thicknesses are guaranteed, and though apparently very expensive, it is claimed to be cheaper to construct than the solid pattern, with its numerous core boxes. It makes up into a strong, serviceable pattern, and they can be used over and over again without being much the worse.

This is a method to be recommended for the constructing of many patterns of irregular shape. intended to be used in connection with loam moulding, though they can be used in green sand also; for all classes of suction pump casings of large variety and many other castings this method is undoubtedly sound.

DISCUSSION.

Green-Sand and Oil-Sand Cores.

Mr. A. Sutcliffe said, in making cores for jobs of the kind described by Mr. Stephenson, he had found gum sand quite as efficient as oil sand for block cores, which are nearly all print, and additionally, it was cheaper. The cost worked out at about 5½d. per cwt. Using oil sand, the cost was about 2s. to 2s. 2½d. per cwt. He had made many rope pulleys weighing up to 20 tons, and he was not in agreement with Mr. Stephenson as to the method which should be adopted. To take one example from the author's practice, a pulley wheel was grooved at the back, facing each groove at the front. It could be made off a block in green sand on the outside and dried, and the inside put in with cores. He (the speaker) had made these in loam blocks in place of bricks, and also in block sand cores for round the outside, the latter being preferable.

Another job he made for Mr. Stephenson was an air pump in loam. A month later, having to make one for himself, which was similar but heavier, he cut the pattern in two and made it in dry sand, and he made it in a third of the time the first one took.

Mr. J. Masters said the use of oil sand in these castings was a matter of experience. At the present time he was making in oil sand a job in which there was a 9-in. section of metal.

Mr. Stephenson said in the cores of the castings he had spoken of the material might be a little in excess, but the cost of labour was considerably less, and the net result was a cheaper job. This portion of the job could not be made in ordinary core sand in an hour and a-half. They used oil sand for all sorts and sizes of castings. Mr. Kay, the foreman, would perhaps give some particulars.

Large Fly-Wheel in Oil-Sand Cores.

Mr. Kay said they had made in oil sand a fly-wheel weighing 37 tons, in which the section of the metal, the outside rim, was 20 in. by 22 in. It was a solid rim, with cores to cover the top. A few weeks before they cast a shear body, the weight of which was 14½ tons.

Mr. A. L. Key said in loam moulding the choice between strickling and making a block was a matter of experience, and dependent upon the locality, the management, and other circumstances. He doubted whether one method alone could be definitely declared to be the cheapest, to cover every job that was moulded in loam.

Mr. Stephenson said, in special cases, blocks were made by his firm. In the Paper he had pointed out that it was not possible to traverse the whole ground in pattern-making, and when he mentioned strickle work he was referring to engine cylinders. It did not matter whether they were of the Corliss or the drop-valve type.

Mr. Masters said he had a casting to make which weighed 14½ tons. On the first occasion a block was used, and it cost 19 weeks' labour. On the second occasion it was made with a block, and the time was 6½ weeks.

What were the results in making large pulleys, say 20 tons weight, in oil-sand cores? Should the cores be put in segments, or as oil-sand cores complete, and finish the segments, or was it preferable to put the loam core with the grooves partly on and then slip them up afterwards in order to get a more accurate casting?

Pulleys in Oil-Sand Cores.

Mr. Stephenson replied that the practice at Messrs. Musgrave was to make a segmental box containing the correct number of grooves required in the pulley. They were put round the mould, secured, and cast in that way. There was no striking up. At another establishment, where he served his time, the practice was to make the cores in a similar form, put them on, and strike them on the mould. By that the amount of machining required was reduced to a minimum. But to his mind, assuming the grooves had been set very accurately—and they must be set accurately—the cores, when they came from the box, were suitable for making the mould and sufficiently good for the machine shop. The machine shop generally took a parting cut across the top to give it its diameter. Then they put down what was called a cutting tool. In the use of the cutting tool it was immaterial whether the joint was slightly stepped or not, because a straight line was cut right away down to it, and where the joints overlapped it took a wider cut than elsewhere. As far as their experience went, it was not necessary to strickle up the cores after they had been laid down.

Mr. Masters said he held that no oil-sand core would stand the pressure of a rope pulley and be accurate; there must be an extra wide margin for machining. By slipping the cores with a loam spindle, after they had been put into position, the machining was reduced to a minimum; it was not necessary to have more than $\frac{1}{4}$ in. machining on the casting.

Mr. Stephenson said they never allowed $\frac{1}{4}$ in. machining on the angle of the groove. For large pulleys $\frac{3}{16}$ in. was all they allowed. Of course, if the moulder was not so accurate as he ought to be, and made the castings a little in excess in diameter, the turning was increased, because the angle was running away from the diameter, and, in consequence, it slightly thickened the metal that had to be taken away. But when using the tool, it did not matter whether the groove overlapped or not. The tool, cutting down the face in the first instance, took a straight cut; then the sides were brought into play. Of course, he was not speaking of an overlap of something like $\frac{3}{16}$ in., he was speaking of an overlap of something like $\frac{1}{16}$ in. or $\frac{3}{32}$ in. If the marginal allowance was $\frac{3}{16}$ in., they had still $\frac{3}{32}$ in. to play with.

Probably Mr. Sutcliffe found some difficulty with the method which had been in operation at Messrs. Musgraves because it was the first one he had made under those conditions, and when one took up a new thing, a difficulty was experienced in operating it. But he could not agree that to build the cores up separately and strike them up was more expeditious than putting them down in segmental form in a core box. They had tried it at their works, and it was very expensive. It happened that a foreman came along who would not have the core boxes; he preferred to build up. So he built the pulleys up groove by groove, used the grids, and so on. It took five days to build up and finish a mould 4-ft. dia. with 12 grooves. It was the first that had been done in that way, and naturally everybody was a little bit lost so far as it was concerned. But they very quickly reverted back to the old method. He quite agreed that the appearance of the casting produced by the old method was not so nice, but that weighed very little with him if it was a machined face. They had found no difficulty as far as the machining was concerned.

Mr. Perryman asked for some further information regarding the ramming of the rope pulleys. His own practice was to ram up the top part on the plate. The centre was generally covered by a loose plate. He understood Mr. Stephenson to say they rammed the arm, and then they rammed other cores up in between. He did not do that himself, but rammed the cores up to the arms, and then rammed the rim part with anything they could get between the arms and the spindle. They did not bother with any core in between.

A Member observed that the system he adopted was to ram it up, to take off the top part, and to ram up the centre. There was 6 in. parting on each side of the flange.

The Chairman reminded the members that this was a Paper on patternmaking, not on moulding. It went to prove that co-operation between the patternmaking department and the foundry was essential.

Skeleton Patterns for Turbines.

Mr. Masters said he would like to express the opinion that for turbine work the complete skeleton pattern was the best method to get a true casting. Quite recently he had occasion to make a turbine casting, and it came out satisfactorily from the foundry point of view, both as to casting and appearance. When the pattern was made originally there were so many radii in it that it could not be made from a drawing; the patternmaker had to be in the foundry constantly to make his patterns after the radii had been formed. Eventually it came out a very good pattern. They got the casting a uniform thickness quite satisfactorily. Just by taking a complete skeleton pattern it was made quicker than any casting of a similar character previously made.

A friend who had been in Belgium informed him that the moulders there made little use of patterns, even with castings which weighed 15 to 30 tons. He had himself seen Belgian castings, but nevertheless he believed that the British moulder could hold his own with the Continental moulder if he had the same facilities.

Mr. Meadowcroft said he believel there were more jobbing foundries in Lancashire and the West Riding of Yorkshire than in any other part of the country, and the jobbing foundry suffered a great deal from bad patterns. Every foundry had its own methods, which varied in some respect, it might be only slightly, from the practice of others. Where one system had been in vogue it was not wise to introduce another without satisfying oneself what the man could do. Even if it was better, then men, not being accustomed to it, did not appreciate it.

The remarks on the necessity for a good understanding between the patternmaker and the moulder were very useful. An instance occurred to his mind, where they were making a big frame casting weighing about 6 tons, with outstanding brackets. It had all sorts of loose pieces. It used to take a couple of days to set it up. The patternmaker talked it over with the foundry people, about £15 was spent on a block, and it was set up in 4 hours. Practically half the cost was saved on the first casting.

Mr. Noble said some years ago his firm, being overwhelmed with orders, obtained castings from Belgium, and patterns were sent out. When they were returned some of them were in a very bad condition, and, additionally, a large portion of the castings had to be made over again. The Belgian moulders were not ahead of the moulders in this country. Often a foundry foreman had to send a pattern back, and alterations cost a good deal of money. If the manager of the firm would encourage co-operation between the foundry and the pattern shop there would be a considerable saving.

Vote of Thanks.

Mr. J. Prescott, in proposing a vote of thanks to Mr. Stephenson, said the Paper brought forcibly to their notice recent developments in the industry in respect to moulding and patternmaking. Reference had been made to the new block system, which had been gradually adopted. When he first started in the foundry department the block system was in use, although it was not quite what was seen to-day. It had been mentioned that castings had been made wholly from cores. It was bringing moulding down to very simple terms; they were becoming assemblers of cores, and that system had been in operation for a number of years for rope pulleys and various other castings.

Mr. H. Stead, in seconding, agreed that it was essential the pattern shop and the foundry should be in close touch with one another. It was false pride for either a moulder or a patternmaker to imagine he knew his job so well that the other could not teach him something about it.

Mr. H. Sherburn, supporting, said reference had been made to a point which was of vital importance and also sometimes difficult of solution. That was co-operation between the pattern department and the foundry. The pattern department had its special difficulties to overcome. It had the productive aspect of the foundry to consider, and there were all kinds of technical problems associated with design to be considered. Heavy expenditure was often incurred in patternwork which might be thrown over at the last moment by the man in charge of the foundry. That left the patternmaking department in a very difficult position. He much appreciated Mr. Stephenson's presence with them and the Paper submitted. By getting in touch with one another in these discussions they would make better progress. They ought also to know something of what was happening on the Continent. A few weeks ago he had the pleasure of going through a foundry at Werkspoor, in Holland, which promised to be on conclusion most admirably organised.

The melting equipment was remarkable, and the methods of handling material and organising the work excellent. The foundry had been designed under the personal superintendence of Mr. Van Aarst, who was undoubtedly one of the foremost foundrymen of the present day, and any member who visited it could be sure of a hearty welcome. He would also be sure of getting valuable instruction, and he would be able to form an idea of the best Continental and American designs for producing patterns and modern equipment in cranes, hoists and cupolas. In this country one was apt to become insular in his ideas, and an opportunity of slipping over to the Continent tends to enlarge one's knowledge, and should not be missed.

The vote of thanks was passed unanimously. In reply, **Mr. Stephenson** said he had always valued co-operation with the foundry, and had carried it out in practice. He would go further, and say that the co-operation of the drawing office was also essential. When the design was sent into the pattern shop is was not always perfect for obtaining economical production. Therefore where he was employed the drawing office frequently called into consultation the patternmaker or the foundry foreman, and sometimes both of them.

Birmingham Branch.

GENERAL CUPOLA DESIGN AND PRACTICE.

By A. Campion, F.I.C.

The foundry cupola in all probability represents the simplest form of melting apparatus in general use for large-scale operations; essentially it is simply a vertical cylinder with holes at the bottom for admitting the air necessary for the combustion of the fuel, and others for withdrawing the metal and slag. There may or may not be a door near the top through which coke, iron and flux are charged.

The cupola is remarkable inasmuch as in its essential form it has undergone practically no alteration, and remains in very nearly its original form. Certainly changes have been made from time to time, but it is curious how temporary they have been. The only important modifications which have had any degree of permanence are:—(1) Increased height, giving a greater length of stack above the tuyeres; (2) the addition of a reservoir or belt through which the air is distributed to the tuyeres instead of direct connection of air pipe to tuyeres; (3) reduction of the internal diameter between the furnace bottom and the tuyere level; (4) drop bottoms; (5) metal receivers, whilst many alterations have been made as regards shape, size, number and arrangement of the tuyeres placed in one, two or three rows at various distances from the bottom.

The main object of the various designs and arrangement of tuyeres is the better distribution of the air within the combustion zone.

In melting iron for foundry purposes the cupola occupies the premier position, and its behaviour and management determines to a very large extent the general success of the foundry work. The objective in successful operation of the cupola is to provide a supply of molten metal as rapildly or as regularly as possible suitable for the work in hand, or, in other words, to secure the maximum efficiency.

Efficiency—What is It ?

One often hears of thermal efficiency or the proportion of the heat units in the fuel usefully employed within the furnace itself, but the term cupola efficiency means something more than this. It involves a consideration of the questions of arrangement and construction of plant so that the combustion of the fuel shall be as complete as possible, that the heat produced from the fuel shall be as completely as possible absorbed or utilised within the furnace, or, to put it another way, the coke consumption shall be at a minimum and the quantiy of heat and the temperature produced in the melting zone at a maximum, so that the greatest possible weight of metal per unit of capacity shall be melted and superheated to casting condition. We may therefore define cupola efficiency as meaning the production of the greatest quantity of molten metal suited for the work in hand, with the lowest consumption of fuel, in the shortest time and at lowest cost. It is quite possible to produce metal at a low cost, but not suitable for the job; that is not efficient working.

Requirements for Efficient Working.

1. To attain a temperature sufficiently high to melt and superheat the metal to such an extent as to enable the mould to be filled and casting completely run whilst metal is completely fluid and without separation of the constituents to allow of regular solidification and cooling.

2. To generate sufficient heat to melt and superheat to the desired limit with least possible consumption of fuel. The minimum heat required is a perfectly definite quantity for each quality or mixture of metal. It depends on the melting point, specific heat, and latent heat of the metal.

3. The combustion of a certain amount of fuel to generate the heat under second requirement. It must be remembered in this connection that a given fuel can only generate a certain quantity of heat per unit of weight, and this amount is governed by the composition of the fuel. Whether this quantity is obtained or not depends upon how the fuel is burnt, that is to say how completely, whilst the effect or result of generating this quantity is influenced by the rapidity of burning, the

quantity and manner of application of the air, the extent of the space in which it is burnt, and the arrangements for transmitting the heat to the metal being melted.

4. *Effective Utilisation of the Heat Generated.*—This depends a good deal on the construction and arrangement of the furnace—*i.e.*, position of the combustion zone, the arrangement of the charges, concentration of heat, etc. In ordinary circumstances heat is only transferred or communicated from one body to another by direct contact or by radiation. Gases heat by contact only; they have very little radiating power. In cupola working, heating is effected by:—(*a*) Direct contact with incandescent coke; (*b*) radiation from the exposed surface of incandescent coke (if two pieces of incandescent coke are one behind the other, metal is only effected by radiation of surface of coke facing it); and (*c*) by heat from hot gases by direct contact. This accounts for the largest part of the heat of fuel actually transferred to the metal. The greatest proportion of the heat generated is first taken up by the gases and by them distributed through the furnace. The final product of burning fuel is gaseous, consequently it is of supreme importance to give attention to all factors which influence the manner of distribution or completeness and regularity of contact of the gases with the solid material in the furnace, as these affect the furnace working; if the distribution is bad or irregular, there results irregularity of contact with non-uniform heating, the gases pass away at too high a temperature, and this means waste of heat and inefficiency, and if the gases are insufficiently cooled the zone of maximum temperature rises in the furnace generally or locally.

Cupola Design.

In designing the cupola for certain specified duty it is necessary that careful consideration be given to a number of vital factors:—The size necessary to secure a specified output under conditions—*i.e.*, the diameter at the tuyere level, the number, size, shape and arrangement of the tuyeres; the height from tuyere level to sill of charging door; the relative capacities of wind belt and air-blast pipe; the quantity of air necessary, and the manner in which it is to be delivered to the furnace.

The literature of the subject shows that great diversity of opinion exists as to the relation and proportions of the various parts of the cupola, conditions of blast and fuel consumption, statements by different writers vary so greatly, and in some cases appear so extraordinary that one wonders whether the authors have had closer acquaintance with cupola practice than as travellers for pig-iron or electric wiremen.

It is much to be desired that some rational system of designing cupolas should be established similar to the method of designing an open-hearth steel melting furnace, based upon well-defined data. It is not uncommon for a founder desiring to erect a new cupola to decide the size of his furnace according to what someone has told him ought to give a certain output. The blower, pipes and connections are of indefinite capacity and size, and the tuyeres are of more or less fantastic shape and arrangement. The furnace is lighted and the blower speeded up until a pressure gauge indicates so many inches, ounces or pounds, because some other foundry uses a similar pressure and obtains fair results, and no account is taken of the conditions and requirements in the other foundry, which may be entirely different. There is absolutely no attempt to work upon known or ascertainable data or to develop a system of maximum efficiency.

In designing a cupola, the following facts and relationships must be carefully considered :—

(1) The sectional area at the melting zone determines the quantity of fuel which can be burnt in a unit of time on one plane, and consequently the melting capacity of the furnace. It is therefore very important that the size of the furnace should be stated in terms of the melting zone inside the lining, and not of the stack or external diameter as is often done.

(2) The quantity of metal it is desired to melt determines the amount of fuel which has to be burnt in order to give the necessary quantity of heat after due allowances for losses. The principal directions in which heat is lost or utilised in other ways than melting and superheating the iron

are:—Formation and melting of slag; radiation; heating the furnace, and escaping as sensible and latent heat in the gases.

(3) The weight of coke which has to be combusted determines the amount of air at a given density which has to be supplied to the furnace.

(4) The quantity of air required determines the area of the tuyeres necessary to convey the air at suitable velocity. The total tuyere air must be adjusted according to the number and shape of the openings to allow for frictional effect upon the velocity.

(5) The tuyere capacity determines the size of the air pipe or conduit necessary for the conveyance of the requisite quantity of air from the blower to the wind belt and also the size of blower.

If the design is based upon these facts it should be possible to obtain reliable data for the establishment of a rational system of cupola construction similar to that adopted in the steel industry.

There must be a proper proportion and relationship between all parts of the cupola, and not, as is so frequently the case, only the relative area of furnace and tuyeres considered.

In deciding upon the total area of the tuyeres, it is necessary to take into account the amount of air which is to be introduced at a certain velocity, the penetration factor, and the distribution of the air within the furnace. The latter very largely influences the number and disposition of the individual tuyeres. The question of friction comes in as a factor controlling tuyere area. and this depends upon the shape. The volume passed by tuyeres of equal area but different shape varies with the friction encountered.

If p = pressure, a = area in square feet, S = the area of surface, V = velocity, and K = coefficient of friction

$$pa = KSV^2.$$

The friction varies with the size of the bounding surface. For instance, tuyeres of 12 × 4 and 8 × 6 give the same area, but the area of surface is different, and the amount of air passed will be in the ratio 1.15 : 1.0. The most successful shape of tuyere appears to be oblong, with the horizontal width about 1.2 to 1.25 times that of the height. Tuyeres of this shape offer a minimum frictional resistance to the air and keep clear throughout even long melts when the area is properly adjusted to the size of the furnace, and pressure and velocity of blast such as to give suitable penetration value.

The most economical working is obtained when the amount of air required passes through the tuyere at the rate of 400 cub. ft. per min. for each square foot of sectional area of cupola bore at melting zone.

As the relative velocity can be ascertained of air forced through an orifice at a given pressure, the penetration factor can be calculated.

$$\frac{WV^2}{D}$$

Where D = cupola diameter, V = velocity per sec., and W = weight of air passing per sec.

The ratio of cupola area to total tuyere area should vary with the size of the furnace at melting zone.

In cupolas up to 40 or 42 in. diameter the ratio should be 1: 4 or 1: 4.5; those having diameters between 40 and 63 in. the ratio should be 1: 4.5 to 1: 5.5, and in large cupolas 64 to 90 in. diameter the ratio may be 1: 5.5 to 1: 7.0.

The area of the blast pipe conveying the air from the blower to the furnace must bear a definite relationship to the tuyere area. It must be emphasised that the blast from a single main cannot with the same power be discharged at the same rate through a number of tuyeres having a total area equal to the area of the main, because in dividing the volume between a number of openings there is involved a loss due to friction. The total tuyere area must therefore be greater than the sectional area of the blast pipe.

The ratio of blast-pipe area to total tuyere area should be for cupolas up to 42-in. dia. 1: 1.6 to 1: 1.75; cupolas between 42 and 63 in. dia., 1 : 1.4 to 1: 1.6, and for larger ones 1: 1.4 to 1: 1.1.

The wind belt should also bear a relationship to the blast pipe. The general practice is to make the belt too small, and in some cases the advantages of ample tuyere area are neutralised by this means. A large belt gives steadiness of blast entering the furnace by acting as a reservoir and minimising the effect of pulsations where a positive blower is used, and at the same time allows of the blast being equally divided between the tuyeres.

The ratio of sectional area of wind belt to that of the blast main should not be less than 3:1, and may be 3.5:1 or 4:1 in large cupolas. The belt may be placed so as to be inside the shell, in order to permit of warming the blast, whereby considerable benefit is derived, not so much from a saving of coke between charges—which is small at the best—but the chilling effect of the air as it enters is reduced, and a better distribution of heat is obtained.

The height of the cupola between tuyere level and sill of charging door is important. It is relatively greater in large than in small cupolas, as the melting zone inclines to rise higher, owing to the necessarily increased pressure. In small cupolas the height may be from 3 to $4\frac{1}{2}$ times the diameter, $2\frac{3}{4}$ to $3\frac{1}{2}$ in medium, and $2\frac{1}{2}$ to $2\frac{3}{4}$ in very large ones. It may also be equal to $24\sqrt{\text{diameter}}$ for all sizes.

These heights are given on the assumption that the tuyeres will be placed 16 in. to 20 in. from the bottom of the furnace.

Cupola Output.

This will vary to some extent with the nature of the metal, the size of scrap, etc., but with a furnace of properly balanced proportion in all parts and properly adjusted air supply, travelling through the tuyeres at approximately 30 ft. per sec., there should be melted 16 to 17 cwts. per hour per sq. ft. of cupola area. This corresponds to the most economical rate of coke burning of 180 lbs. per sq. ft. per hour, and requires 25,000 cub. ft. air per hour. It is usual to state the air requirement as so much per ton of metal melted, but this is, in the opinion of the writer, to be discountenanced. The air is for the purpose of burning coke to produce the necessary heat, and the air supply should therefore be stated in terms of coke. The usual 30,000 to 33,000 cub. ft. of air stated to be necessary to melt a ton of iron is only correct when 2 to $2\frac{1}{4}$ cwts. of coke per ton between charges is used. Many foundries work with less, and unfortunately some use considerably more. The volume of air required for different coke consumption is shown in Table I.

TABLE I.—*Volume of Air necessary for Various Melting Ratios.*

Coke per ton of Iron melted.	Cubic feet of air.	Melting ratio.
lbs.		
224	32,000	1 – 10
200	28,000	1 – 11.2
196	27,500	1 – 11.4
180	25,200	1 – 12.4
168	23,520	1 – 13.3
160	22,400	1 – 14.0

The weight of coke has reference to that placed between charges and exclusive of the bed.

The volume of air should be weighed or measured. This has presented some difficulty in the past owing to suitable instruments being either too costly or too liable to get out of order under foundry conditions. An instrument can now be obtained at a moderate outlay which is at the same time accurate, robust and fool-proof. If cupola men scrapped ordinary pressure gauges and installed volume gauges there would be a greater average cupola efficiency obtained than is now the case.

Charging the Cupola.

The filling of the cupola should commence so soon as the bed is well alight and the brickwork warmed up. The practice of burning for hours with the doors and tuyeres open before charging is very wasteful, and not conducive to the best melting. The bed, although requiring to be well lighted, must not be over-burned.

The best practice would appear to be to fill up with coke to the tuyere level, and when well lighted the tuyere doors should be closed, then more coke added to bring the bed the requisite distance above the tuyeres. Charging of the cupola should then proceed. The weight of metal per charge will depend upon the class of iron melted and also the size of the scrap, but light charges are to be preferred to heavy ones provided they are sufficient to give a good covering in each layer. The pig is better placed rather more to the centre, but not to such an extent as to have a central pile of metal surrounded by coke.

The ideal arrangement for fast and efficient melting would be for the coke to be arranged in the form of a sort of basin with sides and bottom of equal thickness, to counteract the tendency for the air to travel up the sides of the furnace more readily than the centre, and also to ensure that the blast always impinged on coke. This ideal is not possible in practice, but it can be approached by placing a little more coke to the circumference than the rest of the cupola area. It is essential that there should be a layer of coke over the whole area between each charge of metal, of a depth suitable to the tuyere arrangement; it averages about 5 in., but varies with local conditions. Weighing does not always secure the best depth owing to variations in density of the coke—that is, a heavy coke made with the usual weight gives too shallow a layer. To overcome this it is recommended that when once the best depth of coke charge has been found for a particular furnace, a sheet-iron ring be made of that depth and with a diameter equal to that of the cupola at the tuyere level. This should be filled with coke and the weight determined; in this way a constant depth can be maintained with different cokes.

The practice of putting on the blast for a short time after a few charges have been filled in is not to be commended; when the coke is called upon to give up its heat, it should do so quickly, and the heat should be concentrated in the melting zone for the purpose of transference to and melting of the metal.

Heat Development and Melting.

This depends principally upon the completeness of the combustion of the fuel. Carbon burns in two stages—to carbon monoxide and carbon dioxide, the latter reaction producing the maximum heat. To secure this it is essential that a sufficiency of oxygen be brought in contact with the carbon. Increased temperature results from concentration of heat, and this in turn increases efficiency. A certain quantity of fuel is necessary to generate enough heat to raise the iron to the lowest temperature at which it can become liquid, and a further amount to increase the temperature of metal and slag to give the desired fluidity. The greater the concentration of heat from burning the fuel, the hotter and more fluid the metal; the density of the coke affects this to some extent, but is mainly influenced by the quantity of air and the manner of its admission; that is to say, the pressure and velocity of the air supply and the surface of the fuel exposed to the blast.

Theoretically, if all the heat from 1 lb. carbon burnt to carbon dioxide was applied to the metal, about 47 lbs. could be melted, or 1 lb. of average coke should melt about 40 lbs. of iron, but there are losses, and it has to be remembered that foundry metal must be raised considerably above the melting-point. The bed coke introduces a disturbing element into the calculations, as it varies so much in different furnaces, some requiring deep beds, others shallow ones. The only proper method of stating coke consumption is to give the fuel ratio so as to show the bed, and charge coke separately. In many foundries a ratio of 1:10 is considered very good; it is not only possible to do very much better, but ratios of 1:14 or more are obtained regularly in many foundries.

The fuel and metal being arranged in position, it requires to be supplied with the appropriate quantity of air for combustion, and although the actual volume or weight can be determined, it may be introduced so that it only just keeps combustion going, or at quicker rates, up to the maximum at which oxygen and carbon are capable of combining. The latter limit is largely determined by the area of the fuel which can be presented to the blast. The actual surface area of the coke in a given space which can be brought in contact is limited by the area of the cupola and the surface area of the pieces of coke. There is a particular rate at which air must be applied in order to obtain the maximum speed of combustion.

The area of coke that would be presented to the blast could be easily calculated if it were a solid mass with plane surfaces, but a mass of coke pieces, interspersed with pieces of metal, is quite a different matter, particularly so because an increase of pressure not only supplies more air to the surfaces of first contact, but also causes penetration of air to higher planes in the coke mass, thus increasing the surface of contact. The size of the pieces of coke and the structure of the coke are also variable factors, so that the best rate of air supply must be finally adjusted by practical trial.

It therefore becomes necessary to consider not only the actual amount of the air supply, but the manner of its application to, and distribution through, the plane of its introduction into the cupola.

The velocity of the air entering the furnace is of itself indicative of nothing, it is only one factor in determining the quantity of air entering. When a given amount of air is passed through tuyeres it comes in contact with a mass of lighted coke, through which it can only penetrate by tortuous routes in all directions. The tendency is to travel upwards more readily than inwards, owing to the absence of outlets except upwards. The area of effective contact takes the form of an inverted cone; although the supply of air and the most active combustion may not extend quite as far upward in the centre as at the periphery, and there may be an appearance of a slower velocity of air in the centre, it is more than probable that the quantity in the centre is not very different from that at the periphery (currents from all the tuyeres converge to the centre).

In a plane a little above the tuyeres melting takes place all over it, but the zone of highest temperature tends to come nearer the lining the higher up; as distance from the tuyeres is traversed, the space for expansion becomes larger.

Velocity or rate of entry is then by itself of little or no significance in determining air quantity, but it is a factor in determining the distribution of the air within a lighted cupola.

In the case of an unlighted cupola, air would travel to the same extent inwards for any velocity multiplied by tuyere area, giving the same quantity of air per unit of time. The course of the current is broken by the pieces of coke, and once within the cupola, the pressure as a factor becomes absorbed in the resultant or quantity and loses its identity; but after the coke is lighted, the cutting action of high velocity and small current would be more noticeable than low velocity and large current, and would have a greater chilling effect at entrance by impinging the same quantity of cold air on a smaller area; consequently it is very important to determine the lowest velocity capable of penetrating to the centre. There is such a minimum velocity, at which it is desirable to introduce the proper quantity of air for each cupola.

If the lighted coke in a given plane zone through the bosh is supplied with an increasing quantity of air, there is reached a maximum quantity which can combine in a given time in that zone, and if the quantity be further increased the excess passes to a higher zone, or, in effect, increases the depth of the zone of combustion, but this cannot go on indefinitely if the air is introduced from the same point, for once the maximum rate of combination of oxygen and carbon is reached, any excess has to pass through the zone in which action is going on, and only serves to dissipate the heat of combustion to a higher zone.

As the quantity introduced in one plane increasingly exceeds that needed for the maximum possible combustion, effective melting is reduced and a certain chilling area is created through which metal has to pass, and there is also the possibility of oxidation and burning of the metal. To remedy such a state of matters it is the common practice to reduce the air supply without redistributing it, which is effective if the supply is really excessive, but bad practice if the excess of air is only local, as the correct remedy in that case is redistribution of the supply.

It comes to this, then, that there is a maximum quantity of air which can be introduced at one level, and that is the quantity to give the maximum combustion in that zone or level. If it is desired to increase the depth of the melting zone, the excess of air should be introduced at a higher level, *i.e.*, just above the hottest part of the original zone. If it be introduced too high, it only serves to increase the waste and increases the proportion of carbon monoxide in the waste gases.

A careful study of the above facts will probably assist in explaining some of the conflicting opinions expressed by cupola men as to the value of one, two or three rows of tuyeres.

Mr. Cook has given certain formulæ for calculating the maximum air supply and successful melting capacity of cupolas, in which the factors quantity of air and pressure of blast assume prime importance.

The rate at which oxygen is brought into contact with the coke determines the rate of combustion for any particular diameter of cupola.

A single row of tuyeres should give the best, most regular, and economical working if all parts of the furnace are properly proportioned and the quantity, pressure and velocity of blast are properly adjusted.

Sometimes a second row of tuyeres gives quicker melting by increasing the depth of the melting zone, but to ensure this it is necessary to know the velocity and quantity of air to give the highest possible rate of combustion with one row of tuyeres, and the second row must be so placed that the air injected through them shall act just below the top and less active portion of the combustion zone set up by the lower row of tuyeres.

Introducing a secondary supply at a point too high to effectively extend the zone is bad and wasteful. If, however, the combustion set up by the first row is below the maximum, the introduction of air at a higher point is advantageous, as it offers a certain amount of resistance to the upward passage of the lower current, giving it longer contact and more opportunity to combine with carbon in its own zone, and at the same time setting up active combustion in the higher plane in such a manner that it merges into the lower one.

In practice, a third row of tuyeres is not effective, as it stands too high and only results in an increased production of carbon monoxide. The useful extension of the zone of combustion is limited by the quantity of the products of combustion. It has to be remembered that 79 per cent. of the air blown in is nitrogen, and this, together with the carbon dioxide formed, causes sufficient dilution to prevent further useful combustion going on.

It has been stated by several writers that a second or third row of tuyeres is useful as a means of securing more complete combustion, by supplying air to unite with the carbon monoxide passing upwards from the bottom row; this, however, is a fallacy, as the temperature is above the dissociation point of carbon dioxide especially in presence of excess carbon. It is extremely doubtful whether additional rows of tuyeres in any way effect the completion of combustion to carbon dioxide. It seems much more probable that they would cause an increase in the carbon monoxide unless placed in the exact position necessary to extend the zone of combustion.

The combustion of the escaping gases gives some useful information as to the efficiency of the cupola working. but care is necessary in sampling to avoid including the products of secondary reactions high up in the shaft. Much investigation is required in regard to the changes which take place in the composition of the gases between the zone of combustion and the top of the charge before definite conclusions can be drawn.

The writer has had such investigations in hand for some considerable time, and he hopes to be able to publish results at a later date.

DISCUSSION.

Opening the discussion, the Chairman (Mr. T. Vickers) said that Mr. Campion was one of the few metallurgists in this country who had done extensive research work in connection with cupola practice, and it was for this reason that he (the speaker) had suggested that particular subject for consideration that evening.

Mr. H. L. Reason endorsed the statement that Mr. Campion had done some valuable work for the Institute in publishing the results of his researches, and said that in many ways he had furnished food for thought for the cupola makers. When one considers the antiquated cupolas that have been and are in use, one marvels at the wonderful results obtained, but there is no doubt that, with applied science, as explained by the lecturer, the efficiency of the cupola can be considerably increased, but as it was generally agreed that blast pressure and air volume were points to be carefully watched, owing to the effect on the properties of the metal, he was surprised to note the lecturer did not consider this aspect of cupola practice of fundamental importance, perhaps he would give his views on this point. As to the information and data given in the Paper, he was quite sure this would be used to good advantage by the members. He also paid tribute to the clear, concise way the Paper had been prepared, so that everyone could clearly understand all the various aspects considered.

Carbon and Oxygen Reactions.

Mr. A. Marks also considered that the information given would be of great value, and he fully agreed that Mr. Campion had probably done more work in regard to cupola practice than anyone else in the British Isles. He thought that constructional engineers should have their attention drawn to his suggestions, but these were also extremely useful to the practical foundry worker. The foundryman, he pointed out, was practically compelled to use cupolas of a certain size and construction because they represented the views of the various makers. He must confess that in his experience he had frequently been compelled to neglect what he might term efficiency of melting, and to consider only the metal turned out from the cupola, thereby setting aside many theoretical instructions regarding quantity, porosity of coke, etc. The coke burden they used was governed by the product. In addition there was the necessity to run on three or four different classes of iron, which compelled a variation in the amount of coke used. He would be interested to know what the lecturer thought on the question of the taper in the shape of the cupola, and possibly he could tell them something as to whether the reaction between carbon and oxygen to carbon monoxide was not the principal source of melting heat, and that calculations as to fuel efficiency should be based upon this reaction rather than upon the reaction carbon plus oxygen to carbon dioxide. The carbon monoxide plus oxygen reaction probably occurred in the colder zones above the melting zone, and Mr. Campion's views would be of interest on this question, which was of vital importance in view of melting efficiency.

Shape of Cupolas.

Mr. E. Longdon asked what would be the effect upon the melting of an increased diameter in the cupola 15 or 16 ins. above the tuyeres. Perhaps the lecturer would give then a little guidance as to the measurement of the coke bed, which was affected by the question as to what part of the cupola was the place of measurement, if one agreed that an increased diameter just above the tuyeres was desirable. Also what would be the effect of blowing in a jet of steam along with the air through a belt suitably protected against corrosion. While he had seen many mechanical chargers, none of them seemed to be without objections, and he thought the labour expended was about equal to that of hand charging.

Mr. F. C. Edwards inquired whether experiments had been carried out as to the effects of oxygen; and also as to the time which ought to elapse between the charges where they were of a different character.

Mr. T. Henry Turner agreed with the lecturer that the cupola was the oldest and crudest of furnaces, indeed, it had not been altered in principle, but only in the introduction of certain auxiliary plant. He suggested that they were apt to make a mistake in regarding the cupola from the point of view of its big brother the blast furnace, which was, of course, entirely wrong. Much that had been said about coke applied to blast furnaces, but not to cupolas, which were in this country comparatively small furnaces. One aimed at the production of the greatest quantity of molten pig-iron consistent with quality in a blast furnace, whereas in cupola practice one must aim for the *highest quality for a quite definite quantity* dependent upon the foundry requirements. No doubt what the lecturer had said about auxiliary plant was correct, but he thought that losses incurred through blast pipe friction, etc., were relatively negligible compared to the losses sustained through bad metal and useless destruction of moulds. If superheat was so important, how was it that some type of forehearth partial bessemerising and if necessary recarburisation was not practised? He emphasised the need of considering the cupola from the point of view of the casting rather than from the point of view of coke economy.

Mr. W. Roxburgh (B.T.H., Rugby) raised a point as to the iron mixture used where the melting was done with 1¼ cwt. of coke to the ton.

The Chairman remarked that a great deal of controversy had arisen over the question of tuyeres, and confident opinions had been expressed in favour of a small number of large tuyeres, while others, on the contrary, preferred a large number of small tuyeres. He would like to know whether the lecturer considered spiral tuyeres better than straight ones, and for what reasons. It was also important that the tuyere area should bear some ratio to the cupola area; some designers state that this is governed by the kind of metal to be melted. What would happen, therefore, in the event of miscellaneous mixtures being used? Another controversial point is if the air pressure is varied during a melt, has it any effect upon the melt?

THE AUTHOR'S REPLY.

Mr. Campion, in reply to the discussion, said that certainly blast pressure by itself was of little value, and bore no relation to the quantity of air, neither was velocity or rate of entry of much significance, being only one factor in determining quantity of air entering and its distribution.

As regards the charging, he certainly did not mean to imply that all the coke should be on the sides and none in the centre; that certainly should not be, and he distinctly said the whole area must be covered.

As to founders being forced to take what the makers offered, as suggested by Mr. Marks, that was entirely the founders' own fault. If he wanted a certain design he should insist upon getting it; but, of course, the maker could not be held down to a guaranteed output or fuel consumption.

To work the cupola so as to give metal suitable for the job was correct, and, as he pointed out at the beginning of the Paper, it was not efficient working to melt metal that would not give the desired result in the castings. It was correct practice to vary the coke for different metals. Mr. Marks referred to metal that was perfect, but was not hot enough. He considered that metal too cold for the casting was far from perfect.

He preferred the straight lined cupola; it soon burned into its own shape. He did not believe in sloping the lining below the tuyeres; any splaying should be above the tuyere level, according to the rules he had given.

The question of equilibrium between CO_2 and CO and the zones of dissociation was rather too big a question to discuss in the time available, but perhaps he might have an opportunity to do so on another occasion.

He did not think that increased efficiency would result from blowing steam into the cupola; in fact, the reverse would be the case, as the action would be endothermic, and must be intermittent.

Mechanical chargers were an advantage with very large cupolas, but there was difficulty with distribution of the charges.

Pure oxygen blown instead of air would result in more active combustion and higher temperature, but it was hardly a practical proposition at present.

As regards separation of charges of different mixtures, he did not believe that was possible. If it was necessary to do so two extra charges of each mixture should be put in, the first and last of each lot tapped and put into castings of secondary importance. There is always some drip from the charge above. The mixture would thus be better separated. The reactions of the blast furnace were quite different from those of the cupola; the former were required mainly reducing, and the latter melting.

Metal could certainly be superheated by bessemerising, but it would not then be cast iron, it would be steel.

The cupola he mentioned as melting with less than 1½ cwts. per ton was in regular work, and had a special type of internal belt.

Some doubt was thrown on the possibility of melting a ton of metal with 1½ cwts. of coke, but he had known that done on many occasions. It was being done in several light foundries. Where the products were heavier, as, for example, hot water pipes, they would put on 8 lbs. per cwt., which was a little below 1½ cwts. per ton. In rain-water gutters 9 lbs. per cwt. could easily be done. The metal used in that case was a mixture of 30 per cent. Scotch iron and 70 per cent. of Cleveland, but there was about 25 per cent. of scrap in the charge. As to the shape of the tuyere, he preferred it to be nearly square, 8 × 6 or 9 × 7; he did not believe in a continuous ring.

If the tuyere was too narrow it was liable to get filled up with slag. For a furnace over 4 ft. he preferred eight tuyeres, for a furnace 3 to 4 ft. diameter six tuyeres, and below 3 ft. diameter four tuyeres would be sufficient. If they were fitted with shutters it was possible to control the distribution of blast round the cupola. With regard to the means of producing blast, a fan was better for a small cupola, whereas for a big cupola he preferred the positive blower. After the first tapping of slag he would leave the hole to trickle all the time. One of the best preventives of sulphur was to secure a high melting temperature. The thing to be avoided was a low temperature. He believed there were great possibilities from the introduction of pre-heated blast, but all his information about the Schurmann cupola was second hand; he had never seen one at work.

Birmingham Branch.

ALUMINIUM CASTINGS.

By C. Dicken.

Aluminium is considered to be one of the most important metals, and there are many brass founders anxious to branch out in the aluminium trade because their own business has so much decreased owing to stampings replacing brass castings, and because of the increasing popularity of aluminium, chiefly for the aero and automobile trade, but also for domestic and electrical purposes. This Paper may then assist anyone who may be seeking the method to produce aluminium castings. Progress with this particular metal has been remarkable during the last 18 or 20 years.

Aluminium in its pure state is not much used, owing to the elongation being too high and the tensile strength too low, but when alloyed with other metals it is increased in strength. Each of these alloys have their own particular properties and uses.

During the war the Air Board laid down several specifications which have since been brought into general use for commercial purposes, such as the L5 alloy, which contains 2 to 3 per cent. Cu, 12 to 14 per cent. Zn, and the remainder aluminium.

This alloy is much used in the automobile trade for producing both light and heavy castings, such as crank cases, gearboxes, rear axles, etc. It is a fairly strong metal, having a tensile strength of 10 tons sand cast and 14 tons chill cast, with an elongation of 6 per cent. when sand cast and 4 per cent. when chill cast.

The L11 alloy, containing 7 to 8 per cent. Cu, 1 to 2 per cent. Sn, and the remainder aluminium, is a metal that will stand a fairly high temperature and is, therefore, most suitable for castings such as cylinders. Castings which have to withstand a considerable stress combined with high temperature are best cast with this alloy.

The L8 alloy, containing 88 per cent. aluminium and 12 per cent. Cu, is universally known as "piston alloy." It is suitable for castings which are to be cast in a permanent mould where elongation is not required. As the permanent mould method of making castings saves machining, it pays in the case of various castings, although of course the cost of the mould must be considered, and so this method of production is only economical if there are a large number of the same castings required. The tensile strength of this alloy is 10 tons per sq. in., and about 1 per cent. elongation when chill cast.

An alloy containing 5 to 13 per cent. Si and the remainder aluminium is used by a few firms holding patents for different methods of production. This alloy is not widely known at present, but is undoubtedly an alloy which will, when more generally understood, assist greatly in overcoming many difficulties which arise in casting, feeding and porosity.

Selection of Metal.

There are two important points to remember concerning the so-called aluminium scrap which is upon the market. Firstly, aluminium castings made 12 or 14 years ago were very far removed from the castings of to-day so far as quality of metal is concerned, and then, too, aluminium does not improve with keeping. Besides these facts, refiners are buying swarf turnings and sawings of all types of alloyed aluminium and placing them on the market in ingot form.

In some machine shops where castings made from L5 and L8 alloys, phosphor bronze, gunmetal, white metal, iron and steel are machined, the operator (who is usually working piecework) cannot afford the time to be extremely particular about the turnings, and so sometimes L8 turnings are mixed with white metal because they are both white, and perhaps through carelessness a little phosphor bronze, gunmetal and sometimes iron and steel too. A very small portion of any of these metals will spoil the physical properties of aluminium. On one occasion the author bought some "re-melt" and had a test bar made which passed the laboratory for both physical and chemical results, and yet he was surprised at the weight of an ingot. It weighed 6½ lbs., whereas an ingot of the same size cast from L5 alloy made from virgin metal weighed only 6 lbs. This explains why customers now prefer to buy aluminium castings per unit instead of per lb.

Melting Details.

Aluminium may be melted in gas-fired tilted furnaces, pot furnaces, oil- or coke-fired furnaces, and sometimes in reverberatory furnaces. For the L5 alloy the preferable way to introduce the Cu. into the aluminium (owing to the difference in melting temperature) is to make a 50:50 alloy. This is made by placing 50 lbs. of virgin Cu into a crucible in the furnace (well covered with charcoal to prevent oxidation), and when heated to a temperature of about 1,150 deg. C., 50 lbs. of aluminium should be cut into small pieces and added a little at a time, so that the temperature is not too suddenly reduced. When this is melted thoroughly the molten metal should be well stirred with a graphite stick, or an iron bar covered with graphite, and then poured into ingot moulds. To prepare metal for casting 82 lbs. of aluminium should be heated to about 750 deg. C., 5 lbs. of the 50: 50 alloy should be added, and when melted 13 lbs. of zinc should be held in a pair of tongs and moved about in the molten metal until melted. This should then be drawn from the furnace and the moulds poured according to the given temperature. In the case of L8 alloy the mixture would, of course, be 76 lbs. of aluminium and 24 lbs. of 50: 50 alloy.

Temperature.

It is not possible to state a definite temperature for casting aluminium, because as the design and thickness differs with each type of casting so must the temperature also differ, but each important casting should be cast by the aid of a pyrometer. Metal too hot is the cause of many wasters, for although the analysis of burnt aluminium differs very slightly from metal melted correctly, yet it reduces the tensile strength, deprives the casting of its elongation, and removes that elasticity which should enable it to yield when contracting. Personally the author considers 700 deg. C. to be the best temperature for most castings.

Patterns.

Before commencing to mould, it is very necessary to examine the pattern thoroughly and to notice the position of the thicker sections. Great importance must be attached to the rate of cooling. If it is found to be impossible to feed the thicker sections whilst the thinner sections are contracting, then it is necessary to use chills. Sometimes pieces of flat or half-round iron can be used (as in crankcase corners). In the more intricate sections it may be found to be necessary to mould plaster patterns to make special fitting chills in gunmetal or iron. It is not possible to enunciate a hard-and-fast rule as to where these chills should be used. It usually depends upon the distance between the runner and the thicker sections. The aim in view should be to feed the casting so that the same rate of cooling takes place in each section. It is only by paying careful attention to this that a sound casting, free from porosity, can be produced. Patterns should preferably be placed upon moulding machines. Cores should be released from the casting as soon as possible.

Running.

This is another important point but one which must vary with the particular casting. In the majority of cases it is wise to have the runner on a thin section. This is not always the quicker method, but the result is more likely to be successful. When the runner is on the thicker section, flat-bottom bushes should be used to avoid oxidation.

Moulding.

Sand suitable for aluminium castings is just an ordinary fairly tough mixture of red and black sand. Great care must be taken to place the chills close to the pattern, and these must not be moved in the ramming of a mould. In cases where loose patterns are used the moulder should make a practice of rapping the pattern a definite number of times each way so that if a quantity of castings are required from the same pattern each casting will have received the same amount of rapping, and the weight of each will consequently differ very little. The facing of the mould after the pattern has been drawn is a matter which has caused considerable discussion. Some foundrymen maintain that the best method of obtaining good results for castings, such as crankcases, gearboxes, etc., is to paint the mould with a mixture of graphite and water and dry with a blowlamp, or gas with an added pressure. Others prefer to mix the sand with a percentage of moisture and brush the mould with dry French chalk and then dry, but experience and various experiments have shown that the best results are obtained by using dry sand with a little water (91 of sand and 9 per cent. of water), mixed with the shovel and put through the sand mixer, rammed in the usual way, and then the mould faced with an equal percentage of graphite and French chalk, using a brush for this process, and cast in a green state. Much care should be exercised concerning the chills. To ensure these being absolutely dry they should be heated and allowed to cool.

Blow-Holes.

It has been found that most of the machine-shop operators consider this to be almost the only cause of scrap, but to prevent scrap from this particular source foundrymen must consider the root of the evil. One class of blow-holes is caused when the gases cannot escape through their proper channels, when the sand contains an excessive amount of moisture, or if the mould has been rammed too hard, thus causing the grains in the sand to be so close together that it deprives the sand of its necessary porosity, and when the metal is poured the gases are unable to escape through the pores of the sand, and of course blow-holes must result. Damp chills may easily cause blow-holes. If insufficient care has been taken concerning the drying of these, and the metal comes in contact with the moisture, causing steam to arise, the result is sure to be a scrap casting. the chief objection to moulds being faced with wet graphite and skin dried is that there is a great danger of scrap from this method. The mould may appear perfectly dry, but there is a possibility of steam arising from the back and sides of the chills which may travel to the face and so cause blow-holes.

Tubes are often cast in crankcases, and it is sometimes necessary to make many experiments before these can be successfully cast without blow-holes. Castings which reveal holes on the top faces after machining are usually caused through the metal being cast at a low temperature. So-called blow-holes which are exposed after the first turning in the lathe are sometimes due to the metal having become oxidised as it enters the mould.

DISCUSSION.

Mr. E. H. Tyson, in opening the discussion, said he had always made crank cases the opposite way from the author, that is, face downwards. In such castings they had often to try different methods of running. In a great many cases he ran them with horngates. He remembered two very similar crank cases that were being made, both of which were run with horngates. One was a success, but the other being slightly differently constructed, there was trouble with blow-holes on the valve guide bosses. He favoured green-sand moulds and cores, but they had to control the moulders closely because they would work the sand too wet. That was often the cause of blow-holes. Where there was a large flat face on a casting blowholes were often found underneath the surface due to the metal having been at too low a temperature. The sand-cast piston always revealed speckled metal when machined. They could get over the trouble by chilling, but the problem was to make a sand casting without chilling and endeavour to get rid of the speckled metal which showed up on the machine.

Mr. D. Wilkinson said the troubles he had experienced in aluminium were a distinct class and required rather different methods to overcome from those which might be applied in the case of ferrous metals. With aluminium he had always found it better to try to cast at as low a temperature as possible. When rather stringent specifications had to be met, it was not generally considered wise to run the temperature much above the melting point. To overcome trouble with trapped air he favoured the use of a horn gate, forcing the metal in with great rapidity and putting a considerable riser on the higher part. One should not exceed the melting point of such alloy by more than 40 degrees. He admitted that it was not always possible to adopt that method. The only alternative was to increase the temperature of the metal and run the risk of the open grain of the casting reducing the strength beyond the desired limits. One of the great difficulties of the conscientious foundryman was to overcome in the best way he could the awkward designs the designer put out. With careful chilling, melting and gating, some of the weird designs that were submitted could be cast satisfactorily. It was much to be deplored that awkward designs were sent out, because difficult castings could often be simplified to the advantage both of the founder and the engineer. By careful attention to the runners and feeders, and above all to the melting, so that there were no oxidation troubles and no trouble from the nitrogen of the atmosphere combining with the aluminium, it was possible to succeed in producing satisfactory castings which at first glance seemed impossible. Speaking generally, he considered aluminium was a fairly easy metal to handle if it was remembered that the greatest care must be exercised in melting and in avoiding trapped air in the castings. In ordinary iron they had a metal of a specific gravity of 7.2, and in the case of an ordinary aluminium alloy they were dealing with a metal of about one-third that specific gravity. There was also a difference in the viscosity of the two metals. Two things in the case of aluminium made trapped air much more troublesome to deal with than in the case of cast iron. One was the added viscosity and the other was the low specific gravity, and the problem of producing a good casting had to be approached from a different standpoint. It was a great deal less expensive to cut off, say, 10 per cent. of metal and secure a sound casting than it was to have an additional 4 or 5 per cent. of waste castings, while there was the satisfaction of feeling that one had secured a good casting which, when machined, gave the minimum amount of scrap.

Mr. Aldridge inquired what was the best flux and also if the lecturer could supply him with the analysis of a suitable mixture for aluminium patterns for odd side work.

Proposing a hearty vote of thanks to Mr. Dicken, **Mr. J. B. Johnson** said he had given a thoroughly practical Paper.

Mr. F. G. Starr seconded the motion, which was enthusiastically endorsed by the meeting.

The Author's Reply.

In reply, **Mr. Dicken** reverted to the question of trapped air, remarking that once when he was on holiday the supervision of the foundry was entrusted to a man who thought he knew the best temperature at which to cast crank cases, *i.e.*, 660 deg. The result was that there was not a casting that did not show blow-holes on the top face. A temperature of 700 deg. would be considered rather high by the majority of aluminium founders, but owing to casting at 700 to 710 deg. they had obviated the trapped air trouble. Aluminium founders would bear him out that they cast a test bar as a rule half-chilled, and that was accepted. But if they took a bed-plate casting and cut six pieces of metal from six different places, had them turned up and put them on a tensile machine, they would not get two parts which gave the same tensile strength. He disagreed with Mr. Wilkinson that aluminium was a fairly easy metal to cast.

Mr. Dicken, continuing, said it was not necessary to vent green-sand cores for aluminium. It was not even essential to vent all dry-sand cores. He admitted, however, that there was a certain amount of risk in not venting dry-sand cores. A great deal depended on the ramming. As to fluxes, he said he used all virgin metals for everything, and he never fluxed his first melts because the flux left dust. There was a danger of the dust getting into the castings and causing holes. He took the skimmings from the first melt and put them through the furnace and fluxed with chloride of zinc. With regard to the analysis of a metal suitable for patterns, he recommended 88: 12, because it had the least contraction and would be a very suitable metal for small patterns. He could supply the analysis of a good pattern metal, but a very expensive one. Its contraction was ½ millimetre to the foot. That was 50 per cent. tin and 50 per cent. zinc.

CASTINGS FOR DIESEL ENGINES.

Conference between the Scottish Branch and Mechanical Engineers.

The interest taken in problems connected with the production of castings for Diesel engines was shown by the large number of prominent foundrymen and engineers who attended a joint conference held in Glasgow under the auspices of the Institute of British Foundrymen and the Institution of Mechanical Engineers. As is well known, many of the large engineering firms in Glasgow are at present engaged in the construction of Diesel engines of high powers, and demands are being made on iron founders for castings which will prove reliable under higher temperatures and greater stresses than have ever been known hitherto in either steam or internal combustion engines. It was thought therefore that a joint meeting between the Scottish Branches of the two Institutions would serve to bring the foundryman and engineer into closer association and afford a means of discussing the problems associated with the successful production of oil engine castings. The various speakers dealt with different phases of these problems.

Temperature Stresses and Working Conditions in Diesel Engine Cylinders.

By Professor A. L. Mellanby, D.Sc.

When the proposal to have this short group of papers was made, it was thought that it would be of advantage if the first speaker would give some indication of the temperature conditions that existed in Diesel engine cylinders. As the author has had a fairly large experience in temperature measurement in Diesel engines of large and small powers, he proposes to give one or two illustrations which will show, first, how temperature stresses may arise in pistons and cylinders, and, secondly, how cast iron may be expected to behave at elevated temperatures.

It is well known that in the early period of the history of the Diesel engine, cracked liners and pistons occurred very frequently. Experience has shown, to a large extent, how to overcome these troubles, but there is always the fear that, when cylinders are made larger and the power per cylinder increased, such experiences may be repeated. If, however, the designer can have some information as to the conditions under which the engine has to work, he will be in a much stronger position to guard against possible difficulties.

In Fig. 1 will be found information as to the temperature existing in an uncooled Diesel engine piston. This example is not taken from the writer's own experimental results, but is from some German tests, and it is given because it represents the most severe conditions he has encountered. In the larger engines where the pistons are water- or oil-cooled, the temperature conditions are much less severe. With the uncooled piston most of the heat has to pass from the centre to the circumference and from there to the cylinder walls, and with such a path for the heat there is a large temperature difference between the centre of the piston and the outer circumference. This naturally sets up very severe temperature stresses which, combined with the loads produced by the high pressure, may result in failure. It has been estimated by Professor Hopkinson that, if the top of the piston were treated as a flat disc, the stresses in a piston 11½ in. dia., when the temperature

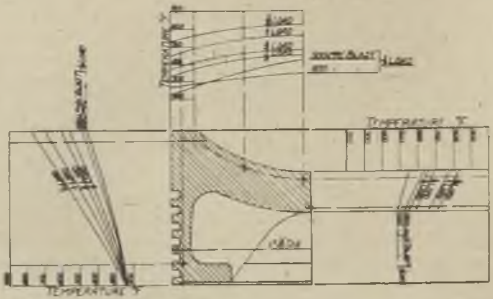


Fig. 1.—Temperature Conditions in a Diesel Engine Piston.

difference between the centre and circumference was 390 deg. F., would be about 7½ tons per sq. in.

It has been stated that Fig. 1 shows the worst temperature conditions with which the writer is acquainted. This statement requires some qualification. While the maximum temperature is the highest that he has come across, the temperature difference between centre and circumference is relatively small. With a 12-in. cylinder temperature differences of 400 deg. F. between the centre and circumference have been observed and under these conditions the stresses set up will be very severe.

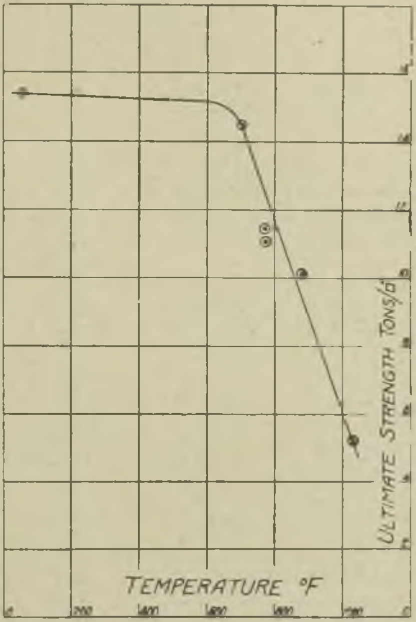


Fig. 2.—Strength of Cast Iron at High Temperatures.

With liners the temperature never reaches so high a point as in the piston, and a maximum temperature of, say, 300 deg. F., at the inner surface of the liner has been measured. Here again the temperature difference between the inner and outer surfaces is the source of danger, a point that is now being appreciated by designers. Changes in liner design are constantly taking place, and, where temperature and pressure conditions may be severe, the placing of large chunks of metal, which acted as heat reservoirs and set up large stresses, has been abandoned.

Actual Temperatures.

While from the stress point of view temperature difference is of importance, it is equally important that the value of the maximum temperature should be known. The cast iron has to stand the stresses induced by the high pressure and temperature difference, it is repeatedly heated and cooled, and it is subjected to wear. It is therefore necessary to know how cast iron will behave under high temperature conditions.

So far as tensile strength is concerned, Fig. 2 illustrates how this is reduced as the temperature rises. In this diagram the specimens were heated and stressed at the same time. That is to say, the load was applied during the whole test, which, in some cases, amounted to many hours. In this connection it may be well to issue a warning against accepting test results in which the specimen was left at the high temperature for a short time only, say, half an hour or an hour, and the load then applied till breakage occurred. Such test results will always give too high a value for the tensile strength at the higher temperature. The important point to notice from the figure is the rapid diminution of strength that results from an increasing temperature above 700 deg. F. (370 deg. C.). This diagram represents the performance of both good and bad varieties of cast iron. The strength at low temperature may be either greater or less than the values shown in Fig. 2, but the rapid strength diminution always appears to take place somewhere in the neighbourhood of 700 to 800 deg. F. (370 to 425 deg. C.).

Growth.

There are, however, other points that must be considered when the behaviour of cast iron at high temperature is receiving attention. Experience has shown that cast iron which is subjected to alternate heatings and coolings is liable to undergo changes in volume. This phenomenon is generally classed under the heading of growth, and it is well known that many examples have arisen in practice when engineering details, subjected to alternating high and low temperatures, have so far changed their shape and volume that they have caused considerable trouble. It becomes necessary, therefore, to know with some accuracy to what extent these changes of dimension can take place. Fig. 3 throws some light upon this subject. The curves illustrate the changes in length of a number of specimens, 6 in. × $\frac{3}{4}$ in. diameter, which have been raised a number of times to a temperature of 977 deg. F. (525 deg. C.), and then allowed to cool slowly. How far the growth properties of different varieties of cast iron can differ when subjected to this treatment is well brought out by the figure. Curve 4 represents the behaviour of a sample which was supplied as an example of good cast iron for steam-engine cylinders. Curve 3 is from a sample of Continental iron which was supplied with the recommendation that it was suitable for Diesel engine pistons. The figure shows that this claim can hardly be upheld. Curve 2, which is, by comparison, quite good, is supplied by an iron which was taken from a Diesel engine liner that had done a large amount of satisfactory service. Curve 1 is from a cast iron that was also put forward as suitable for Diesel engines. So far as

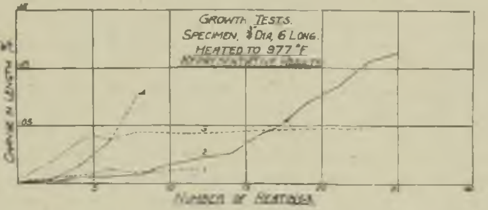


Fig. 3.—Growth Tests on Grey Cast Iron.

resistance to growth is concerned, it would appear to satisfy the claim.

Wear.

There is always the problem of wear to consider, since it is well known that liners have had in some cases to be renewed after a comparatively short life on account of the rapid abrasion by the piston rings. Wear measurements are rather difficult to make in the comparatively short time that is available for a test, but comparisons that have been made by the help of a quite simple abrasion test have shown that the wearing properties of cast iron may differ quite as much as their growth properties. It is, however, of interest to note that resistance to wear may be associated with resistance of growth, and that the iron of Curve 1, Fig. 3, came out equally well when its wearing properties were tested.

The author has thus attempted to give some idea of the nature of the temperatures that are reached in the working parts of a Diesel engine, and to point out that one of the dangers to be guarded against is the setting up of big temperature differences across any section of metal. Some indication has also been given of the way in which the tensile strength and the growth of cast iron is governed by high-temperature conditions, and it has also been indicated that good wearing properties of commercial cast iron appear to be associated with a good resistance to growth.

The subject now reaches the stage when we can make an appeal to the metallurgist. We can now tell him what are the worst conditions under which cast iron has to work, and we can ask him to tell us how to produce a metal that will retain its strength at the maximum temperature we might expect, that will not increase in size after a limited period of service, and that will resist wearing away under the rubbing action of the piston rings.

Some Characteristics of Cast-Iron for Oil Engine Castings.

By A. Campion.

The successful development of the internal combustion engine depends in a large measure upon the ability of the metallurgist and founder to produce castings suitable for the components, especially the cylinder, cylinder cover, liner, piston, and piston rings. The special conditions under which the metal is to work have been very fully and clearly stated in Professor Mellanby's Paper, so that it is unnecessary to repeat them here.

The purely metallurgical aspect of the problem is of importance, because only special sorts of cast iron can withstand the temperatures and stress conditions which obtain in oil engines. The properties and characteristics of these special qualities of cast iron differ in many respects from those of irons ordinarily employed for steam or general engineering castings, and the complicated nature of many of the castings demands from the foundryman great skill and initiative in devising the best methods of preparing the mould, placing and securing cores, venting, etc. It requires very careful consideration to determine the type of runners to be used and the position in which they are to be placed. An intricate casting requires that the metal used shall be capable of running into the thinnest portions and retaining its greyness; at the same time, it must make the thick parts dense and close-grained.

In considering the nature of the metal to be used it is not proposed to give detailed analyses of iron for any particular purpose, as these will naturally vary according to the size and intricacy of the casting, but rather to indicate the general metallurgical principles which have to be applied in determining the type of the metal to be used. The first requirement is that the casting shall be perfectly sound, as even a minute pin-hole in an oil engine cylinder or liner will render it useless. The term soundness has a very special significance when applied to these castings, owing to the heavy duty they have to perform under severe conditions. Slight flaws or imperfections which would be of small moment in ordinary castings would be fatal in a casting for an oil engine. The chief properties required are:—Soundness, the metal must be close-grained, with strong crystalline cohesion, and there must be freedom from draws or blow-holes. It must be of high tensile strength and other physical properties, and show constancy of form and dimensions, with high resistance to wear, and no cracking when submitted to high or fluctuating temperatures.

Principal Factors in Production of Cast Iron.

The main factors concerned in the production of cast-iron materials having these characteristics are:—(1) Composition; (2) melting and casting conditions; (3) rate of cooling and solidification; and (4) structural arrangement of the components.

As regards composition, the controlling element is the carbon, as all physical properties of the material are dependent upon the quantity and condition of this element present. The effect of all the other constituents being mainly according to the effect they have on the carbon and the compounds it forms. The total quantity of carbon in the iron is a matter of much greater importance than is commonly realised. The proportion of carbon which is in combination is always given much attention, and it is quite common to find statements about the combined carbon being the determining factor in regard to the strength and hardness of cast iron, or to find specifications in which the percentage of combined carbon to be present is given without the slightest reference to the total amount of carbon present. The total carbon is a variable quantity, and with the same amount of combined carbon present there must obviously be a great difference between a metal with, say, 3.0 per cent. and one with 3.5 per cent. The nature, as well as the amount, of the free carbon may be different.

The total carbon for oil-engine castings should be kept low, although it is not usually possible to get it much below 2.8 per cent., but it should not be present in a greater amount than 3.25 per cent. Silicon is a constituent of outstanding importance in determining the suitability of cast iron for any particular purpose. All cast iron contains silicon, and the proportion varies between wide limits. It exerts a powerful influence upon the condition of the carbon, and, consequently, the fluidity, hardness and other properties of the metal. Mr. F. J. Cook has devised a formula for determining the best proportions of silicon and carbon in metal, for any particular purpose:—

$$Sc = \frac{C}{4.26 - \left(\frac{Si}{3.6}\right)}$$

Sc = ratio of silicon to carbon.
C = percentage of total carbon.
Si = percentage of silicon.

For oil-engine pistons, liners and parts requiring highest tensile strength Sc should be between 0.76 and 0.82, and for water-cooled cylinder-heads or parts requiring high transverse strength Sc should be 0.83. The formula is empirical, but nevertheless is useful as a guide to the relative proportions of the two elements. Silicon usually varies between 1.0 and 1.5 per cent. Phosphorus may be beneficial or reverse, according to conditions, and consequently requires very careful adjustment. It gives increased fluidity and ability of the metal to take a clear and sharp impression of the more intricate parts of the mould, but if present in a large amount tends to reduce strength and make the iron brittle hard. In some quarters it is claimed that, for oil-engine work, this element must be kept to the lowest limit (especially in America, where hematite is used), but the writer considers that this is not only unnecessary but undesirable. The maximum soundness and strength is obtained when the metal contains about 0.5 per cent., and it is advantageous to keep it round about this percentage, and to adjust the casting and cooling conditions so as to prevent segregation. Manganese is one, if not the most important constituent of cast iron for oil-engine work, as it increases fluidity, closes the grain, tends to keep carbon in the combined condition, and acts as a powerful and efficient scavenger. It plays an important part in preventing changes in volume when the metal is submitted to high temperature conditions. It increases the stability of the carbide, and high manganese iron retain their strength almost completely at oil-engine temperatures. They also machine easily and take a high polish. Sulphur when present in large amounts is objectionable, inasmuch as it decreases fluidity and causes blowholes, but moderate percentages, *i.e.*, 0.05 to 0.08 per cent., increase resistance to wear.

Table I.—*Three different methods of expressing the composition of the same metal.*

Ultimate composition.		Proximate composition.		Structural composition.	
	Per cent.		Per cent.		Per cent.
Total carbon	3.144	Graphite	2.334	Graphio	2.334
Graphite	2.334	Carbide of iron	8.775	Phosphide eutectic ..	8.680
Combined carbon ..	0.810	Carbide of manganese ..	0.342	Sulphide of manganese ..	0.303
Silicon	1.840	Phosphide of iron ..	5.572	Pearlite	72.936
Sulphur	0.110	Silicon of iron	5.520	Ferrite (by difference) ..	15.748
Phosphorus	0.868	Sulphide of manganese	0.303	—	
Manganese	0.510	—		—	
Iron (by difference) ..	90.384	Iron (by difference) ..	69.154	—	

One of the principal means of securing permanency of strength and form is to increase the stability of the carbide, and to that end trials have been made of iron containing other elements such as tungsten, chromium, nickel, molybdenum, boron, vanadium, etc., but the results obtained have not been sufficiently good to warrant the extra cost. Chromium certainly reduces growth and retards dissociation of the carbides, and assists in maintaining strength, but the experience of the writer has been that equally good results are obtained more easily and cheaply by using manganese.

Melting and Casting.

The melting is probably best done in a reverberatory furnace, as it can be better controlled and the composition may be more easily and certainly adjusted and the desired casting temperature obtained, but good results can be obtained in a cupola, provided that it is of suitable design and under complete supervision. The casting temperature and the rate of solidification and cooling according to the thickness and contour of metal must be taken into account when deciding the composition to be employed in any given casting, as these are factors which exert much influence in fixing the constitution and structure of the metal upon which largely depends its properties. The ultimate chemical analysis, as usually stated, shows only the proportions of the elements present, but it is necessary to know the form in which they exist, and how they are distributed through the whole mass. The former is shown by a proximate analysis and the latter by the microstructure.

The structure of oil-engine metal should exhibit a matrix consisting mainly of pearlite with the free carbon or graphite in small particles evenly disseminated through it. The phosphide should also be regularly distributed in small patches, or in the form of a mesh. Large plates of graphite or large and segregated areas of phosphide, are to be avoided, as both are contributory causes of growth and deterioration of strength. Casting and cooling rates influence the arrangement of the constituents.

It is commonly assumed that there should be sufficient combined carbon to make the matrix wholly pearlitic with or without free cementite in order to give a certain amount of hardness, but it is open to discussion as to whether this is the most desirable structure. Hardness is no criterion of wearing qualities; in fact, the hardest material often has the lowest resistance to abrasion, and has a tendency to crack under heavy or suddenly applied loads. What is needed is a tough metal that can spread to a sufficient extent to form a highly burnished surface. If free cementite or large patches of phosphide be present they are liable to break off and form a grit which increases wear. It appears that the most satisfactory result is obtained when the combined carbon is sufficient to give a matrix which is not quite all pearlite, a very small quantity of free ferrite. Pearlite may vary in form, and the most satisfactory is when it takes the form of very fine laminæ of cementite and ferrite.

The method of melting a mixture of steel scrap and pig-iron is to be recommended for the production of metal with the desired structure giving high strength, durability, and resistance to heat conditions. The material is known as "semi-steel," and has a particularly close and compact structure, machines well and is capable of taking a high polish. Its preparation, however, demands most careful attention to detail, measurement, or weighing of coke, pig-iron, scrap and air, together with skilled attention to all melting operations, which must be effected in a well-proportioned cupola. The structural composition and arrangement of the components are of the first importance in securing the desired properties and characteristics in metal to be used in oil-engine castings, and can only be obtained by strict attention to details and exact control of every operation. The difficulties of making intricate castings to meet such severe conditions are very great, and can only be surmounted by complete and codial co-operation of all concerned, designer, metallurgist and foundryman.

Oil Engine Design as Affected by Foundry Practice.

By James Richardson, B.Sc.

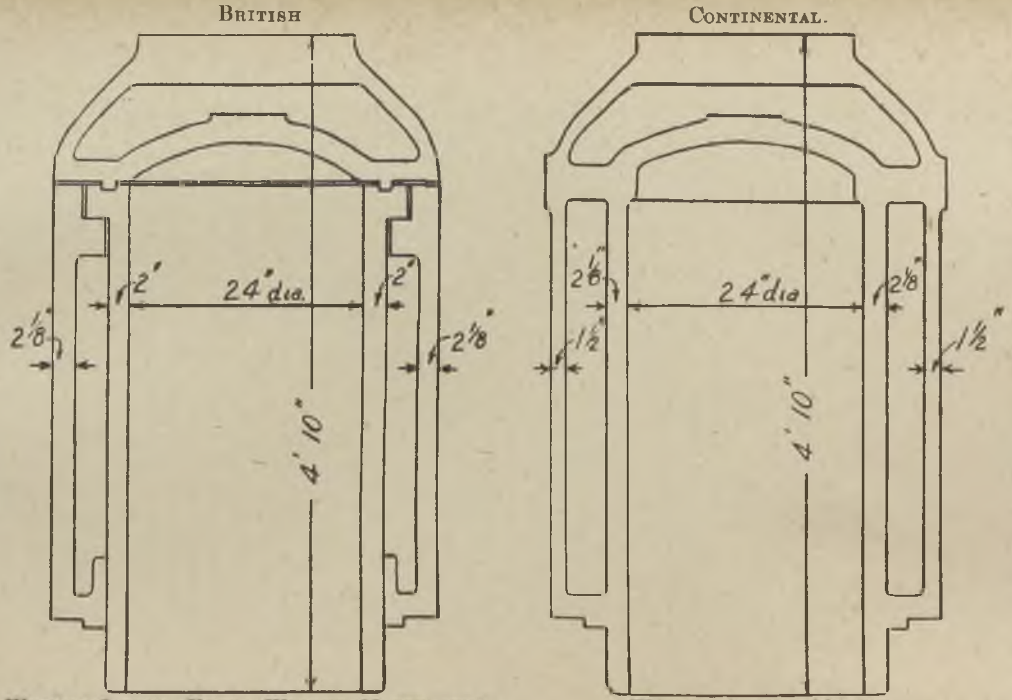
In the question of oil engines, particularly for marine purposes, constructors in this country are faced to-day with more severe competition than ever before in the history of this movement, and in order to meet efficiently the absolute necessities of the future, earnest collaboration between all parties concerned, such as the designer, the foundryman, and others, is essential.

It is unquestioned that the oil engine makes greater demands upon the foundry than any other type of prime mover, since not only have high physical loads to be withstood, but stresses due to intense temperature may be combined with these loads. The author has prepared several diagrams to illustrate what occur to him as the principal points in this connection.

Fig. 4 shows, with dimensions, two designs of Diesel engine cylinders. That on the left is a Continental design. The variation in wall thickness will be noticed. This design is there regarded as a satisfactory solution of the problem, little or no difficulty being experienced in getting the requisite hard material on the inside of the inner barrel of the cylinder to withstand the friction of the travelling piston rings. British practice demands more even thicknesses of material, and in the author's experience sufficiently hard metal on the inside cannot be obtained in this country with the Continental design, so that the designer is faced with providing for an extra weight of 33 per cent. or an extra cost of not less than 100 per cent. Must the British designer perpetually be faced with this disability? Do considerable variations in thickness impose such difficulties on the foundry that such castings are a commercial impossibilty? Can scientific cooling of the casting in the mould, to give chilling of the special surfaces in order to obtain the requisite degree of hardness and wearing properties, not be introduced as a commercial proposition?

The same point is further exemplified in the Diesel compressor cylinders as shown in Fig. 5, the extra weight due to maintaining relatively even thickness throughout, without what would here be regarded as thin metal, and the insertion of a special liner, being 33 per cent. with 60 per cent. increased cost.

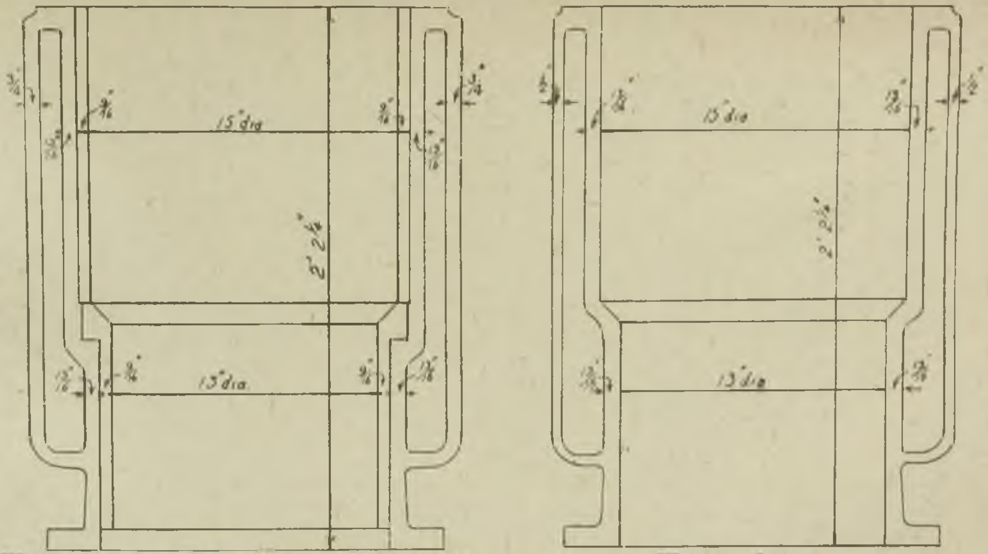
In respect of cylinder liners as shown in Fig. 6, the question of the size of the head is important.



WEIGHT 6 TONS, EXTRA WEIGHT 33 PER CENT.; EXTRA COST 100 PER CENT.

WEIGHT 4 TONS 10 CWT.

FIG. 4.—A COMPARISON OF BRITISH AND CONTINENTAL DIESEL CYLINDERS.



WEIGHT 8 CWT.; EXTRA WEIGHT 33 PER CENT.; EXTRA COST 60 PER CENT.

WEIGHT 6 CWT.

FIG. 5.—DIESEL COMPRESSOR CYLINDERS.

What size of head is necessary to insure a sound casting? It must be remembered that the head represents extra cost, roughly in proportion to its weight. There seems to be no standard in foundry practice in this respect. The author has found that in order to get a requisite hard material for the working or inner surfaces of the liner, that

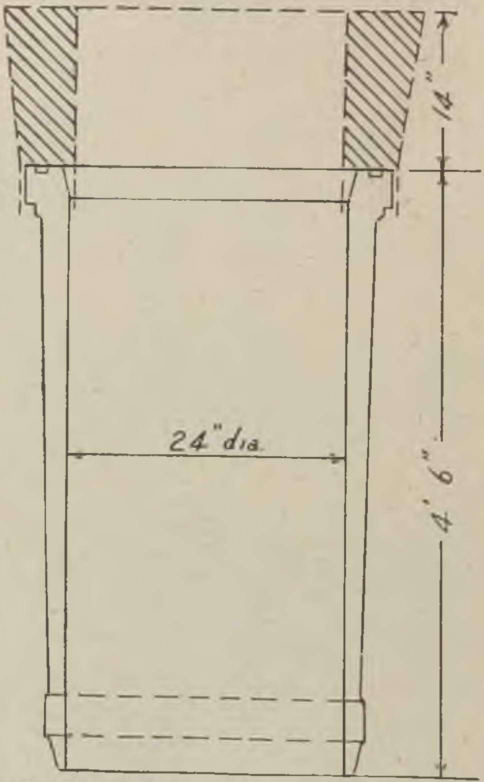


FIG. 6.—DIESEL ENGINE CYLINDER LINER. WEIGHT OF CASTING 1 TON 16 CWT.; WEIGHT OF LINER CASTING PLUS HEAD 2 TONS 5 CWT. EXTRA COST DUE TO HEAD 25 PER CENT.

chills introduced in the core are efficacious, although liable, due to the drawing action so generated, to set up hair cracks.

These few points occur to me as the most important with which British designers are faced, and a definite solution and ruling on these questions would be a decided advantage.

Oil Engine Design from a Foundryman's Point of View.

By William Bell.

From a foundryman's point of view, a great many of the failures in iron castings for oil engines are due to the design. Many of the designs involve internal stresses, which arise from the effects of crystallisation and graphite deposited during solidification, causing unequal contraction, porous and weak castings. This is undesirable at any time, but more especially in castings that have to be subjected to repeated heating. Now, in the manufacture of castings for oil engines, such as cylinders, covers and pistons, the foundryman's difficulties arise from the material cast into the moulds more than from the actual moulding, and although the demands of the engineer. are increasing year by year for more complicated castings, the foundryman of to-day, with his greater store of knowledge to draw from, is in a better position to supply his demands.

When we consider the metal to be cast into the moulds, we must remember that the engineer is striving for a material with all the good properties of cast iron, and also with some of the good properties of steel. It is here that the foundryman's troubles begin, for, as one approaches the chemical composition of steel, one loses the valuable properties of cast iron, or in other words, when the carbon, silicon, and phosphorus are reduced, the valuable properties, such as low melting point, large range of fluidity, and expansion on solidification, which makes cast iron easily cast into moulds, are lost. It is easier for the foundryman to overcome these difficulties if the casting has fairly regular thicknesses, or if it is possible to regulate the rate of cooling.

The conditions that oil-engine castings have to work under are so strenuous that one is inclined to ask the question, Can cast iron stand up to it without failure? The iron must have a certain strength at normal and higher temperatures; it must wear well; it must not crack nor grow under repeated heatings, and it must not leak under water pressure. The metallurgist answers the question and proves that it can. By careful experiment he finds that an iron of specified chemical composition, cast under certain conditions, *i.e.*, noting the rate of cooling, gives the correct structure and physical properties required by the engineer, but if this important factor is neglected, the structure may be coarse and the physical properties destroyed.

The careful designer notes all the conditions specified by the metallurgist, particularly the rate of cooling, and when he takes these into consideration in the making of his design, he places the foundryman in a better position to produce castings to the engineer's requirements. But the average draughtsman bases his calculations on the assumption that cast iron is a material that has the same strength throughout a casting irrespective of the well-known fact that it is possible to cut two test pieces from the same casting and get results as high as 20 tons per sq. in., and as low as 4 or 5 tons per sq. in.—this difference being due to the different rates of cooling in the two parts from which the tests were cut. The foundryman knows, of course, that this is one of the most important factors in determining whether a cast iron will have the right structure to give the required physical properties or not, and they use every means at their disposal to equalise the rate of cooling, such as the use of densener, stripping the sand off heavy parts, etc., and if foundrymen could get the draughtsman to see the great importance of this function they would get a step nearer the realisation of castings to suit the engineers' requirements.

When the design of the castings gives fairly regular thicknesses the foundry metallurgist can use an iron of a definite chemical composition, after estimating what the rate of cooling will be, and obtain dependable results. If, on the other hand, the thicknesses vary greatly, iron of any given composition will not give the same structure in both thick and thin sections. The result must be a compromise at the expense of one or other of the sections. The thick section may be the most important, and naturally the foundryman would like to use an iron with the right chemical composition to give that part the right structure, but the rapid cooling on the thin parts would make them too hard to machine.

DISCUSSION.

In reply to Mr. Richardson's statement as to the comparison of British and Continental foundry practice, **Mr. Bell** said that he had great faith in the British foundryman. What could be cast on the Continent could be cast in Britain. The difference in the rate of wages and the hours worked per day might give the Continental foundryman an advantage in the cost of production, but he believed the advantage ends there. The British engineer was respected all over the world for his high class workmanship, and the British foundryman had made it possible for him to hold that position.

Fig. 4 showed two designs of Diesel engine cylinders—the British one was built up of three castings, while the Continental one was cast in one piece. When the nature of cast iron is considered, together with the size of the casting, and the high physical load to be withstood, this design had nothing to recommend it, but if the cover was cast separately—and he believed from an engineering point of view this would be an advantage—the rest of the casting should present very little difficulty to the British foundryman.

The variation of thickness in the two walls, $1\frac{1}{2}$ to $2\frac{3}{8}$ in., should not make it impossible for the British foundryman to cast with a reasonable amount of hardness in the barrel. The outside thickness on such a casting as this would always contract more than the inside, internal stresses were liable to be set up, and a stronger casting would result from reducing the inside thickness and increasing the outside without materially interfering with the weight. The air and exhaust ports were not shown on this design, and it was generally these details that caused unequal thicknesses.

Fig. 5 showed two designs of air compressor cylinders. From a moulder's point of view, the Continental design would be the easier to mould, the greater space between the two thicknesses would allow a stronger jacket core to be used. On the other hand, if the British design is accepted, the space between the outer and inner walls increased, keeping the thicknesses the same, many of our foundries could produce such a casting with the inside sufficiently close grained to eliminate a liner.

With regard to Fig. 6, the question may be asked, what size of a head was required on a liner of this description? If this casting were cast without a head, the top part being heaviest, would solidify last. The crystals start to grow at right angles to the cooling surface, gradually getting larger as they near the centre, the bottom feeds away the liquid metal, leaving the heavy part at the top porous. He would not say that a head of 14 in. was required, but it was necessary to put on a head sufficiently high to ensure that the last part to solidify was in the head that was to be cut off.

The foundryman generally kept on the safe side, and it was better to have an inch extra than an inch too little, and if a sounder casting was produced by putting on a head, the extra cost was justifiable. In conclusion, he again reminded draughtsmen or designers to consider well the rate of cooling when designing for cast-iron castings.

Mr. J. E. Hurst said, that after listening to Dr. Mellanby's Paper, two points of great importance to those interested in Diesel engine castings emerged. Both these points centred round the fact that the resistance to distortion under heat influences, and the resistance to wear, as pointed out by Dr. Mellanby, were almost synonymous terms, and at the same time cast iron of the type giving a low growth figure were the best type for Diesel engine cylinder construction. The first point he would like to make was that, if this was the case, it was perfectly easy and eminently necessary to specify some property which would differentiate between satisfactory and unsatisfactory irons for Diesel engine cylinder construction. He suggested that it would not be difficult to specify a resistance to "growth" of the type shown by Dr. Mellanby in his best sample. This would at once provide a means for differentiation between irons for Diesel engine work, and would enable those who had irons to offer for this purpose to have recourse to some test which would assist them in assuring designers to whom they presented these irons, that they could at least offer them something equal, if not superior, to what they were at present using. The absence of any such test in the past had hampered metallurgical men very considerably in improving the quality of iron for Diesel engine purposes. The fact that resistance to distortion and resistance to wear were almost synonymous terms was also, in the second place, a fact of intrinsic interest. If the resistance to distortion was due to the stability of the pearlite carbides, then the resistance to wear was due to the presence of pearlite, or conversely, if the resistance to wear was due to the presence of the pearlitic carbide, then the resistance to distortion was also due to the presence and stability of this constituent. This was a point of considerable importance to the metallurgist. He thought all metallurgists would have liked to have heard from Dr. Mellanby some opinion as to whether or not the severity of the working conditions sustained by high-speed internal-combustion engines of the petrol-engine type were at all comparable with those sustained in engines of the large Diesel type. Some such statement, if it could be made, would help metallurgists very considerably in fixing their ideas. In one respect alone such a statement would be of value, as in the case of the former it was a much more simple and inexpensive business to try out castings in the smaller petrol engines than in the large Diesel engines. With regard to Professor Campion's Paper, he might call attention to the fact that manganese in the presence of silicon did not preserve the carbon in the combined condition. It had been frequently shown that under these conditions, other things being equal, the exact opposite was the case. This was a very general error amongst foundrymen, and it was for that reason that he took the opportunity of pointing out the mistake. He was greatly interested in listening to the remarks of Mr. Richardson, which were extremely sound and very much to the point. With Mr. Richardson, he was quite sure that Diesel engine castings equivalent to anything that had been done in Continental practice could be produced in this country. He could not refrain, in concluding, from calling attention to the centrifugal casting process for the production of cylinders and piston rings. Fundamentally the process offered the only solution at present to the production of cylindrical castings with assured freedom from internal defects and porosity. With this process for Diesel engine liners, given certain conditions of quantity production, cast iron of exactly the same composition as that used in the sand-casting methods could be cast centrifugally, and, apart from the assured soundness of the castings, centrifugal castings made an enormous improvement in the tensile strength and resistance-to-wear conditions over the same material sand cast.

Inefficiency of Short-period Heating Tests.

Mr. Donaldson said: The four Papers on cast iron for Diesel engines were of considerable interest, and brought out many points connected with this important subject. They emphasised the fact that difficult conditions have to be met—conditions so difficult and strenuous that one sometimes questioned, like Mr. W. Bell, if cast iron could really stand up to them. Professor Mellanby, dealing with the tensile strength of cast iron as the temperature rises, gave an interesting curve showing the strength of cast iron at elevated temperatures and under prolonged stresses. He discredited test results obtained where the test bars had only been subjected to a particular temperature for a short period before breaking. He agreed with him on this point, and had shown it by submitting test bars to a prolonged annealing at 450 deg. C. and 550 deg. C. before breaking at high temperatures, when results somewhat similar to those given in the Paper were obtained.

Chromium and Growth.

The growth tests shown in Fig. 3 in the Paper were of interest, as they showed not only that this property differs with various cast irons, but also that iron could be obtained which is particularly "non-growing." In connection with growth, he (Mr. Donaldson) had carried out a series of experiments, and found that with 0.4 per cent. of chromium an iron was obtained which did not grow, but, on the other hand, showed a small contraction on prolonged heating at 550 deg. C. (1,022 deg. F.). In connection with wear, Professor Mellanby makes the statement that resistance to wear may be associated with resistance to growth. This is a statement which is of great importance in dealing with Diesel engine castings, as Mr. Hurst pointed out in the subsequent discussion. In support of this statement, Professor Mellanby added that the iron of Curve 1, Fig. 3, came out equally well when its wearing properties were tested, and in this connection he would like to know if the other irons shown in Fig. 3 were

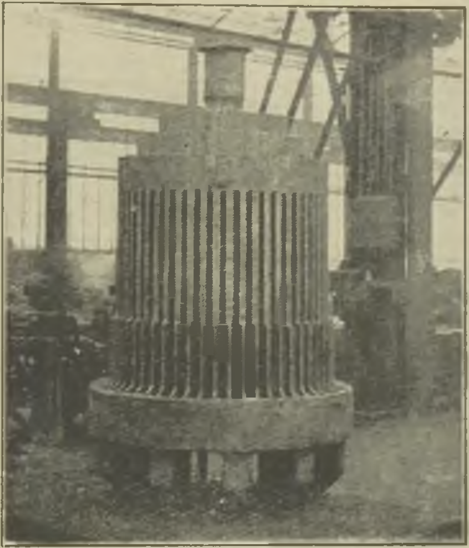


Fig. 7.

also tested for wear, and if a similar relationship was obtained.

Low Phosphorus Content Favoured.

With regard to Mr. Campion's Paper, whilst agreeing in general with what he had said regarding the composition of the material, he was inclined to favour a rather low phosphorus content. Even with 0.5 per cent. there was always the tendency for segregation to take place, and this tendency could be reduced considerably by reducing the phosphorus to 0.2 per cent. without being detrimental to the casting. Mr. Campion also favoured a high manganese-content, but to prepare sound castings containing over 1.5 per cent. of manganese it was rather difficult, especially if the manganese was added in the form of ferro-manganese to the ladle. A small percentage of chromium, 0.4 to 0.5 per cent., produces slightly better effects so far as growth and stability of the carbides at high temperatures are concerned than 2.5 per cent. of manganese. Of course, there is the extra cost and the question of introducing the chromium, but the latter difficulty should be over-

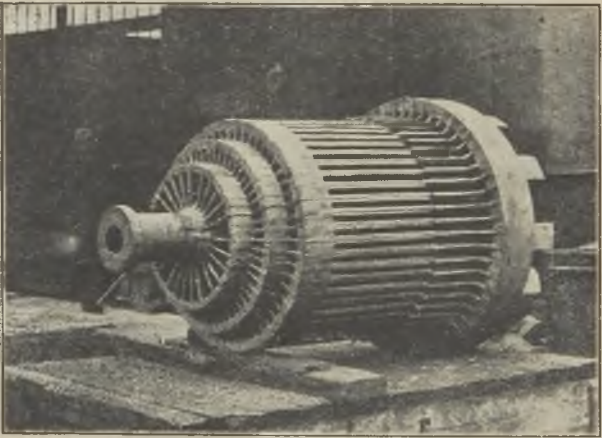


Fig. 8.

come to a great extent by using the chromium pig-irons which are now available. Mr. Campion also favoured the use of the reverberatory furnace for melting, and this was certainly desirable, and also the introduction of a certain percentage of steel scrap in order to obtain the desired structure, high strength, and other properties necessary. Pyrometric control in casting could also be more generally adopted with advantage.

Continental Conditions Discussed.

Mr. Richardson in his Paper gave Continental foundry practice a large amount of credit which did not appear to be altogether justified. His drawing of an integral casting appears to be satisfactory, but designers would be better to ask for such a type only in small sizes where there were large margins in strength. The engineer who proposed such a casting for an engine of the size shown by Mr. Richardson in Fig. 4 in his Paper was asking for more than he is entitled to demand, and if such castings were produced on the Continent, successful results with them must be very much of a lottery. No one could say how the stress was distributed in such a casting, and, even with scientific cooling provided, it was doubtful if the results obtained would justify the faith Mr. Richardson put in this type of casting. In the Paper by Mr. Bell, the many difficulties experienced by the moulder in dealing with these intricate types of castings were fairly considered, and indicated one point where the present series of Papers should help considerably, namely, the pressing need for collaboration between all those interested in this highly important subject.

Heat Stresses.

Mr. Vincent said he was particularly interested in the references that had been made to heat stresses. His attention was drawn to this matter some three or four years ago, but he found that in the majority of text-books a formula was given something on the following lines:—

$$\text{Heat stresses} = \frac{d\ (T_1 - T_2)\ E.}{2}$$

This is obviously in error, as it takes account of stresses only in one direction. At one time he had cause to examine the problem, and, as another step forward, incorporated two stresses at right angles, when he had stresses $= (1 + m)\,\frac{1\,(T_1 - T_2)}{2}\,E$, *i.e.*, an increased stress. Not being satisfied with this, Mr. Vincent said, he turned to the theory of flat plates and deduced a formula, but here the result obtained was so complicated that for practical purposes it was useless. He observed in the "Journal of the Institute of Mechanical Engineers" recently a treatment of this subject so far as the liner is concerned, but here again for ordinary purposes the results are too elaborate. It must be borne in mind that the average person during calculations fought shy of mathematics. He suggested to Professor Mellanby that he might apply himself to the problem and deduce something fairly easy to use and yet giving greater accuracy than the above. The results mentioned in the "Journal" were from an old engine having a high fuel-consumption and probably out of date from modern standpoints. It was certainly very

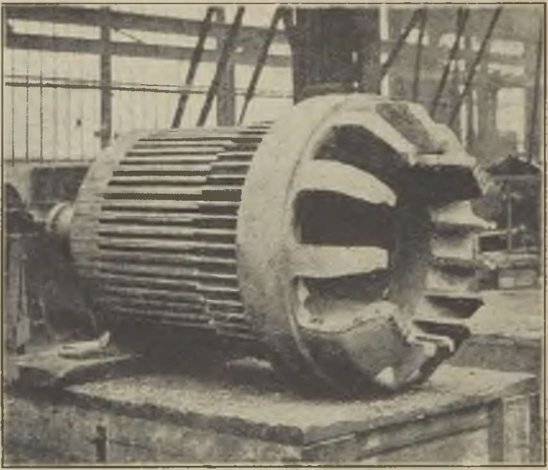


FIG. 9.

unfortunate that our professors only had the chance of working on old gear that has been discarded for commercial use; the results obtained are of use, but cannot be applied to modern conditions in most cases without assumption. The differences between engines of 10-30 h.p. per cylinder and modern ones of 400-500 were very great, and a great step forward would be made if the academical men could work upon up-to-date machines.

Suggested Elimination of Cast-Iron.

Turning again to the question in hand, it was obvious that the thickness must enter into the problem; the thinner the metal the less the stress due to heat-flow. There were various examples where attempts have been made to do this, *e.g.*, the Doxford and Still engines, particularly the latter, but here the factor was carried to the extreme, resulting in a very difficult casting, at the same time involving shrinking on bands of steel, etc., and the result was still a very heavy article. He therefore suggested the abandoning of cast iron—one of the weakest metals—and the use of a stronger one, namely, steel, when the thicknesses could be reduced by half without elaborate ribbing, resulting in a corresponding reduction in the temperature stresses. Of course, the full advantage of steel cannot be obtained, since it is necessary to have rigid liner, additional metal has to be left on to secure freedom from distribution, but even so, great advantage results.

The marine world is very conservative, but it should not hesitate to adopt proved practice. Why not survey the automobile and aero-engine fields and gather in the experience gained? It is true that there the engines are relatively small, but none the less they are highly stressed and have running speeds far in excess of anything in the marine field. By this means great saving would result. Did it not seem absurd that one engine develops 1 h.p. for about $2\frac{1}{4}$ lbs. weight, whilst another requires 400 lbs., the maximum and mean pressures being similar? Assume $2\frac{1}{4}$ lbs. at 2,000 r.p.m., therefore at 200 r.p.m. weight per h.p. = 25 lbs. Reducing the rating by 25 per cent., therefore weight per h.p. = 32 lbs. approximately. Now allowing stresses 3/4 of aircraft practice, this coupled with the reduced frequency considerably reduced, the effective stresses and the weight became 45 lbs. per h.p. For accessibility which spread the cylinders, etc., this figure could be doubled to 90 lbs. per h.p., and an engine should

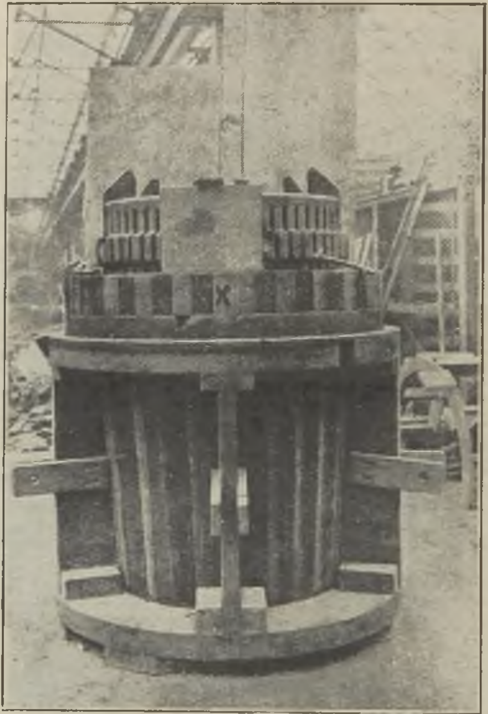


Fig. 10.

be obtained perfectly free from breakdown, and at the same time a great advance on present practice for slow-speed work. This was little in excess of the weight of such engines as those used at present for submarines, etc.

A car-engine in the average person's hands runs two or three years with no attention at all, so an engine as above, which was always being run by trained engineers, surely should be a sound proposition. Now, how is this to be carried out? Obviously by discarding cast iron. It is this material that is responsible for most of the weight of the present engines. Nearly all aero-engines of large size are fitted with steel liners, and they have proved very successful, giving a good life with piston speeds of 2,600 r.p.m. and over. Surely, then, a steel liner was possible at 500 to 900 r.p.m. Steel liners of 8 in. to 14½ in. have already been tried in some cases, and have proved successful, the weight reduction being considerable, while the engine was capable of continued operation at higher mean pressures than are pos-

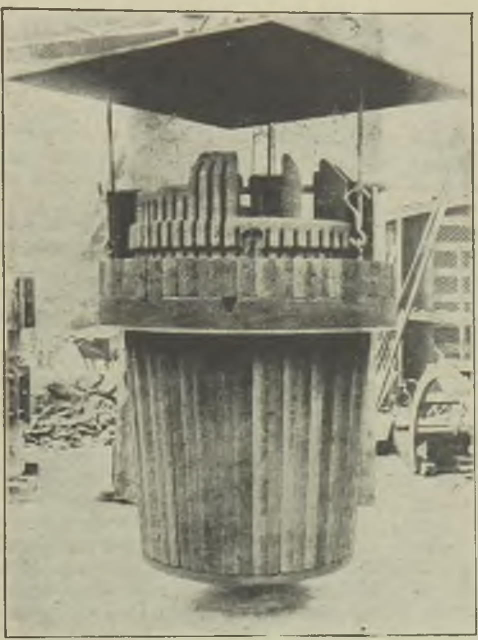


Fig. 11.

sible with cast iron due to the reduced heat flow. In conclusion, he would like to suggest that some radical departure of the nature suggested should be considered. If the industry was to expand beyond its present limits, 300 to 400 lbs. per h.p. must be altered, and the best way of doing it was to eliminate cast iron. Many doors, covers, etc., at present in this material could be made as easily in aluminium.

THE MAKING OF A "STILL" ENGINE.

Mr. N. McManus said: At the former meeting of the Institutes of British Foundrymen and Mechanical Engineers on Diesel engine castings, reference was made during the discussion to the fact that engineers had to go to the Continent for these intricate castings, having regard to the workmanship and quality demanded. The Branch President of the Institute of British Foundrymen, Mr. Affleck, in reply to this remark, purposed showing what can be done in a British foundry with such castings when the problem was presented and sympathetic consideration given by the engineers. Unfortunately, he was away from home on business, and he had therefore been asked to reply on his behalf. Mr. Affleck's contribution reads:—

The casting he proposed describing was a combustion cylinder for the "Still" oil engine, with which, no doubt, many were already familiar.

Fig. 7 gives a general idea of the type of casting, which has a bore of 22-in. dia., terminating in a cone-shaped end, at the apex of which is a $2\frac{3}{4}$-in. dia. hole entering the projection seen at the top of the casting; the thickness of metal in the cylinder wall is 0.62 in. Surrounding the cylinder there are a series of ribs, 55 in number, which extend the full length of the casting and surrounded with three belts, as seen on the upper portion. Fig. 8 shows these belts much clearer. The height of casting is about 5 ft. and weighs 25 cwts. Having now received some idea of the nature of the casting, it may be interesting to know that the whole scheme for making this casting was drawn up in the "Foundry Planning Department," and drawings prepared, giving complete details to the patternmaker for the patterns and core-boxes, also to the foundry for the procedure to be adopted in preparing the mould and cores, etc. Another departure from general practice that was adopted was to make both the mould and all the cores in oil-bonded silica sand.

Fig. 8 shows the cylinder lying horizontal and gives a more complete view of the ribs and belts, the ribs on the end being only $\frac{1}{2}$ in. thick. This view also conveys some idea of the work involved in producing such a casting.

Fig. 9 is a view taken from the opposite end, and shows the projections which form the various ports in this cylinder; the narrow ones are solid, the others being cored out by the projecting portions of the rib cores, which is shown in Fig. 11. A feature of this casting is the method adopted for forming the ribs; each core is a separate one, and, as previously mentioned, there are 55 in number with 29 different types. These are all made from 4 half-core-boxes, which are fitted with loose removal pieces, so arranged that with the aid of a chart the complete set can be produced, otherwise a number of core-boxes would have been required. Each core is made complete, and owing to its shape, which is very irregular, is dried on a sand bed, the bed being formed on the core before the box is drawn. The core cannot be made in halves, as the thickness of sand at one end is only $\frac{1}{4}$-in. thick.

Fig. 10 shows a set of these cores assembled and fitted together in a fixture, previous to placing in the mould. The assembly of these cores must be accurate and close fitting, and, reverting to Fig. 8, it will be seen that they have to follow the contour of the cylinder from the 2 ft. 11 in. dia. of the large belt at the right, down to the neck of the projection seen on the left, which is $4\frac{1}{4}$-in. dia. Each core has a back or print which is wedge-shaped and serves to strengthen the core and facilitates the building. Fig. 15 makes this point more clear. In assembling this core, there are what are called so many "master cores" inserted first, which have a special locating lug formed on them. One is seen on Fig. 10 at X. The intervening spaces between these are then filled in.

Fig. 11 illustrates the assembled core lifted out of the fixture and ready for lowering into the mould. It will be noticed that the diameter of the core is tapered to suit the mould, which is also tapered. This was done to facilitate closing and also to reduce the weight of the rib cores. The core seen at the base is for the purpose of locating the cores to give the correct position relative to the cylinder barrel contour, each rib having a recess which fits over a ring formed on this core. In a similar manner the large ring core also locates the upper portion for diameter as well as spacing. The weight of this core is carried by a steel ring seen below the large ring core, and to which hook bolts are attached; the base plate core is also kept in position while lifting by a suitable hook bolt attached to the lifting plate, this being removed after the core is set into the mould. The steel ring remains in the mould.

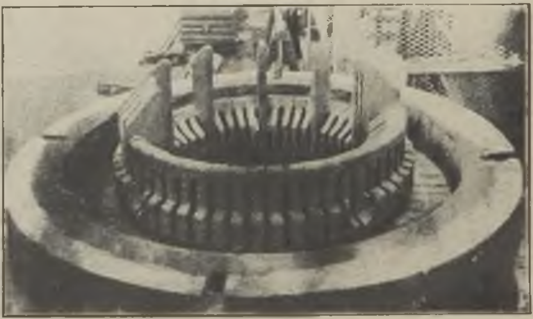


Fig. 12.

Fig. 12 is a view looking on the top of the mould with the assembled rib cores in position, and ready for the barrel core to be placed in position, and Fig. 13 shows the mould built up of three rings made with oil-bonded sand; no boxes are used, but a sheet-steel band is placed over the joints, being a case of "Safety First," so as to prevent any possible accident due to bursting. These rings are about 5 ft. dia., 19 in. deep, and have a tapered bore, which is approximately 3 ft. dia.

Mr. Ross, of the Argus Foundry Planning Department, has prepared diagrams (Figs. 14 and 15), one showing the complete arrangement of the mould in which is shown the barrel core in position and the closing top core, neither of these having been shown in previous views; and one giving a section through the assembly of cores (Fig. 15). It is hoped that these brief remarks have at least been interesting and that they have conveyed some idea of what can be done when some consideration is given to the foundry by the engineer, but it

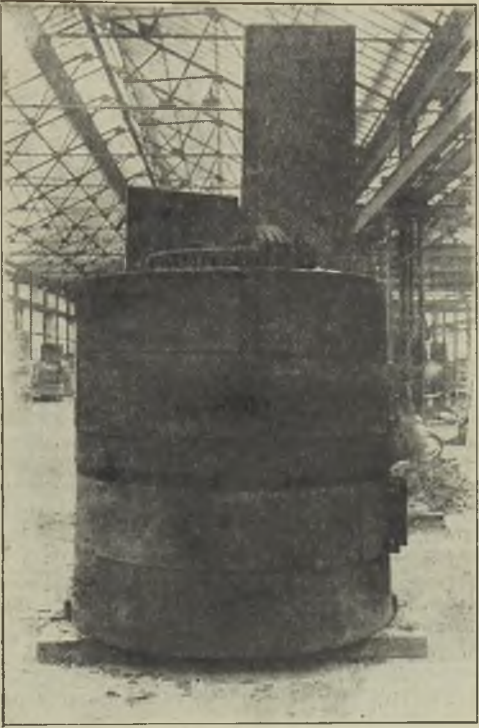


Fig. 13.

must be clearly understood work of this nature requires much more attention, the risks are greater, and the metal "special." Therefore, when buyers are considering quotations, they should not be biased by the lowest price quoted. The speaker then asked Mr. Ross to explain Figs. 14 and 15.

Foundry Planning for a "Still" Engine.

Mr. A. Ross said Fig. 14 is a sectional view showing the arrangement of the mould for the casting of a Diesel engine cylinder. The entire moulding and casting process is carried out to a planned scheme of operations to ensure definite control and accuracy at every stage of the process. In foundry planning it is necessary to keep in view the duty of the casting and the quality necessary, both as regards material and requirements of design.

Every core of itself has a specific purpose and is arranged and made accordingly. There are in all 63 cores, as follows:—Three external cores, forming the mould; one core behind the flange at the bottom; one master core at the bottom (a complete circular disc), which positions the rib cores by a registering key; one master core at the top (complete ring), positioning the rib cores by a registering key; 55 rib cores (29 different designs) made in four adjustable boxes; one barrel core; and one top or closing core, making all the scavenge and exhaust ports, runners and risers.

When the exceptionally thin sections for such a large core of a cylinder and the general intricacy of the casting are considered, the advantages of having every step planned for the manufacture and building of mould and cores are very obvious.

The finished thickness of barrel of ⅝ in. does not give any allowance for discrepancies in alignment, therefore it is absolutely necessary to have all cores accurately registered and rigidly held in position. The barrel core is registered by a bottom print and is centralised at the top and held in position by the closing core. The rib cores are positioned by the registering keys on master cores. The building of the barrel, comprising the 55 rib cores, is of itself quite a formidable job, but may be carried out quite easily by means of the appliances provided.

If engineers were asked to produce a similar article in steel or iron they would demand the finest and most expensive machines and tools.

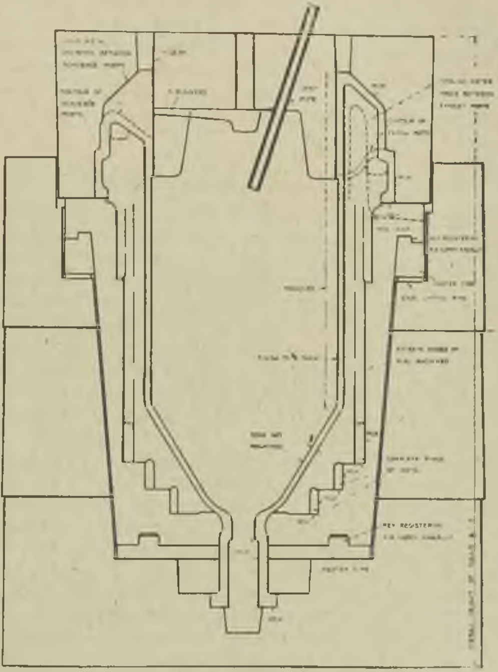


FIG. 14.

To make a success of this casting the foundryman is called on to produce a barrel built with staves of sand. Probably designers and draughtsmen do not quite realise that there are limits to what can be made in sand, having in view the commercial side of the question. As progress is made in engineering, designs in many cases become an accumulation of additions or alterations to the original design. These additions are very often embodied in the design without consideration for the difficulties which they may occasion in the foundry.

The Chairman remarked that some people said that if they wanted a good article let them go to Germany for it, but he thought that the work which had just been described and illustrated would be difficult to improve upon. It was a job made up purely of cores. If that became a standard casting it would no doubt become much cheaper, but where one had to do all the experimenting and make money at the same time it was very difficult.

Question of Costs and Quality.

Mr. James Richardson, B.Sc., said every shipbuilder and engineer in this country was trying to induce the shipowner to order new tonnage, but the shipowner was naturally only willing to do so at an economical price, and unfortunately the shipbuilder and marine engineer were unable, in this respect, to meet his wishes. We sought to reduce the cost of shipping tonnage to such an economical level that the shipowner will buy. There was no difficulty whatsoever in regard to reducing, by a very considerable amount, the weight with the standard design of marine machinery, whether steam or Diesel. If steel were used instead of cast iron for certain parts, and aluminium substituted for others, then the weight would be very much reduced, but the cost would be greater, leaving us in a still worse position to meet competition. The difference in scantlings used by various makers of engines mentioned by the chairman is understandable. Many owners have their own ideas in this matter. For example, take the case of commercial motor vehicles, where different buyers will choose different types. Some require slow running engines, while others will readily take the risk of high maintenance charges in order to obtain a figure of low first-cost. In exactly the same way some shipowners are not willing to pay an extra price for a design with a high factor of safety and probably low maintenance charges.

He felt that the engineer would ask the foundryman to satisfy his requirements in regard to castings, without any inordinate increase in the cost per cwt. or per ton in these castings. It is inevitable that the question of cost should come into this discussion. Secondly, the engineer must be satisfied as to the definite physical qualities of the castings, in order to avoid the risk that it might prove unreliable. The illustrations of design which he gave in the Paper he read at the former meeting must not be taken to represent actual practice. They simply represent basis designs in order to indicate the nature of the simple problems with which designers were commercially faced to-day. The present position was that there is no difficulty in building a set of machinery to fulfil the shipowner's specification, and there should be no difference in the foundryman's case of the way in which the design was tackled in the design stage. Nevertheless, we sought to get down to a commercial basis, and in order to secure work, the engineer had to undertake onerous guarantees for the machinery for which he tendered. He must definitely specify, in many particulars, the performance of the engine in question. Therefore he asked the

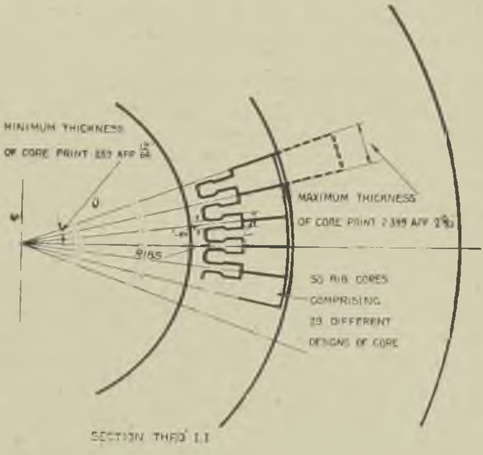


Fig. 15.

foundryman to assist him by guaranteeing the physical quality of the castings supplied, thereby to lessen the risk which the engineer had to undertake in regard to the whole contract.

The question of Brinell hardness or other suitable tests should be studied, and figures should be capable of being specified by the foundryman as well as other physical properties which can readily be measured by the buyer. If the foundryman and the engineer could get closer together amicably to discuss these questions, he was sure the result would be the removal, if not of all, at least of some of the difficulties.

Metallurgical Considerations.

Mr. J. Arnott said he proposed to limit his remarks to the metallurgical side of the subject, with which Mr. Campion has dealt in a general way. When one examined the figures he (Mr. Campion) suggested for the various elements, he found nothing differing in any way from what is at present being used for steam cylinder and similar castings. His figures were:—Total carbon (maximum), 3.25; Si, 1.0 to 1.5; P, about 0.5; S, 0.05 to 0.08 per cent., and for Mn no figures were given.

There was nothing distinctive about that. Several firms were making quite ordinary castings (steam cylinders) every day of metal which exactly met these limits. In considering the subject of the metal for the highly-stressed and heated parts of Diesel engines, there appeared to the speaker to be two definite questions to be answered. First, did we know what composition is best suited for the work? Second, could we make castings of such a composition at a reasonable price? With regard to the first question he ventured to say that we did know what was wanted, and were in a position to draw up a definite specification.

The speaker, dealing with features of the composition of Diesel engine castings, said:—

Starting with total carbon, it was practically agreed that it should be low in order to ensure strength, soundness, and resistance to growth. We certainly did not want anything over 3 per cent., and preferably not over 2.8 per cent. With regard to the distribution of C, it was generally agreed that for strength and resistance to wear it was desirable to have neither free ferrite nor free cementite. That implied that what was wanted was somewhere in the region of 0.8 to 0.9 per cent. of combined carbon. Silicon should be as low as possible. It was definitely established that, other things being equal, increase in silicon results in increased growth. For that reason alone silicon must be kept down. The actual percentage should be settled after consideration of the thickness and size of the casting. He placed the limits at 0.7 to 1.2 per cent. He thought Mr. Campion's limits of 1 to 1.5 per cent. were far too high. A casting 1 in. thick and of moderate size could be safely cast with 1.2 per cent. Si iron without fear of chilling, provided the sulphur was low, and very thick, heavy castings were quite machinable with 0.6 per cent. Si. Admittedly difficulties arose in settling the silicon content of castings with widely varying sections or with thin projections. It might be necessary to hasten the cooling of heavy chunks of metal or retard that of thin sections, but in any case the silicon content should be kept to the lowest figure possible. As far as sulphur was concerned, he found it very difficult to make low-silicon castings with sulphur under 0.07 per cent. He did not think any bad effect would be experienced as long as the sulphur did not exceed 0.10 per cent. With regard to phosphorus, in his opinion this element deserved more attention than was paid to it. Mr. Campion had expressed the view that low phosphorus was not only unnecessary but undesirable, and stated that maximum strength and soundness were obtained when the phosphorus was about 0.5 per cent. With this he totally disagreed. It was quite a common belief that low-phosphorus iron was weak. It must be taken into consideration, however, that hematite and low-phosphorus irons were almost invariably high in TC, running generally to 4 per cent. and over, and most probably that is the reason for the weakness. Phosphorus certainly added fluidity, but this effect had been so much commented on that many foundrymen imagine that low-phosphorus iron poured like treacle. He testified that no difficulty was experienced in casting a shopful of castings made in green sand, and weighing from, say, 2 lbs. upwards, for weeks on end with iron containing 0.3 P and 3.3 per cent. total carbon. On the question of soundness, there could be no doubt as to the adverse influence of phosphorus. Examination of broken-up castings of low- and high-phosphorus iron left him in no doubt as to the effect of phosphorus in places where " draw " was to be expected. In his experience, reduction of phosphorus was the most successful method of avoiding sponginess in thick sections or at junctions of various walls of metal. Smalley had demonstrated the effect of phosphorus on liquid shrinkage in a way that left little room for argument. It was also significant that the average phosphorus-content of American motor-car cylinders and pistons was well below 0.5 per cent. He thought that this was done to avoid sponginess. Yet another point regarding phosphorus was its effect on the resistance of iron to shock at high temperatures. He had no personal data on the subject, but he understood that research by some of the Continental Diesel manufacturers had established the fact that phosphorus very adversely affected the resistance of iron to shock at high temperatures. He thought that for many reasons phosphorus was not wanted. As for manganese, unless it was being added to stabilise the carbides, 0.8 to 1.0 was a suitable percentage.

Commercial Aspect.

Reverting to the second question as to whether castings could be made of such composition as outlined and at a reasonable figure, the main difficulty was to melt a low-phosphorus charge in a cupola without getting a high TC. If a moderate percentage of steel was included in the charge, the TC might or might not be reduced. Admittedly, careful control of the cupola went a long way towards obtaining the desired carbon content, but he (Mr. Arnott) had not found it possible to get the TC below 3 per cent. every time. Hence he thought that to meet such an exacting specification it was desirable to melt in a furnace in which the charge did not come into contact with the fuel. Leaving out the electric furnace, there was the choice of an air furnace or an open-hearth furnace. He had no data on the cost of melting iron in an air furnace, but, judging from the fuel consumption on melting gun metal, he estimated the extra fuel cost over cupola melting should not exceed 10s. per ton. There was no doubt that melting in a hearth furnace fired either by coal, powdered coal, oil, or producer gas, much closer control on consumption would be possible than in the cupola, and the effect of additions of steel and ferro-alloys more exactly foretold. This seemed to be the case with malleable cast iron, the best quality of which was melted in hearth furnaces.

For the castings which were known to be subjected to high temperature, and where growth was feared, it was desirable to add some element which would prevent dissociation of the carbides. Manganese was very good, but he believed the best agent that has yet been investigated is chromium. He might refer those interested to the Paper given by Mr. Donaldson to the West of Scotland Iron and Steel Institute last session. He tested, amongst others, an iron with 0.4 per cent. Cr and found that the 0.4 per cent. Cr had a greater effect in stabilising the carbides than even 2.4 per cent. Mn. The cost of adding 0.5 per cent. Cr is less than 5s. per ton of iron melted, and there would be no difficulty in adding it to an air furnace. Many works had available stainless steel scrap, and this would be an excellent material for introducing chromium.

In summing up his remarks on composition, he advised for highly-stressed and heated Diesel castings the following:—TC, 2.6 to 2.8; Si, 0.6 to 1.2 per cent., according to section, and adjusted to give 0.9 CC in the casting; Mn, 0.8 to 1.0; S, under 0.1; P, under 0.2; and Cr (if desired), 0.5 per cent.

Hematite iron, low in S, was as cheap as ordinary Scottish foundry pig. He submitted that even with the extra cost of melting in a hearth furnace and adding chromium the total cost would be only about £1 per ton more than that of ordinary pig-iron melted in a cupola. It would certainly be less than that of cold-blast iron, or even of the many so-called refined irons on the market.

Weight per Horse-Power Limits.

Mr. Robert Love said Mr. Vincent had referred to the weight per b.h.p. of the present-day Diesel engine and quoted figures which he thought would ultimately be attained with this class of prime mover. He (Mr. Love) stated that engines were now being built, the weight per b.h.p. of which worked out at from 75 to 80 lbs. These engines operated at from 300 to 350 r.p.m., and cast iron had of necessity been displaced by cast steel and aluminium for most of the castings. For the cylinder liners, cylinder heads, and piston, cast iron has been retained, so that if steel or other suitable metals of high tensile strength were used for those parts, the weight per b.h.p. could be further reduced. Mr. Richardson had explained one reason why the thickness of metal for similar duties varies in the patterns received from different firms. Another reason was given by the author of one of the papers, viz., that it was possible to cut two test pieces from different parts of the same casting and get totally different results as to the tensile strength. It will be clear that if one designer fixes his scantlings with regard to the low tensile-strength and another to the high-tensile strength, different thicknesses must result. When the foundryman can supply castings in cast iron which can be guaranteed to have a tensile strength not below, say, 10 tons per sq. in. in any part there will then be some hope of uniformity in the thickness of metal used by designers.

Regarding the contraction during cooling of castings in steel, it had been found that in intricate castings for Diesel engines steel did not contract any more than cast iron. The illustrations showing the cylinder liner for the Still engine (Figs. 7 to 15) clearly showed that carefully considered design and planning of foundry work were essential. They also showed that the British foundryman is not behind his Continental neighbour in ability. The unfortunate position was that less attention had been given to intricate casting work in Britain than on the Continent.

Electric Cast Iron Gives Good Results.

He thought the foundryman was wrong in supposing that the average Diesel engineer expects to get an intricate casting in special cast iron at the same price as an ordinary casting. The engineer will usually be found quite prepared to pay a slightly higher price for special quality castings for parts subjected to heat stresses. Mr. Arnott referred to the special cast iron required for this work, and he confirmed the view that the cost of this material need not be excessive. He found that the composition of the metal proposed by this speaker agreed with figures which he had found to give good results in practice. These were as follow:—

	Gr. %	Cc. %	Mn. %	Si. %	P. %	S. %
Cyl. Head	2.35	0.35	1.0	1.49	0.167	0.08
Cyl. Liner	2.2	0.5	0.6	1.53	0.12	0.11

These were actual results of analysis of castings which had given good service in Diesel work. There was one point in connection with this question, and that was the method used in melting the iron. The cast irons referred to above were not melted in an ordinary cupola, but in an electric furnace, thereby giving more control over the carbon contents. For Diesel engine work he considered that castings for similar liners should have a Brinell hardness number not below 180, and he would prefer from 200 to 220 if possible. He was aware that some authorities did not consider the Brinell number as a reliable indicator of wear-resisting qualities, but it was the only method which can be easily applied in the workshop. The type of cast iron required by the engineer for Diesel engine work was a metal free from growth at high temperatures and having a high tensile strength. If designers could rely on always obtaining cast-iron castings of tensile strength of from 12 to 15 tons per sq. in. throughout a casting, then they could reduce the scantlings and therefore the weight of the parts to a considerable extent.

Fundamental Desiderata.

Mr. J. G. Pearce (Director B.C.I.R.A.) pointed out that Professor Mellanby gave as the most severe service temperatures in Diesel practice, a full load maximum of about 420 deg. C. At these temperatures he considered the danger due to growth over-estimated, and that more attention should be paid to ordinary thermal expansion, thermal conductivity, specific heat, mechanical strength, which diminished to a marked degree at

400 to 500 deg. C., and resistance to abrasive wear. Below 600 deg. C. he considered that growth was very small, being roughly 3 per cent. to 5 per cent. of the thermal expansion, but it increased rapidly beyond that temperature. A good standardised test for growth was badly needed, and the value of Fig. 3 would be greatly increased if Professor Mellanby could add the analysis of the irons concerned and the nature of the heating. The Cast Iron Research Association at the present time was investigating the question of heat-resisting irons, and the resistance of irons to abrasive wear. Mr. Hurst had stated that ferrite was not good when iron had to have high abrasion resistance, and Mr. Campion had emphasised the danger due to free cementite. The pearlitic condition, therefore, appeared to be desirable for liner and piston castings. For obvious reasons it was not possible to get precisely similar irons for both liner and piston ring, but the reciprocal character of abrasive wear suggested that the wearing surfaces should not be too dissimilar either in the material, treatment or nature of surface. It would be dangerous to conclude hastily that an ideal abrasion-resisting iron was an ideal heat-resisting iron. Any similarity is probably more due to the negative virtue absence of harmful constituents than to the fact that two service conditions so different in character demand the same properties from the material. The requirements might well be antagonistic, especially with regard to total carbon. Metallurgists might be able to say within limits from general principles the lines on which composition and treatment of irons for internal-combustion engines should go. Engineers might carry on the expensive process of experimenting on the client, but the most rational way was to carry out investigations in such a way that the information required would be placed at the disposal of the designer with the minimum of cost and danger.

Low Phosphorus Deemed Undesirable.

Mr. A. Campion said Mr. Donaldson had referred to the effect of chromium, and stated that 0.4 per cent. Cr. gave the same result as

2.5 per cent. manganese. He was quite aware of the influence of chromium and had referred to it in the Paper, but his experience had been that everything obtainable from chromium could be obtained more easily by manganese and at lower cost. The loss of chromium was liable to be considerable, and further manganese irons machined more easily than chromium irons. He had never stated 2.5 per cent. as the desirable content of manganese. With regard to phosphorus, there need be no segregation with 0.4 to 0.5 per cent. if the metal was suitably cast and cooled, and he took it for granted that where metal for Diesel castings was concerned, attention would be directed to proper manipulation. Mr. Arnott had also referred to the phosphorus, but as a matter of experience over many years, he was quite certain that excessively low phosphorus content, *i.e.*, below 0.2 per cent., was not only unnecessary, but undesirable. The question of thermal conductivity of the metal was of the greatest importance, and it might possibly be shown eventually that it was a measure of the suitability of the iron for Diesel liners, etc., but some further investigation was necessary. It had been suggested that the engineer should discard cast iron as undesirable, but he entirely disagreed with that, as under proper control the manufacture of castings could be produced of great uniformity and regularity of properties. He thought that Mr. Vincent's suggestion that growth tests on iron which had been cut from old engines were unreliable, owing to growth having finished, was correct. Brinell hardness and absence of porosity could be guaranteed, but personally he was not satisfied that an ordinary Brinell test was a correct measure of hardness in the case of cast iron. Mr. Arnott had apparently found a specification of composition in his Paper, but he had given nothing of the sort, and if Mr. Arnott would read the paragraph above the one which had so perturbed him, he would see an express disclaimer of any such intention. He had simply mentioned some limits between which the elements were usually present. Mr. Arnott had also attributed to him statements which he had never made, such as low phosphorus irons were weak, and could not be properly melted. Both statements were absurd, and he never heard them from any one but Mr. Arnott himself. If draws occurred in iron containing the quantity of phosphorus mentioned it pointed to faulty manipulation. Mr. Arnott appeared to think that a pin-hole was of no consequence, and had defined it as meaning a hole 1/16-in. dia. If he thought that engineers would accept important oil engine castings with such sized holes in them he was welcome to his opinion, but he would probably change his view when he had some experience. Mr. Pearce had stated that he agreed with every word which Mr. Arnott had said, so that the reply already given applied to Mr. Pearce's remarks regarding the same points. As regarded the growth of cast iron, that which occurred at temperatures above 600 deg. C. was of very small moment as far as Diesel work was concerned. Mr. Pearce stated that growth below 600 deg. C. was of small dimensions, and its importance had been over-estimated. He could not agree with that statement. It was of sufficient magnitude to have caused considerable trouble to engine builders in the past, and it was, in fact, the first thing that brought home to them the necessity of using special cast iron for internal-combustion engines.

Small Engines as Bases for Experiments.

Professor Mellanby said Mr. Vincent complained of the intricacy of the formulæ necessary to estimate the stresses in cylinder liners. He should not, however, blame the mathematician. He had admitted himself that the forces at work must be very complicated, and it was unreasonable to ask that any formula which took into account the stresses thus produced should be a simple one. There were many other cases in engineering practice where complicated methods of investigation must be adopted if results approaching the truth were to be obtained. Take, for example, shaft oscillations. It was true, of course, that some engineers had disdained to seek the assistance of the mathematician and have fixed dimensions by the aid of what they called their engineering instinct. Disaster had often followed this practice and probably also a period of reflection when the cost of engaging a technically-trained designer had been balanced against the losses incurred by the failure.

It has also been stated by Mr. Vincent that experiments on small engines were of little use. While he strongly disagreed with him on this point he called his attention to the fact that a very complete investigation of the temperature distribution in the liner of a large internal-combustion engine had been given in the Proceedings of the Institution of Engineers and Shipbuilders in Scotland. The engine upon which these measurements were made was the double-acting two-stroke cycle one built by the North British Diesel Engine Works, and examination of the curves would reveal how low these liner temperatures are.

Steel Liners.

The question of steel liners had also been raised. It was well known, however, that steel liners have been tried in large engines in this district and had not proved particularly successful. It was pleasing to meet with such an optimist as Mr. Arnott. He only wished he had met him some years ago, when he was looking for someone to cast liners and pistons to a definite specification. Mr. Arnott had complained that the limits suggested by Mr. Campion were not sufficiently rigid, but in his own experience he had come across very few foundries which were prepared to guarantee to produce castings within them. He mentioned, however, that a liner and piston, according to the specification outlined by Mr. Campion, were made for an engine working in this College and they had given every satisfaction under very trying conditions. This engine had worked for considerable periods with an indicated M.E.P. of 170 lbs. per sq. in., and since there was no water cooling in the piston it would be recognised that the conditions there must have been very severe.

The fact that cast iron had stood such conditions successfully indicates that it was not so bad a material as some people would lead one to believe. There were other points that have been raised, but he gathered that there was a possibility of this meeting being adjourned, and that these questions might be dealt with at a later date. It will be apparent, however, to all that progress was being made. Difficulties which a few years ago were very great were now only of minor importance, and he felt sure that meetings such as this, where troubles were frankly ackowledged and discussed, would result in removing these difficulties altogether.

Mr. John Bell, who presided during the latter part of the meeting, proposed a cordial vote of thanks to all who had taken part in the discussion and for the valuable contributions they had made to the subject. He referred especially to the courteous way in which the members of the Institution of Mechanical Engineers had met them and discussed the various points which had been raised.

Newcastle Branch.

(JUNIOR SECTION).

THE MELTING AND CASTING OF HIGH-DUTY IRONS.

By F. Hudson.

By high-duty irons is meant that material used for the manufacture of castings which have to withstand both pressure and friction, as in loco-cylinders.

The suitability of such castings in service is mainly dependent upon their mechanical tests, which are controlled as far as possible by chemical analysis and the rate of cooling of the casting. When it has been decided what tests are required, an analysis is fixed, termed the final or finished analysis, and it is desirable to work to this to very near limits. This is very difficult, due to the exercising of a certain amount of unavoidable guesswork brought about by the passing of definitely analysed material through a furnace, the changes in which are not known. If these changes were known, it would be possible to have more control, if more control were possible, over melting operations, and to work to definite analysis, as is the case in the reverbatory or electric furnace. It was with these views in mind that an attempt has been made which, although not nearly conclusive, may clear up obscure points.

The Melting in the Cupola.

The melting of cast iron has been very badly neglected in the past, and very little real progress has been made. The cupola furnace is in universal use in foundries at the present time, due to its cheap cost of working and rapidity of melting large quantities of metal. As a furnace which has to be controlled to give definite results, nothing could be very much worse. New developments which have from time to time been brought out tend to perfect the working of the cupola or to cheapen the running cost. They do not necessarily improve the metal, and they decidedly give no further scientific control over the actual melting operations. In this respect mention may be made of the latest innovation in cupola design, namely, the Schürmann hot-blast cupola. In this furnace, of German design, the saving of coke by the utilisation of a hot side-blast amounts to 22 per cent., including the bed coke, or 51½ per cent. saving of charged coke over the ordinary standard cupola. However, there seems to be a heavy oxidation of the elements in iron made in this new furnace. Again, the use of receivers and mechanical charging has only come into use in latter years.

FIG. 1.—WROUGHT-IRON BAR JUST BEFORE MELTING, SHOWING CARBON ABSORPTION. × 50 DIAS.

Another matter worthy of attention is the syphon tapping block, suggested by Mons. Ronceray, for obtaining pure metal free from slag. The cupola used by his firm is of the drop-bottom type, suspended from the charging stage without legs, which facilitates the clearing up of all rubbish after the day's blow. The working of this special tapping block is as follows :—The metal flows into the centre of the ganister block and out of the first hole. This hole is then closed or "bottled up." More metal is melted, and it reaches the level of the second hole, which is also closed. Still further melting takes place, and it begins to flow down the spout from the top hole. No tapping and closing of this hole is done during the cast, the flow of metal being wholly controlled by the starting or stopping of the air pressure in the cupola.

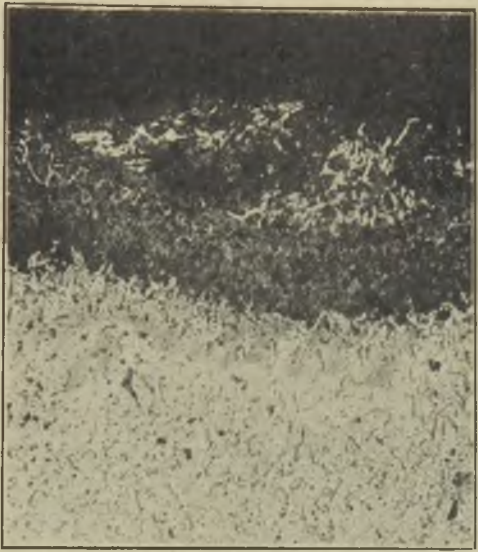


FIG. 2.—WROUGHT-IRON BAR IN MELTING ZONE. × 50 DIAS.

Many other improvements may be cited, but not one has any influence on the actual control of the melting of cast-iron mixtures as regards working to a definite analysis specification.

Many theories have from time to time been put forward suggesting the changes taking place inside the cupola furnace, but they have usually been discarded through unreliable data. For instance, at the present time many foundrymen believe that a temperature to melt steel cannot be obtained in the cupola. Another investigator put forward the suggestion that the fluidity of molten cast iron was dependent upon the amount of combined carbon in the pig-iron, but omitted to give conclusive evidence that this was so.

Before considering the changes taking place during melting, it is essential that the cupola be worked to the best advantage. This can only be obtained by calculation and experimental running over a period. It must be borne in mind that successful cupola working is very rarely the most economical, as far as coke consumption is concerned. In this respect rapid and hot melting is essential. The appearance of the flame at the charging-door when melting is an excellent index if the furnace is running well. There should not be, as is so often seen, a continuous, persistent "flaming up" through each topmost charge. Cupolas are too often left to be managed by practically unlettered men, who, through lack of scientific knowledge, dare not deviate from their present practice. The essentials to be sought in good cupola practice may be stated to be: (1) Careful weighing of all pig-iron, coke, etc., including air; (2) careful analysis in conjunction with physical tests of all raw materials used; (3) correct fluxing; (4) rapid and hot melting; (5) the brickwork at the charging-door should never exceed black or dull-red heat until the last 30 minutes of the blow; and (6) correct flame at the charging-door. (A bluish-pink flame, clinging to every little projection and ledge in the chimney stack, and now and again running down and burning at an opening in the charges. If this flame is obtained, it is not necessary to look at the metal, as it denotes good practice.)

A large amount of very useful data on how to obtain the best results in cupola practice is to be found in numerous text-books and in the FOUNDRY TRADE JOURNAL.

Cupola Reactions.

In the first instance, there is still a doubt in foundry practice as to what is the maximum temperature that can be obtained in the foundry cupola. This will obviously vary in different foundries, according to whether their practice is good or bad. In good practice at least 1,650 deg. C. can be obtained in the chief combustion zone. In recent technical literature German metallurgists measured the temperature in this zone, which gave 1,650 to 1,700 deg. C. A certain amount of air is supplied through the tuyeres at some particular rate in order to get the maximum rate of combustion according to the exposed surface area of the coke. The size of the coke pieces and the physical structure of the coke surface considerably affect this rate of combustion. The air encounters a mass of coke, through which it can only penetrate by tortuous routes leading in all directions, and tending to travel upwards more rapidly than inwards, due to the resistance of the opposing tuyeres' air current and the lack of outlet other than at the top. The zone of highest temperature, however, will tend to come nearer the lining continuously the higher any one plane is carried, as a certain distance must be travelled by the air before maximum combustion takes place. Taking a plane at any point a little above the tuyeres, melting probably takes place across the whole area. The atmosphere of this zone should be neutral, or only slightly oxidising.

Constant blast pressure and volume is most important in cupola working, as this is the absolute index of a constant melting zone. In this respect another point, which is often lost sight of, is that the melting zone is fixed by the tendency of the air to travel upwards. Any disturbing factor, such as a large open slag-hole, will lower the melting zone, and possibly give dull metal. The slag-hole in cupola working should only be opened when necessary, and then closed as soon as possible.

Ordinary mild steel, with a melting point of nearly 1,500 deg. C., will melt quite easily in this zone at its actual melting temperature, no carbon absorption taking place before melting to lower its melting point. Some time ago an eight-ton cupola in the author's charge melted ten tons of ordinary mild steel, with ferro-alloys to give an iron of the following composition cast in sand-pigs :—Total carbon, 2.94; silicon, 1.26; manganese, 0.76; phosphorus, 0.09; and sulphur, 0.115 per cent., and giving 15.5 tons tensile.

Obviously the maximum temperature in the combustion zone is well above 1,500 deg. C. One may confidently state that the melting zone in the ordinary foundry cupola is at least 1,650 deg. C. in good practice. The next point for consideration is the amount of carbon absorbed by the charges before melting in their descent down the cupola. The following experiments were done during ordinary practice in the eight-ton furnace referred to previously.

FIG. 3.—CARBON ABSORPTION FROM MOLTEN CAST IRON. × 50 DIAS.

Carbonising of Metal During Descent in Cupola.

A $\frac{5}{8}$-in. wrought-iron bar of sufficient length to extend from the charging-door to the melting zone was placed in the furnace on top of a charge of cast iron and allowed to descend the cupola, with that charge, into the melting zone. After a certain time the bar was withdrawn by means of a crane, through the following charges, and the end examined.

Wrought iron was chosen because of its strong affinity for carbon. If any carbon is absorbed by the iron or steel when melted in the cupola, an iron or steel very low in carbon will tend to absorb more than high-carbon material, such as is usually melted for cast-iron mixtures. The main point noted immediately upon extraction of the bar was the pronounced difference of temperature zones, which seemed to consist of three different temperatures:—(1) The very hot zone; (2) radiation zone of slightly lower temperature, immediately above first zone; and (3) low-temperature zone, representative of the usual stack heat.

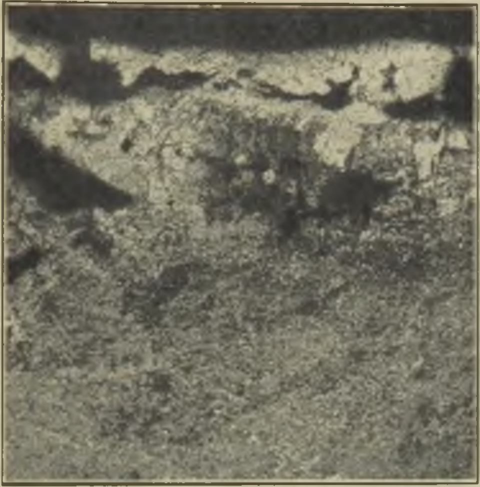


FIG. 4.—SHOWING DECARBONISATION DUE TO OXIDISING ATMOSPHERE. × 50 DIAS.

It was noted that the drop in temperature from zone two to three was from bright red to nearly black heat within a few inches. When examined under the microscope very little carbon penetration was found. Fig. 1 shows the carbon penetration before melting, whilst Fig. 2 shows the melted portion of the bar. It should be especially noted that no oxidation can be traced on the outside, and that it is quite possible that the melting of other lower melting-point material may possibly induce easier melting of the iron or steel. A trace of this easier-melting material will be noted adhering to the bar. Even to-day many hold the opinion that when hard spots are encountered in machining iron castings those hard spots should be ascribed to steel. How this opinion originated is hard to say, but it must be perfectly obvious that when steel is melted in the cupola, even as very small punchings, the temperature of melting and the very high solvency of cast iron for steel, together with the subsequent disturbances due to tapping into the ladle, yield relatively homogeneous metal. Fig. 3 illustrates the powerful solvency of cast iron for mild steel. A ⅜-in. mild-steel bar was moved up and down in a ladle of molten cast iron, and in about two minutes was reduced to ¼ in. The microphotograph, taken at a magnification of 50 dias., shows that the outside of the bar has absorbed carbon from the molten iron, and so lowered its melting point, this taking place in each successive layer of steel exposed by the action of the cast iron. Analyses of other steel sections passed through the cupola and trapped at the melting zone have shown that this increase, to all intents and purposes, does not affect the analysis for carbon, and cannot be detected by ordinary routine works analysis and sampling. For instance, steel charged into the cupola with carbons of 0.28 per cent. and 0.33 per cent. respectively gave 0.23 and 0.37 per cent. on being trapped just before melting. If any excess blast be used, as, for instance, when the furnace is "blowing down," instead of this layer of carbon we get a decarbonised layer of iron, as shown in Fig. 4. No carbon absorption seems to take place in the ordinary run of cast-iron scrap and pig-iron usually melted.

However, it is interesting to note the ill-effects of excessive blast, causing the oxidising atmosphere so detrimental to good melting for high-duty castings on a high-carbon hematite iron. This specimen was retained by the lining after the bottom had been dropped, and exhibited a most interesting point. The pig had half-melted with the formation of a high melting-point skin. This skin seems as if it had enclosed a core of molten iron, and then collapsed, due to either weight or temperature. Upon analysis the skin showed very heavy decarbonisation. Fig. 5 shows this pig. The analysis of the skin was found to consist of 6.76 per cent. sand and 93.24 per cent. magnetic material, this magnetic material being further analysed as follows :—Total carbon, 2.0; silicon,

Fig. 5.—Decarbonised or Oxidised Skin on Hematite Pig.

1.30; manganese 0.94; phosphorus, 0.06; and sulphur, 0.100 per cent; in comparison with the centre of the pig, which analysed:—Total carbon, 4.19; silicon, 1.46; manganese, 1.20; phosphorus, 0.054; and sulphur, 0.04 per cent. The extent of oxidation will be noticed.

At first it was thought that this skin had been formed by the refractory sand usually adhering to the pig, but similar results have been obtained with perfectly clean-machined samples. In some of these cases it seemed that the iron had first started to melt from the centre. A refractory skin on pig irons would be a decided advantage in cupola melting so long as this skin was not formed by some such element as might prove injurious to correct melting. The reason for this suggestion will be further considered in a later part of this Paper. These experiments give some idea of the changes taking place before melting, and will end in a position according to their respective melting

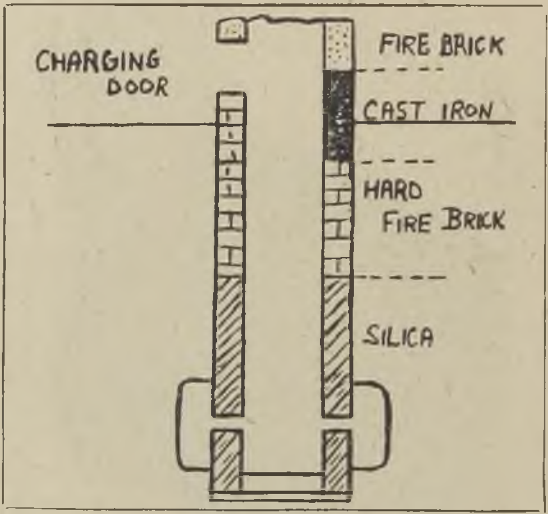


Fig. 6.—Showing Proposed Method of Lining Cupolas.

points in or just above the melting zone. For instance, steel will melt lower down the furnace than low-phosphorus iron, likewise high-phosphorus material will melt above low-phosphorus metal. The melting points are as follows:—Steel 0.2 per cent., 1,480; low-phosphoric iron, 1,110; ordinary cast iron, 1,088; and high-phosphoric iron, 1,086 deg. C.

Superheating Cast Iron.

At a first consideration it would seem that for a means of imparting superheat it is not very satisfactory, for the very reason that the molten iron is only in contact with the maximum combustion zone for a very short time. It should be borne in mind, however, that when a piece of cast iron melts it does so just above the hottest zone and falls through the intense combustion zone in the form of small drops. The temperature of the hottest part of the cupola is sufficient in good practice amply to superheat the small weight in a short time.

The following facts are worth noting:—(1) All cast iron is superheated in the true sense of the term superheat; (2) iron and steel is not superheated in the true sense of the word, but by melting at a high temperature and solidifying at a much lower temperature obtain a superheat greater than in the first instance. The changes taking place during and after melting are much harder to determine. The only work that the author has done in this instance is the sampling of the molten iron at the tuyeres and comparing similar iron tapped out of the furnace after contact with the bed coke. It must be borne in mind that these results were obtained after melting in a neutral atmosphere, and could only be applied to another furnace with exactly similar conditions of melting. The main element for control is the total carbon, and these analyses were taken with that in mind. The results are as given in Table I.

Conditions for Carburisation.

Due to lack of sufficient time, further analyses have not been obtained, and, although no very definite conclusions may be drawn from them, it seems highly probable that the molten iron absorbs

TABLE I.—*Analyses of metal above and below the coke bed.*

Above Bed Coke.					Below Bed Coke.				
T.C.	Si.	Mn.	P.	S.	T.C.	Si.	Mn.	P.	S.
4.26	1.68	0.86	0.15	0.045	3.24	1.24	0.71	0.24	0.100
3.65	2.04	0.81	0.70	0.067	3.46	2.06	0.76	0.63	0.076
3.73	2.48	1.20	0.76	0.052	3.57	2.02	0.70	0.61	0.067
3.87	—	—	—	—	3.50	—	—	—	—
3.27	—	—	—	—	3.27	2.54	0.88	0.88	0.055
3.61	—	—	—	—	3.53	—	—	—	—

the most carbon when actually melting, and not, as usually supposed, from the bed coke. The four main points for carbon absorption in cupola operations are temperature in the melting-zone, time in the melting-zone, the atmosphere of combustion, and the initial analysis of the material melted. The higher the temperature the more carbon will be absorbed by the iron in a certain time, according to the facility of applying free carbon. In the cupola the iron itself will receive a temperature of at least 1,500 deg. C. during melting, and at this temperature a large amount of carbon will be absorbed in a very short time. Any further increase of temperature or time in the melting-zone will allow the iron to absorb more carbon. The loss of carbon in molten cast iron in contact with the bed coke is possibly due to the lower temperature in the well. Cast iron, including material with a range of total carbon from 2.8 to 3.5 per cent., when melted in the cupola, will tend to absorb the maximum amount of carbon that can go into solution at that temperature attained in the melting-zone. At any lower temperature no carbon will be absorbed; in fact, the molten iron will tend to "throw off" carbon in the well of the furnace. At any rate, if the maximum amount of carbon is not absorbed in the melting-zone, it is very probable that enough is absorbed which will not permit of any further addition by the bed coke. High steel mixtures may possibly prove an exception to this rule, due to the larger amount of carbon it will have to absorb. This will conveniently explain why slow-melted hot iron is much higher in carbon than quick-melted hot iron, and also shows that the oxidising atmosphere in a melting-zone gives low total carbons, even when the iron has been in contact with the bed coke.

These little experiments throw light on the changes taking place inside the cupola. For convenience sake, they may be divided up into three zones :—

Zone 1. *Extending from the charging-door sill down to beginning of melting-zone.*—For practical purposes cast-iron and steel mixtures in this zone absorb no extra carbon until actual melting begins.

Zone 2, or the Actual Melting Zone.—Cast iron and steel melt just above the hottest zone at their respective melting temperatures, and fall through the hottest zone in small drops. This hottest zone has a temperature of at least 1,650 deg. C., amply sufficient to superheat these small drops. These drops absorb carbon very rapidly, due to their high temperature and with being in intimate contact with incandescent coke, more carbon is absorbed in this zone than in any other part of the furnace. The atmosphere should be neutral.

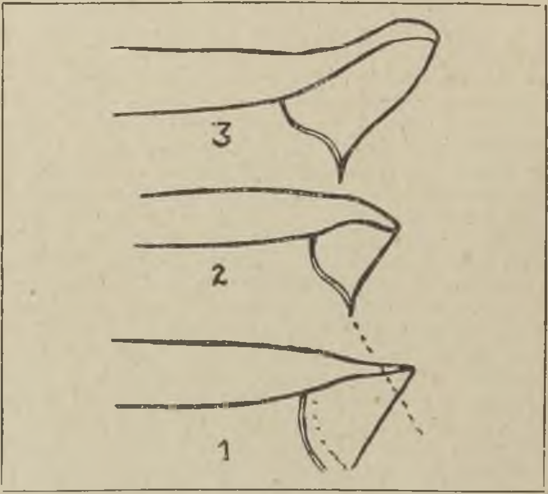


Fig. 7.—Forms of Ladle Lips. No. 1 is a Poor Form, whilst Nos. 2 and 3 are Good.

Zone 3. Extending from the Melting Zone to the Well.—The molten metal lying in the well gradually falls in temperature, and in the case of cast iron probably loses carbon. Sulphur is absorbed in this zone, and also to a small degree in the second. It is essential, in order to obtain the best results in cupola melting, to have the correct amount of air to combine with the coke to give a neutral or very slightly oxidising atmosphere. To give low total carbons a certain percentage of steel can be used. The lower the blast pressure, consistent with correct volume, the hotter the metal is, due to a lower melting zone. For high total carbons melt hot but slowly. High melting-point irons with low total carbons, including steel, will give hotter metal than iron with lower melting point. Heavy sections melted with too little coke will give cold metal, due to the molten drops having less distance to fall through the hottest zone. Many other difficulties can be overcome if one appreciates the changes taking place inside the cupola.

Results Summarised.

From a practical standpoint these results may be summarised as follows:—(1) No carbon is absorbed until melting begins. (2) The temperature of the hottest zone in the cupola furnace will melt steel very easily indeed. It has been found to be *at least* 1,650 deg. C. (3) A neutral atmosphere is required for melting high duty work in order to obtain, as far as possible, a set of constant melting conditions. (4) Total carbon can roughly be controlled by dilution with steel and speed of melting. (5) The cupola furnace will superheat cast iron in the true sense of the word, the resulting temperature being slightly affected by the melting points of the material. The higher the melting point the hotter the iron. (6) The most carbon tends to be absorbed by the molten metal in the hottest zone of the furnace. (7) As long as the molten metal is in contact with the fuel, it is not likely that any direct control could be exercised with a definite analysis specification in view. However, some control can be obtained in the melting of cast iron for high duty work if the changes taking place during melting are definitely understood, and steps taken to obtain definite melting conditions.

Melting of Heavy Duty Irons.

These points will be of the same importance, whether steel is included in the mixture or not. The first point is that the analysis of each grade of iron charged should be known, and a mixture calculated by analysis for each important casting, allowing a certain percentage loss due to oxidation found by experience. As far as possible similar sized pieces should be charged, not too heavy, and preferably clean and free from excessive dirt or sand. The bed coke should be measured by volume, and the charged coke by weight. Only the necessary air should be used to give complete combustion of the charged coke in a certain time with the formation of a neutral atmosphere. Every care should be taken to keep a constant standard melting zone, which is influenced by the pressure and volume of blast used, the resistance to penetration of the blast and any openings below the stack outlet such as the slag hole. Proper fluxing, using a slightly basic slag, together with hot melting, will keep the sulphur low. This can be obtained by the use of a small amount of manganese ore with the limestone. Careful attention to the small points. Hot melting is essential for good work. Placing charges for important work half-way through the blow gives an advantage in the use of hot ladles and hotter metal.

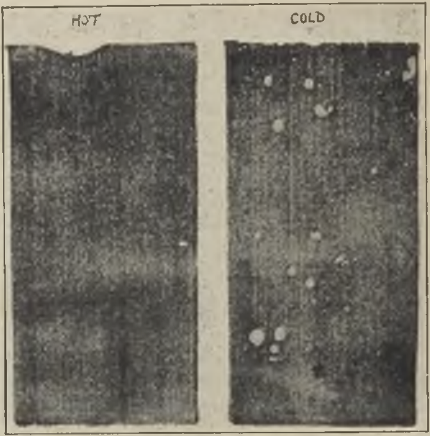


FIG. 8.—DIFFERENCES IN THE HOT AND COLD CASTING OF HIGH-DUTY IRONS.

Refractories.

The temperature required for the hot melting of high duty irons necessitates the best grade of silica bricks. Ordinary fire-bricks are used in most foundries, but they are far from satisfactory. The most economical way to run the foundry cupola is to arrange the day's output so that a certain sized cupola may be run at full load. This naturally has a very destructive effect upon the lining, and unless suitable bricks are used trouble may be experienced towards the end of the "blow" through the furnace showing red or even "coming through." Firebricks are unable to stand this overloading, for the very reason that they are not made to withstand temperatures usually obtained in the cupola. All furnaces should be lined in some manner similar to that shown in Fig. 6. From the bottom of the well to above the melting zone silica bricks should be used, and from there to the charging door use some very hard brick such as a high iron-content firebrick or magnesite, with hollow cast-iron bricks opposite the charging door. If magnesite bricks are used it is advisable to insulate them from the silica bricks with some neutral material such as high alumina or chrome bricks. The best Sheffield ganister with a high silica content should be used for setting and repairing the silicas. A refractory wash is a very great advantage in closing the pores of the bricks, especially in and below the melting zone. The method used by the author is to incorporate silica bricks in the melting zone and high iron-content firebricks and hollow cast-iron bricks above, and a final wash of high silica ganister in the melting zone. Ordinary quality firebricks can be used above the charging door. This method lasts roughly half as long again as the best grade of firebricks.

Pig-Iron.

Cast iron for high duty irons may be divided into two classes. In the first class is used a mixture without or with very little steel additions, and in the second class those with a fairly large steel addition, which is commonly called semi-steel. A much better name to differentiate between different steel additions is steel mix iron, as suggested in THE FOUNDRY TRADE JOURNAL, placing the percentage of steel in the mixture before the term. For instance, supposing there is 20 per cent. steel in a certain mixture, that mixture could very conveniently be called 20 per cent. steel mix iron. A very large amount of trouble has been experienced in the past, due to the lack of knowledge in applying this very useful iron. The usual moulding methods in cast iron are not suitable for the use of heavy steel additions, except those simple and regular sectioned castings with large heads, such as cylinder liners or hydraulic rams. The ordinary run of work, such as cylinders, etc., require no more than 10 per cent. steel additions at the most. Every metallurgist or chemist should so control his mixture with a view to obtaining sound castings. This necessitates very close co-operation with the moulding methods employed, and no attempt should ever be made to cast any mould with any high shrinkage iron without insisting upon careful placing of risers and feeding heads.

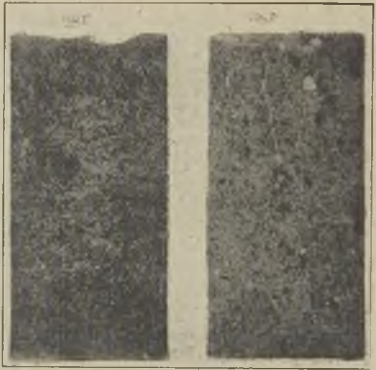


FIG. 9. FIG. 9A.

Fig. 9, contains Gr 2·86 ; Cc 0·56 ; Si 1·41 ; Mn. 0·84; P 0·27 and S 0.103 per cent. whilst Fig. 9A contains Gr 2·85 ; Cc 0·49 ; Si 1·37; Mn. 0·78; P 0·28 and S 0·072 per cent

The ideal cast iron for cylinder and intricate high duty work is an iron with low liquid shrinkage, yet reasonably soft. Grey cast iron does not solidify at once, but does so over a considerable temperature range. The softer this iron usually is the larger this range of temperature from incipient to final solidification. White iron, on the other hand, solidifies without this temperature range. All liquid shrinkage, draws, etc., take place in castings during this period of setting, and it is a very great help if advantage be taken of this fact to obtain, as far as possible, a cylinder iron with a low liquid shrinkage.

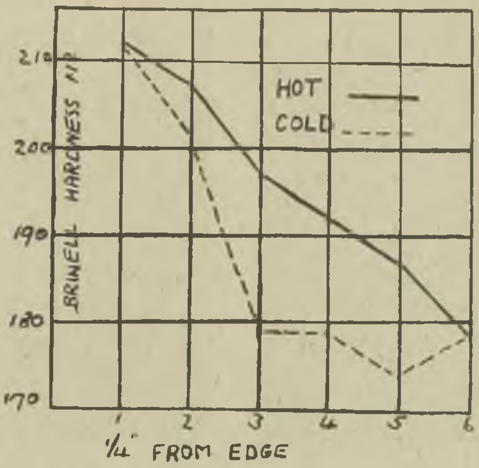
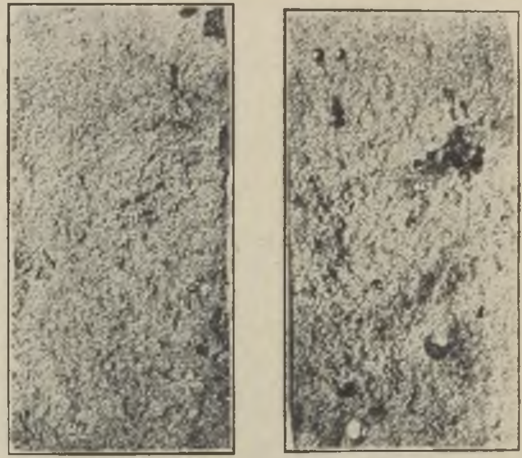


Fig. 10.—Showing Uniformity of Hardness through 2-in. thick Section.

Every foundry has its own idea as to which pig-irons are most suitable for the type of castings made. Personally, the writer prefers a synthetic cold blast iron, containing at least 10 per cent. steel, made in a cupola or open-hearth furnace. This is re-melted with silicious hematite (5 per cent. Si) and a slight percentage of steel and domestic scrap for cylinder work. For heavy hydraulic work or large cylinder liners more steel is used, but never over 15 per cent. is employed directly without re-melting. Low total-carbon iron is not recommended for ordinary work, but is quite satisfactory for uniform sections with suitable feeding heads. Perhaps 3.5 per cent. is the best all-round carbon percentage for intricate and cylinder work. When hematite is used for mixing it is advisable to use the 5 per cent. silicon variety, as less is required to make up the silicon to any desired percentage. This saves money and gives a better mixture. All pig-irons should be very accurately and carefully sampled and analysed, as this is essential for correct mixing.



FIGS. 11 AND 12.—SHOWING DEPTH OF CHILL.

Special Pig-Irons.

Pig-irons bearing alloys such as nickel and chromium, naturally formed from their own ores, will possibly soon come into use, and perhaps revolutionise cast iron. At present there is one on the market, called "Mayari" pig-iron. This is a natural nickel-chrome pig-iron with slight traces of titanium and vanadium, found in Cuba. Another similar ore is found in the Island of Skyros, off Greece. Similar pig-irons are being initiated by the synthetic melting of nickel chrome steel scrap obtained from the breaking up of war vessels.

Coke.

Good coke is one of the most important factors for correct cupola melting. To obtain fast and hot melting together, a brand of coke with certain physical properties is essential. It is usual to buy coke to a certain specified analysis and with certain physical properties. For instance, the following is a specification for coke used in cupola work:—1.0 sulphur; 9.0 ash; 4.0 water; and 6.0 per cent. dust on delivery; all being maximum allowances. The physical properties looked for in good coke are:—(1) Well-developed cellular surface structure; (2) not too dense; (3) rapidity of combustion; (4) uniformity of size; (5) hardness to resist abrasion; and (6) freedom from blackheads.

Of these, one of the most important is rapidity of combustion. Experts are divided into two groups on this point. One school of thought says that the combustibility of coke depends upon its density, whether porous or close. Another ascribes it to volatile hydro-carbons. The author is of the opinion that neither of these ideas is correct, but that rapid combustion is due to a certain cellular surface structure on certain cokes which exposes a maximum amount of carbon to the oxygen in the blast. However, this is only an assumption, and still remains to be proved. Many foundrymen are still very dogmatic about the strength of coke. Resistance to abrasion is really the main requisite, and not strength. The pressure on coke, even in large blast furnaces, is not more than 42 lbs. per sq. in. An important saving in cupola working can be made by sorting the unburnt bed coke out of the refuse at the end of the blow. This coke is suitable for drying or pre-heating ladles. In practice, blast-furnace and cupola coke are differentiated, but there is very little difference between them in reality.

Methods in Casting.

It is usual, in grey iron foundries, for the melting staff to have all maintenance of ladles, etc., but the actual pouring gang comes under the moulding department. The writer considers that it is necessary that the works metallurgist or melting department should have control of the pouring operations, as well as ladle maintenance. This is usual in steel practice and many malleable plants. One of the most important factors for the correct pouring of moulds, especially for high duty work, is correctly designed ladles with suitably shaped spouts or lips. These spouts should be deep and well above the level of the metal in the ladle. A comparison of good and bad ladle lips is shown in Fig. 7. It will be noticed that if any cast iron solidifies on the end of the lip in the badly designed ladle (No. 1) the metal, when poured, will not flow down the spout in a controlled stream, but will "slop" over the sides and possibly miss the runner basins altogether. The best design which the author has ever seen used in any foundry is No. 2, commonly used in blast-furnace work, but No. 3 is a very good design, and many ladles in use may be conveniently

FIG 13.—MICRO-PHOTOGRAPH AT 50 DIAS. OF MATERIAL CAST HOT.

altered to give this shape by the use of the pneumatic chisel. Another type of ladle employed in the foundry with which the writer is connected is the bottom-poured ladle, as used in steel practice. In the author's opinion, this is the best type of ladle to use for important work, as hot, clean metal free from slag may be always ensured. The main point, however, in pouring operations is to be always able to control a constant stream of molten iron free from slag. In top-poured ladles this slag is a very real menace to the production of castings to be machined, and careful skimming cannot be too strongly emphasised. Any entrapped slag will cause blow-holes in the castings, and when any important casting is being poured very careful attention should be paid to this point. and every possible means taken to combat it. In ordinary hydraulic or similar work, where no projection in the mould may catch this scum (if any

FIG. 14.—SAME CONDITIONS AS FIG. 13, BUT CAST COLD.

may find its way into the mould with the molten metal) an ordinary deep basin without plugs, using a top-poured ladle, may be used. In cylinder work, however, or any job with internal mould projections, a very deep basin is required, together with plugs and bottom-poured ladle. One very important point in the use of plugs is to see that they are a perfect fit in the runners. If they are not metal may leak into the mould, solidify, and, when the metal does enter the mould, not unite.

Pouring Temperature.

All high duty work should be poured hot. Pouring hot is essential, whether the casting be large or small, thick or thin, if the best work is to be turned out.

Lack of density in castings is due to casting at too low a temperature. This lack of density is due to either blow or shrink holes. In large castings foundrymen have often a certain fear of casting hot and allow the metal to stand. That this is a fallacy was brought home very forcibly in the writer's experience some time ago. A Diesel engine flywheel, of about 12 tons in weight, and having a section about 36 in. thick, had been cast on the cold side, and was badly drawn under the risers. Prior to this, one had been cast very successfully at a higher temperature. The first wheel had taken about 6 or 7 hours to feed. The second had only taken about 5 hours. Obviously the faulty wheel had taken less metal and had a lower density. If it had been cast hotter a sound job would have been the result. The following experiment was carried out to see what was the result of casting cold and casting hot. Two identical blocks were made in dry sand moulds and cast with hot and cold metal from the same ladle. Figs. 8 and 9 show the blocks sectioned through the centre, illustrating blow-holes and lack of density. With regard to the top of the sections, it will be noticed that the cold block has a perfectly straight top, whilst the hot cast one has shrunk.

Other differences between casting hot and cold may be found in the test results taken from different bars cast from the same ladle. It seems, from experiments that have been done, that there is some relation between casting temperature and the thickness of the casting, but the highest tests are inclined to be obtained with a casting temperature between 1,350 and 1,400 deg. C. Casting hot does not seem to increase the hardness nor the chilling effect as much as some people think. Figs. 10, 11 and 12 show the depth of chill obtained by casting hot and cold, together with the Brinell hardness from the edge to the centre of a 3-in. square block cast in dry sand. Figs. 13 and 14 are microphotographs showing the structure obtained by casting hot and cold.

East Midlands Branch.

CONTRACTION STRESS: CAUSE AND REMEDIES.

By F. C. Edwards, Member.

Of all the many forces operating against the production of reliable castings, that of contraction stress is the most insidious and persistent. It is particularly insidious, in that it possesses the faculty of remaining unseen and unsuspected until a suitable moment arrives, when, without warning, it may work incalculable havoc and endanger human life. It is persistent, simply because it is the expression of a natural law—it cannot be defied with impunity. Nevertheless, when clearly envisaged by designer and founder, contraction stress may, to a very great extent, be obviated, or its effects nullified. Like ordinary difficulties it may usually be overcome by intelligent anticipation.

Happily the prime importance of this intelligent anticipation of contraction stress is becoming more and more generally recognised. In the general run of work, one does not now meet with so many monstrosities of casting design as was formerly the case. There are fewer instances in which very sudden changes of metal section make it impossible for a casting to survive its own cooling stresses. Further, the moulder is not perhaps so often called upon to exercise his "practical" knowledge in saving a casting from the fatal effects of, say, purely mathematical design. But contraction stress still levies a more or less constant toll upon the output of castings; and it may safely be assumed that very few castings are made which are not to some extent weakened by what may be called permanent contraction stresses.

Depreciation of Contraction Stress.

Everyone knows that most metals shrink or contract whilst cooling. This shrinkage varies, of course, for different metals. A bar of ordinary cast iron, for instance, of 1 in. square section, and 12 ins. long, contracts about 1-10th in. in length; a steel bar shrinks double this amount. In the case of this plain, straight bar, no contraction stress would be induced in a normal casting. Neglecting, of course, the slight frictional resistance offered by the sides of the mould, the bar would be perfectly free to adjust itself in taking up a shorter length of the mould as it passed through the various stages of cooling. Incidentally, it could be relied upon to support—within fairly narrow limits—a certain load according to its chemical composition.

But, to take a common example, let us suppose that a bar forms one of four arms of a pulley having a comparatively thin rim and heavy boss, similar to that shown in Fig. 1. The thin rim would obviously cool—*i.e.*, freeze first, and the heavy boss last. It therefore follows that the rim, by setting first, would constitute a rigid band of a certain irreducible diameter, upon which the arms would exert a pull in their efforts to adjust themselves to the effect of the still shrinking boss. The arms, in fact, would be placed in tension. Their strength as connecting links between boss and rim would, accordingly, be less than that of the bars cast as separate units. And the casting, as a whole, would be thereby weakened. The actual extent of the weakening effect of contraction stress would depend, of course, upon the relative proportions of rim, arms, and boss, and also upon the composition of the metal. We may consequently say that the casting—and specifically each arm—would be under contraction stress. This stress, it may be added, would render the arms liable to fracture at their juncture with the rim, as shown at A.

A little consideration of the above, in conjunction with other examples, should enable one to solve many of the contraction stress troubles met with in the foundry. The designer of castings, from a clear grasp of the principles involved, should be able to utilise the full strength of the metal he proposes to employ as indicated by the test bar.

The root cause of the contraction stress set up in the example shown in Fig. 1, is, of course, lack of uniformity in the respective metal sections of rim, arms and boss. But there are also present

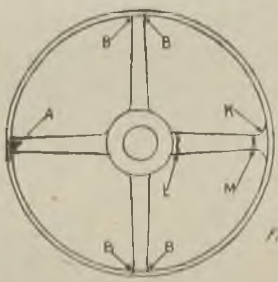


Fig 1

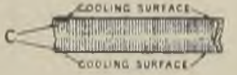


Fig 2

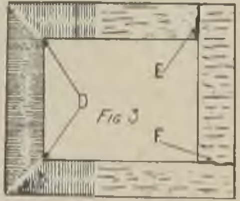


Fig 3

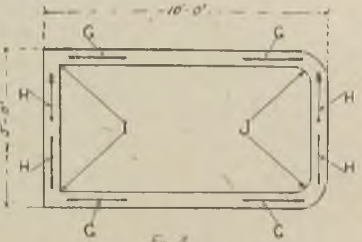


Fig 4


Fig 5

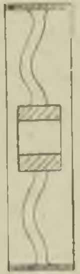


Fig 6

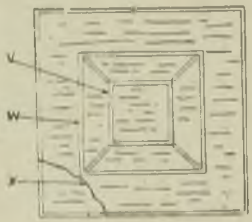


Fig 8

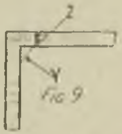


Fig 9

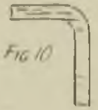


Fig 10

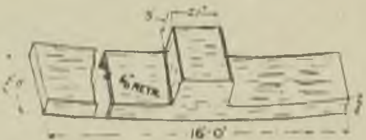
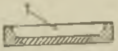
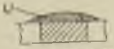


Fig 11



SECTION OF LIGHTENED BAR Q



SECTION AT P

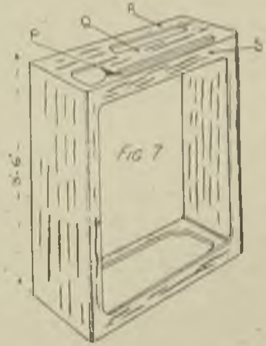


Fig 7

contributory sources of stress, and, in seeking a remedy, it is well to keep these clearly in view. For instance, the rim of the pulley has a greater surface area per unit of metal section than the boss. This relatively greater exposed surface accentuates cooling in the rim, in addition to that induced by the difference in size of the different metal sections of boss and rim respectively. Consequently, there is a wider margin between their respective contractions, and, as a necessary corollary, an increased stress.

Re-entrant Angles.

Another contributory source of stress—or what, to be more precise, may be termed an aggravating factor of stress effect—is that promoted by the re-entrant angles B. Here, to digress a little, it may be observed that, from examination of many re-entrant angle fractures, the author has arrived at the conclusion that the generally accepted theory of the source of these fractures does not seem to agree with what actually happens. A theory that does not agree with fact, although it may possess a certain academic interest, is of little or no practical use—even if it does not mislead.

Briefly stated, the usual explanation amounts to this:—As molten metal cools, it crystallises on solidification. These crystals arrange themselves side by side (like a line of soldiers, so to speak, with their principal axes in the direction of the flow of heat—or of the heat wave radiated from the body of the metal—*i.e.*, along lines at right angles to the external surface of the casting, as shown at C, Fig. 2. So far, the author of this Paper is in complete agreement. But it is further held, that *as the lines of crystallisation intersect at the corners, they form diagonal planes of separation, along which fracture is liable to occur*—as shown at D, Fig. 3.

Although there is the undeniable possibility of a weakened structure across the corners consequent upon the segregation of a weak eutectoid at the areas last to cool, it is a fact that when fracture occurs it invariably takes a line more or less as shown at E, or F—not (as the orthodox theory would lead one to suppose) in a diagonal direction.

The weak—diagonal—plane theory, then, as an explanation of contraction stress, cannot be substantiated by fact. Foundrymen must seek a more fitting hypothesis. Let them endeavour to visualise, from assumptions based upon common every-day experience, what probably takes place, during cooling, in, say, a frame casting, as shown in Fig. 4.

First, it may be expected that the casting (in grey iron) will be about one inch shorter, over all, and half an inch narrower than its mould. This means that, during cooling, a process of shortening has been going on in each of the four sides. Further (if the mould is of even consistency), it may be assumed that this self-adjusting shortening action—in taking up less space consequent upon shrinkage—will operate, in the sides, in the direction of arrows G, and in the ends, as indicated by arrows H. There would be present what may be termed a " contraction pull " towards the centres of the sides and ends respectively. One is further justified, it is thought, in assuming that this " contraction pull " has its source in the cumulative cohesiveness of the metal as it passes from the fused to the solid condition. It would thus appear that the forces G and H, acting at right angles to each other, would tend to produce rupture at corners I. And the " sharper " the corners the greater—because more concentrated—would be the effect of the differently-directioned forces.

This concentration of stress may be obviated. It is an elementary law of physics that a given stress is more easily carried in proportion as the area is increased over which that stress is distributed. This principle applies to the particular case under consideration—and, also, of course, to analogous cases in casting design generally. By increasing the " length of the bend " by substituting a curve for a corner, as at J, one renders less concentrated the effect of the forces G and H. Instead of the stress being confined to what almost amounts to a point at corners I, it is spread over the longer radius J.

The incidence of rupture thus not only becomes more indeterminate. but the forces tending to produce rupture are very largely dissipated. The way in which this is accomplished becomes clearer, perhaps, when it is remembered that metal solidifies (and thus acquires strength) from the outside. Regarding bend J, incipient solidification would take place along this edge immediately the job was cast. The rapidly solidifying line of metal round the bend would then assume what may be compared to a kind of chain formation, each "link" of which would be loaded with a share of the tension that, in the former case, was concentrated at I. Moreover, as the interior of the metal at the bend would be in a more or less plastic condition as forces G and H came into operation, each "link" would be in a position to adjust itself, and thus absorb and nullify some of the tension.

It therefore follows, from the foregoing, that not only is contraction stress caused by differences in the relative size, *per se*, of the metal sections at various parts of a casting, but that it may also be promoted—or retarded—by local, or general contour. Applied to the pulley, Fig. 1, a large radius, as at K, should be regarded merely as a local remedy: whilst mitigating the stress at the juncture of rim and arms by distributing it over a greater length, it does not altogether eliminate that which is set up between rim and boss and which may still fracture under its own cooling stresses, at L or M.

Here, it is useful to keep in sight Euclid's axiom that a straight line is the shortest distance between two points. Fig. 1, shows straight arms. Now, by the above axiom, the straight arms represent the irreducible minimum length by which the rim may be connected to the boss. But metal contracts in cooling. Therefore, since the boss cools subsequent to the setting of the rim, the straight arms occupy an untenable position: by Euclid's axiom, they cannot be further reduced in length without fracture. Little wonder, then, that they sometimes give way. Indeed, when it is considered how inevitable is the formation of contraction stress in such circumstances, it seems marvellous that straight armed wheels can be made at all! Unquestionably, contraction stress is always present, even in those castings which may appear to be quite sound.

To eliminate this stress, the *general* contour must be altered. The *design* of the arms must be modified because, as the casting cools, the arms tend to shorten. The connecting link between rim and boss should, therefore, be of such a nature as to allow of variation in its length with the least ultimate overall strain on itself. It should be amenable to contraction pull. In other words, it should exhibit, in itself, the power of length-adjustment; it must be longer than a straight line. This may be attained, either by resorting to the well-known S-shaped arms (Fig. 5), or by varying their plane (Fig. 6). In either case, the conditions are favourable to contraction stress elimination—the stress is relieved by the straightening of the arms. It should be noted that, in Fig. 5, five arms are purposely shown, instead of the usual four or six. The odd number tends further to reduce stress by substituting an indirect for a direct pull across the diameter of the wheel.

Contraction Stress Between Cored Holes.

Consider, now, a case which calls for a different line of treatment, but which also contains points applicable to the solution of contraction stress troubles generally. Fig. 7 represents a light frame casting. The sides are $\frac{1}{4}$-in. in thickness, the front and back are open, and the top and bottom are cored out as shown. When the first casting was taken from the mould, it was found to be fractured at P. Before interfering with the design, several attempts were made by the foundry to overcome the trouble. The body of the mould was eased immediately the casting was set, in order to permit the sides to come inwards. Then the section where fracture took place was chilled, so as to make that part stronger—the better to endure contraction pull. In spite of these and other special methods adopted, however, the castings continued to fracture, either before or during fettling or machining operations. It was then decided to treat the root of the trouble—to modify the design. And, since this Paper is intended to deal more especially with the why and wherefore of contraction stress, rather than with a bare recital of results, it is proposed here briefly to touch upon the reasons for the steps taken.

First, it should be noted that the requirements of the component precluded any increase in the width of the narrow isthmus of metal at P. Neither was it permissible to cut through this part completely. Either alternative would have afforded a solution of the difficulty; the first, by rendering adjacent sections more uniform, would have tended to harmonise their respective rates of contraction, and thus reduced or nullified the stress; the second, by removing the metal, would have eliminated the possibility of stress at this point—for where there is no metal there cannot be stress.

It will be seen that the middle bar, Q, the reduced end of which fractured at P, is of a heavier section than the side bars R and S. It naturally follows that cooling—and consequent contraction—would continue with this bar after that of R and S had ceased. This means that these outside bars, when once set, would act as rigid stretchers between the two sides. And each end of the bar Q would, therefore, be fixed before it had finished shrinking. Contraction stress would gradually be induced in this bar, until, with cumulative force, it would overcome the cohesive resistance of the metal at the reduced section P. As an inevitable consequence, fracture would ensue.

From the above reasoning on cause and effect the remedy soon became apparent. Greater uniformity in the rate of cooling of the bars Q, R and S was evidently required. The middle bar was then lightened out, as shown at T—thus speeding up its rate of cooling. The section at P was thickened up on the top, as shown at U. This was almost equivalent to increasing its width (which was not permissible)—it slowed up cooling at this point. No special supplementary precautions were taken in the foundry. The result fully justified the methods adopted. The next and subsequent castings were quite satisfactory; severe tests failing to reveal any sign of fracture.

Modifying Design by Thickening Sections.

In certain circumstances, as, for instance, the addition of metal to a casting with a view to obtaining a stronger component, contraction stress occasionally brings about a diametrically opposite effect to that intended. The author calls to mind a case of this kind, which may here be of general interest.

A plate 5 ft. square, as at Fig. 8, was required to carry a heavier load than it had previously taken. The design was accordingly "strengthened." This strengthening consisted in thickening up and deepening the centre ribs V from $\frac{3}{4}$-in. wide by 1 in. deep to 1 in. wide by 2 in. deep, and adding similar ribs at W. As the casting was being taken to the dressing shop it collapsed. One corner of the plate, as at X, fell off.

The pulley example, Fig. 1, explains the above very well. The lighter—and more exposed—outside rim cooled first, and assumed a rigid form before the heavy frames of ribs had set. As a consequence, the plate between the ribs W and the outside was subjected to a tension load, which finally overcame the cohesiveness of the metal. It may be fairly assumed that the tension was evenly distributed, but, by the way in which the plate was supported on the wheel-barrow, and the jolting, the tension would probably become concentrated about one corner—the broken one. The remedy was found in reducing both sets of ribs to $\frac{3}{4}$-in. in width, and taking the frame W down to 1 in. deep, tapering the diagonal ribs down, of course, to suit.

Moulding Boxes.

Contraction stress generally works havoc with square-corner moulding boxes. The trouble is further aggravated where a large fillet is formed in the corner, as at Y, Fig. 9. Fracture occurs, sooner or later, as at Z. A very effective remedy is to make the corners round, instead of square, as shown at Fig. 10. The explanation of this, of course, is the same as that of the "round" corner J, in Fig. 4—the stress is distributed over a larger area, and the shape itself is more accommodating.

Camber Allowances.

Camber, again, is the outward expression of contraction stress in a casting, which primarily arises from a variation in the respective cooling rates of opposite surfaces. An interesting example of this is given in Fig. 11. If the pattern of this frame is rammed up straight, the casting comes out bent hollow on the top (plate) side, as shown.

To obtain a straight frame casting, in grey iron, a camber of 3/16-in. must be allowed when the frame is made without the central projecting pocket. In a semi-steel casting, without the pocket, 5/16-in. is necessary. When the central pocket is required to be cast on, however, and with semi-steel, a camber of 9/16-in. must be given.

In the above case, the lower edge of the ribs, being not only lighter than the top surface, but more exposed to cooling influences, naturally freezes first. This edge, then, may be compared to an iron bar, which, endwise, is practically incompressible. It may be assumed that, since the upper portion of the casting is more or less plastic when solidification of this lower edge occurs, the latter takes the shape of the mould below it. As cooling continues in the higher strata of the casting, a corresponding diminution of the overall length may be expected. The lower edge, being set—*i.e.*, irreducible lengthwise—contraction stress operates between upper and lower surfaces. This stress forces the lower, first-cooled, hollow-edge straight. And so, a straight casting is produced from a bent mould.

The different degrees of camber allowance which are necessary in this case are, of course, attributable to the differences in composition and design. The grey-iron casting, with its lower ratio of contraction per foot of length, as compared with semi-steel, requires less camber allowance than the latter. The massive projecting pocket, again, accentuates the difference in the rates of top and bottom cooling respectively between frames with, and those without, the pocket. Hence the need, in this case, for greater camber allowance to nullify the increased stress effect.

In these cases of cambering, it is not suggested that the castings undergo any material weakening as a result of contraction stress. Provided, of course, that the rate of cooling is not unduly hastened (a very important proviso), the castings should gradually accommodate themselves to shrinkage requirements.

Danger from Contraction Stresses.

The disruptive forces present in a casting which is under contraction stress are probably quite beyond computation. Nevertheless, one may safely assume that in some cases they reach a very high figure. The release of these forces is occasionally spontaneous—and unexpected. It is then accompanied by more or less danger to life and limb. Within the last few weeks the writer personally experienced a reduced-scale example of this.

An experimental cover plate casting in grey iron, 18 in. dia., with an external rim $\frac{7}{8}$ in. by $\frac{5}{8}$ in. and a variously-relieved centre plate $\frac{1}{8}$ in. thick, came out badly warped. Although the pattern was quite flat across the plate, the casting was found to have bulged outwards at the centre—under the compressive stress, presumably, of the later-cooling rim.

As the writer was in the act of turning the casting over for purposes of examination it collapsed. One piece, about half of the casting, shot away to a distance of from three to four feet. The arm supporting another portion was jerked violently backwards, as from the recoil of a gun, and pieces of the thin centre plate flew in other directions.

Examination showed that the fracture was quite fresh and that the metal itself was clean and sound. The total sectional area of metal fractured was well over 1 sq. in. It is fairly safe to assume, therefore, that in this comparatively small casting (it weighed about 10 lbs.) the stresses present—*i.e.*, regarded as tensional stresses—amounted to at least 10 tons.

Now it should particularly be noted that, beyond the slight strain imposed by its own weight, the casting was not subjected to any form of external shock; it was not being laid down when it flew to pieces, but was being quietly taken up, preparatory to being turned over, from a box part upon which it lay hollow side down. The mere change of position probably supplied the "last straw" to the stresses in the already over-loaded casting.

The above "close-up" (though none too pleasant) demonstration of the reality of contraction stress naturally strengthens the writer's long-held view of the importance of this subject. Such evidence is irrefutable. Surely, if improper design leads, through the operation of contraction stress, to the auto-dissolution of a casting, is it not justifiable to maintain that the highest efficiency of the metal employed can alone be secured where contraction stress is eliminated by proper design?

The incident further suggests that similar impressive methods of instruction might be well worth the consideration of those who formulate curricula for foundry education. From castings especially designed to exhibit extreme examples of stress effect the student would be enabled the better to visualise its operation. Visualising leads to clear thinking. And it is probably quite true to say that the successful design and production of castings require not so much, perhaps, brilliancy of mathematical or metallurgical attainments as well-balanced powers of judgment; the ability to form sound deductions from past experience.

Conditions Summarised.

To conclude, contraction stress may be said to be the resultant of conflicting forces operating within castings and tending to cause fracture. These forces arise from the shrinkage which takes place in castings whilst cooling. They come into neutral opposition (thus militating against the strength of the casting) through one, or both, of the following causes:—

(1) Sudden change of form, producing a corresponding change in the direction of shrinkage—as with the re-entrant angle; (2) differences in the size of the respective sectional areas of parts of the casting (especially those in close juxtaposition), thus giving rise to different rates of cooling. These stress forces are further intensified where the general rate of cooling is accentuated. Conversely, the more gradual the general rate of cooling the less pronounced is the effect of the forces upon the casting.

The chief remedy—*i.e.*, means of prevention—lies in adopting sound principles of design. For although the moulder may to some extent mitigate the effects of bad design by suitable gating, or by judiciously exposing parts of the casting, the best results can only be secured where the designer himself has a keen appreciation of these principles. When these principles are flouted, either through ignorance or expediency, there is bound to be a distinct loss of efficiency with the metal employed;

the foundry is penalised; scrap is increased; and the user of castings loses faith in their employment when they fracture through causes—to him—quite unfathomable.

DISCUSSION.

Mr. Perry asked about castings 11 ft. long and 6 in. wide, ribs 4 in. on one side and 2 in. on the other, with rounded edge. They came every time in a hollow, and they had had the casting face downwards because of machining. They had been turned over, but still came hollow and warped.

Mr. Edwards said he had seen hundreds of such castings from 3 ft. long to 18 ft. long, 6 in., 8 in., and 15 in., or even 2 ft. 3 in. wide, and had never had one example of the plate coming round on the unribbed side. How were the castings run?

Mr. Perry: With two runners at each end.

Mr. Edwards, continuing, said in some of his castings the end cores formed a channel for running, others were run at the side, and the castings were true to $\frac{1}{16}$th of an inch.

A **Member** insisted that such castings were always worst on the nearest round side when ordinary grey iron was used.

Mr. Edwards said it passed his comprehension why the castings came as they did.

Mr. Russell suggested that the ribs cooled last instead of first.

Mr. Edwards said he would expect the ribs to cool first; the thicker metal should hold its heat longer than the thin.

Mr. Russell agreed, and explained that his suggestion was the trouble.

Mr. Edwards said that the heavier top in Fig. 11 had a greater contraction capacity than the smaller ribs, and by reducing the length it pulls the bottom up to it because with this being extremely thin, just a long strip, there is a cooling surface 2 ft. wide, and surely 2 ft. wide had a greater heat-sustaining capacity than 5 ins. wide. That was only common-sense reasoning.

Mr. Russell agreed that the sets must have cooled last and the top must have gone first.

Mr. Edwards said his firm made all sizes, and very large numbers, and the plate side always came out hollow. There was a large conduction of heat on the top side.

Mr. Perry asked if the sand could act as a reservoir of heat.

Mr. Edwards explained that the sand intervening would not act as a reservoir of heat but as a radiator, and the heat from the face would radiate away. If the ribs go down into the body sand, they would act as radiators.

Mr. Perry, interposing, suggested it would radiate to the centre of the sand and there act as a reservoir of heat.

Mr. Edwards pointed out that the heat is radiated *away* not *to;* it went away to the outside atmosphere. Heat was taken away from where there was most to where there was least. He believed the ribs acted as a radiator, and heat was radiated away from the surface body of the metal.

Mr. Lucas said he had listened with very great interest, but he was surprised more had not been said about mixtures. He had found that by altering mixtures one could, to a certain extent, overcome a number of these contraction troubles, though, on the other hand, the designers were sometimes at fault.

Mr. Edwards said the reason he had not touched on mixtures was because contraction affects all mixtures, and if the designer arranged the casting in such proportions as to eliminate these contraction stresses then the casting was stronger if it was a good mixture. If the design was correct in the first place, then the mixture could be chosen accordingly.

Mr. Russell said in Fig. 7 he noticed the lecturer used a chill under the weak point. He could not follow the argument; it was an original suggestion to strengthen the weak place by chilling it. He admitted one closed up the grain, but he failed to see how one could strengthen it by chilling. If he wanted to put a chill at all it would be under " P," as obviously " Q " shrank last on account of its greater thickness. The cooling at Q was speeded up by putting on the chill, and the thick section had been converted into a thin section, and the cooling was then normal. The thickening up at P, he suggested, was quite unnecessary. The cure was due entirely to the reduction of area in the metal at Q, and that the thickening up at P, although apparently right, if taken away one would be no worse off.

Mr. Russell voiced the thanks of the meeting to Mr. Edwards for his very interesting and stimulating Paper.

Mr. Edwards, in reply, said it had been a great pleasure to read the Paper. In putting together one of these Papers he found it was really an education to the individual, and many points became clear as they endeavoured to put new thoughts on paper. One became more exact in one's ideas, and he thought it would be better if more members would prepare Papers, but unfortunately many of those with the longer experience were disinclined to do so, and it was a great pity, for they could give most interesting information.

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Wales and Monmouth Branch.

HIGH-TENSILE CAST-IRON.

By A. Marks, F.I.C., A.I.M.Mech.E.

The problem of improving the tensile strength of cast iron has engaged the attention of many workers. It was very early recognised that the excessive amount of graphite in cast iron, in which the flakes became interlocked one with the other, formed lines of weakness in the material which precluded any possibility of the material having a high-tensile strength. The early recognition of this fact led to many workers adding a material to the cast iron, namely, mild steel, which did not contain graphite, and which, therefore, acted as a diluent to the graphite and increased the tensile strength. The results, however, of adding increased amounts of steel did not show a consistent relation in increased tensile strength with increasing additions of steel, and the problem of later workers was chiefly in endeavouring to correlate the facts indicated in this way.

It soon became evident that increasing the additions of steel led to a hard and sluggish metal, and the practical limit was in many cases reached by the addition of 20 per cent. of steel. It is, however, easily possible to make additions of 50 per cent. of steel to pig-irons and still at the same time obtain a soft workable material which will readily flow. The strength of the early cast irons was of the order of 7 to 9 tons per sq. in., but immediately the question of regulating the graphite content of the iron was solved the strengths went up to the figures of the order of 10 to 14 tons per sq. in. The problem of adding steel to the pig-irons for the purpose of increasing the strength involves a knowledge of the working of the cupola and the composition of the pig-iron. Early workers tried the addition of steel by "rule-of-thumb" methods by a practical knowledge of the pig-iron, and very soon were into difficulties.

Their material has frequently been hopelessly at fault, hard and quite useless as a machinable product, the reason being that they had no realisation of the factors which it is necessary to take count of in making such a semi-steel. To carry a high percentage of steel it is necessary at the same time that the pig-iron should carry a high percentage of silicon, and also to melt the metal at a high temperature with a good coke ratio. Only thus can the economy of high-steel additions be taken advantage of, and a soft metal obtained. As a typical example of a charge of metal for a mixture containing 50 per cent. of steel one may take a high silicon No. 1 iron containing, say, 4.5 to 4 per cent. of silicon and 50 per cent. of steel, and obtain a soft machinable material using a coke ratio of the order of 1 to 6. The economy which is obtained when using the higher percentage of steel is, of course, nullified by the fact that a high silicon iron is necessary to accomplish this object, and, therefore, whilst it is easily possible to produce these high-percentage semi-steels, the economy of adding steel scrap is usually reached at a figure varying from 20 to 30 per cent., but it is quite a practical proposition to run these high-steel mixtures without getting hard iron. The tensile strength which will be obtained will not exceed figures of the order of 14 tons per sq. in., or 16 tons for thick castings of hard quality.

Influence of Section.

The problem of high-tensile cast iron is also involved with the question of section of metal. It is well known to practical foundrymen that a mixture of material which may be used for casting steam-engine cylinders and an average thickness of 1¼ in. would be quite unsuitable for casting, say, a steam engine liner of 2½ in. thickness throughout, and that the same mixture used for the two jobs would result in a very open-grained liner. Mixtures which are used for heavy castings of the type of a liner can be run either from very soft pigs or from hard pigs. In the case of the soft pigs the metal is able to carry much more steel and scrap additions, but in the case of the low-silicon irons increasing the tensile strength by the addition of steel is not possible to any great extent. For instance, one might run a steam-engine cylinder liner from a mixture of No. 4 and 5 irons and keep a tensile strength of 14 to 15 tons. An equally good liner can be made by running No. 1 iron with, say, 30 per cent. steel and 30 per cent. scrap, and this liner would come out with a tensile strength of the same order. Thus the graphite which is the chief factor in the tensile strength is adjusted in both mixtures (run in the same furnace) to a common factor, namely, the percentage of graphite, upon which the tensile strength of the iron largely depends. It is, however, quite common in the experience of foundrymen that certain types of pig-iron will carry more steel than others, even when the silicon content is the same in both irons. The variations in these irons will be found in the manganese and phosphorus contents, thus a high phosphorus iron will carry only small additions of steel before the mixture becomes hard, assuming the silicon content is constant, so that for the manufacture of high-percentage semi-steel mixtures it is necessary to use low-phosphorus irons or hematite pigs which will readily carry 50 per cent. of steel provided the silicon content is suitable. On the other hand, a high-phosphorus iron will not usually be satisfactory with more than 20 per cent. of steel for the same job. Again, when the section of the metal which has to be cast is considered, the amount of steel which can be added to increase the tensile strength by reducing the graphite content requires careful consideration. For example, if one is running 5-16-in. metal in a semi-steel mixture one may use either a hematite or high-phosphorus mixture, as in the last instance, but the amount of steel which can be carried would have to be considerably reduced, say, with a hematite metal, not more than 20 per cent. and a high-phosphorus metal with not more than 6 to 8 per cent., so that the economy of adding an increased percentage of steel can only be equated against the increased cost of the lower-phosphorus irons.

With a high-phosphorus iron the advantage of running thin sections is well known, and a small addition of steel of the order of 8 to 10 per cent. will very soon make one of these irons hard. Increased hardness, whilst giving an increased tensile strength, has a limit, and the upper limit of tensile strength of the mottled to white iron is of the order of 15 tons per sq. in.

Improving the Matrix.

Having considered the problem of increasing the tensile strength of irons by reducing the planes of graphite weakness, we next have to consider how, when the graphite has been reduced to the extent so as to leave a machinable iron, we can increase the strength of the ferrite matrix in which the graphite is embodied.

The increased strength of the ferrite matrix can be brought about by various means. The first is the elimination of impurities, such as phosphorus and sulphur. Both of these materials are hardening agents, but as the percentage increases brittleness comes in. For high-tensile cast iron, therefore, it is definitely necessary to eliminate phosphorus, involving increased cost, so that for all work, whether large or small, in which is required tensile strength above 14 to 16 tons it is necessary to remove the phosphorus content. The phosphorus content cannot be removed in the cupola, and hence one is forced to increase the cost by expenditure on high-class pig-iron. If this is quite in order, one can at once increase the toughness of the iron by the elimination of the phosphorus, but the tensile strength will only improve moderately. With no phosphorus present in castings the tensile strength comes out at the order of 14 to 16 tons, provided the graphite has also been simultaneously corrected. The elasticity as shown by the bending test, however, increases considerably.

The sulphur content, for similar reasons, it is necessary to reduce below 8 per cent., which involves the use of first-class coke in melting. The next item, therefore, which is to be tackled in producing high-tensile cast iron is the question of the metallographic structure of the ferrite. In carrying out research work at the Swansea Technical College some years ago, investigating the possibility of producing malleable cast iron with the tensile strength of the order of 22 tons per sq. in. without the use of the annealing process, irons were made with a view to producing pearlitic structure or pearlitic cast iron. In these irons the weak graphite planes were reduced, and also the ferrite matrix strengthened by increasing the combined carbon, so that on cooling the structure consisted of pearlite and graphite. These irons were easily machinable in addition to having a higher tensile strength than the ordinary structure. On subsequent dates the work was carried out on a large scale.

Iron of this kind has been made on a large scale with a tensile strength of 19½ tons per sq. in. in thicknessses of sections of 1½ in. to 2 in. It is readily forgeable, and has considerable elasticity, about 0.3 per cent. elongation, and takes a permanent set on the bend-test machine.

FIG. 1.—PEARLITIC CAST IRON × 1,000.
TENSILE, 19.5 TONS PER SQ. IN.

The essential facts in producing pearlitic cast irons are: (1) It is necessary to reduce the graphite in quantity and size of flakes; (2) it is necessary to get the phosphorus down to practically negligible limits, as this induces weakness in the pearlite; and (3) it is necessary to adjust the silicon content of the iron so that the combined carbon in the finished casting is not excessive for the thickness of metal being cast.

The percentage of combined carbon may vary between fairly wide limits. Pearlitic irons have been made with 0.55 to 0.89 percentage of combined carbon. A specimen of metal having a combined carbon of 0.56 per cent. exhibited under the microscope an all-pearlitic structure at the high magnification of 600.

Additionally, slow cooling in the mould is essential to avoid chilling the job, hence the desirability of a hot mould; but this again is a function of the weight of metal to the weight of moulding sand, and not in itself a special factor, but only a relative one. Fig. 1 shows pearlitic iron at 1,000 magnification.

FIG. 2.—CENTRIFUGAL CAST IRON × 100.
TENSILE, 20 TONS PER SQ. IN.

The production of pearlitic cast iron has been approached from different points of view. The German advocates of this material evidently attached chief importance to wear, whereas in England it has been approached on a large scale from the point of view of increased strength of the material and resistance to cracking when the material was subjected to high stress at a high temperature. It has been known for a long time that one of the strongest structures in steel was a pearlitic one, and, therefore, it was deduced that stronger irons would be produced by having an entirely pearlitic structure with graphite present as the only other constituent, and this graphite, as far as possible, should be as finely divided as possible. It is easily possible to produce the pearlitic structure providing the question of cost does not enter into the matter, but it is not easy to produce the graphite in an entirely non-flake or spheroidal form. The German patent does not make any attempt to control the form of the graphite. It is a question of commercial interest to know when it will be worth while to manufacture castings in pearlitic cast iron. In all cases where strength is the chief requirement, it will pay to ensure the increased cost of manufacturing castings in this material. For general purposes, however, where green sand and semi-dried sand castings are quite satisfactory there is no object to be attained in increasing the cost of production by introducing more expensive material. For rolls where high heat resistance is required, it will be extremely useful, but it still remains to be shown that its wearing qualities are higher than present rolls.

Lanz Pearlitic Cast Iron.

The essential point in the production of pearlitic cast iron is composition, and in a recent lecture at the London Branch* the lines upon which trials had been made were indicated. High temperature of the mould is also a desirable factor, and apparently in this respect the German patentees have drawn up an elaborate scheme for the control of the temperatures of the moulds, although it has been stated that the actual control could be, to a considerable extent, dropped after the workman concerned had gained experience in the application of these methods.

There can, of course, be no question of any mixture for the manufacture of cast iron being patented, and therefore the production of the pearlitic structure, in so far that it is not completely controlled by the composition of the metal, is

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* See the Foundry Trade Journal, October 16, page 327. "Pearlitic Cast Iron," by J. E. Hurst.

covered by the process of heating the mould to definite temperatures. The German patent claims that the mould is heated to a certain definite temperature depending upon the mass of the material and other factors which are indicated. Now, it is quite a general practice in many foundries making special castings to return a dried mould, after having been partially cored up, to the stove for further heating, finally closing down the top of the mould and casting whilst it is at a fairly high temperature, so that apart from any further details which may be disclosed, there is nothing new in casting in a hot mould to anneal the metal. The manufacture of pearlitic cast iron in moulds which have received a double heating has been practised in this country.

The principal factor to attend to in the production of pearlitic cast iron is that of composition, and provided this is attended to with due regard to the thickness of the metal being cast, it is quite possible to produce pearlitic cast iron in reasonably dry warm moulds, regulating the cooling from the heat of the metal if there is sufficient mass of metal in relation to the mould.

The problem of high tensile strength cast irons, however, is one which for general practice is not of first importance. It is somewhat of less immediate practical importance than the question of sand mixtures.

It is necessary that foundrymen should get rid of all unsoundness in castings. The troubles associated with foundry practice are more involved in moulding than with metal, and the metallurgical side of foundry work is well abreast of general moulding practice. This applies particularly in relation to the keeping back of dross and the breaking away of sand from the various cores, etc., during running.

Hence, for practical foundrymen it is essential to consider every way by which these defects may be removed from castings, as a casting with a test-bar strength of 18 or 19 tons per sq. in. is of little use if there is a junction of metal which holds a hollow due to trapped gas or a surface on which dross from metal or mould has been deposited.

The possibilities, however, when these defects are overcome, of pearlitic cast iron are many.

Since its possible strength is high, and it will maintain its strength at temperatures of the order of 550 deg. C. over long periods, it becomes exceedingly useful material for special work, such as internal combustion engines. Further, its wearing qualities render it a good substitute for other bearing metals, and it is understood that it is being used without bronze bushes for wearing work in Germany. It may be a long time before pearlitic cast iron is used generally for a bearing metal, although in some of the cheaper motor vehicles ordinary cast iron, without bushes, is being used as direct bearing metal, and it would be a national economy for further development along these lines. Typical charges for various ordinary, special cast irons, and pearlitic cast irons were given.

The lecture was illustrated by some 30 lantern slides, and samples of pearlitic cast iron in mass and under the microscope at high magnification. The microphotographs, Figs. 1 and 2, show the comparison of pearlitic and centrifugal cast iron of approximately the same strength. The latter requires further annealing.

DISCUSSION.

A short discussion ensued, in which **Mr. Jenkins** mentioned, in connection with semi-steel, that to make 50 per cent. steel with 4 per cent. silicon one must have very special iron, and with the ordinary foundry cupola 10 to 15 per cent. would be better. In making marine cylinders 4 to 5 tons in weight and 2 in. to 3 in. thick, if high tensile semi-steel was used one might reduce the section to 1½ in. or 2 in., which might serve some purposes, but as there is as much labour in moulding 1½ in. section as a 3 in. section the foundry owner would probably lose about 2 tons of metal. The idea of warming moulds was quite an old one, as the system had been practised in his apprenticeship days.

Mr. McClelland asked whether it would not be far more beneficial to drive the metallurgical question home to the manufacturers of pig-iron, so that it could be branded in such a manner that the ordinary foundryman would be better able to grasp the class of metal he was dealing with.

Mr. Williams asked whether it was considered that open or closed risers were better.

Answering a question raised by Mr. McLean as to 14-ton tensile strength high-phosphorus cast iron. Mr. Marks explained that there was no need to use steel at all for making castings up to 14 tons. tensile. Pig-iron and scrap can be used, but it is much more easy to adjust when steel is used than when buying high carbon pigs.

When making some crane parts Scotch iron No. 3 was used with 50 per cent. steel. This was easily machined, and would give 14 tons to the sq. in. There was no difficulty, providing the coke bed and coke charge were right, and the iron was run hot enough. If clean iron was required one should use high manganese.

Replying to Mr. Jenkins, for ordinary foundries 2.0 per cent. silicon iron as used will not carry more than 10 to 15 per cent. steel, according to the percentage of phosphorus present. Hot metal was also necessary for the production of good castings from a fluid metal from which the dross would rise was obtained bv means of high phosphorus metal. The author preferred open risers, but unfortunately dirt is more easily introduced, and the general tendency was for closed risers. The point was to get the gases away as quickly as possible. In casting pipes on end one had to open the mould at the bottom to the very limit in order to get rid of the gas.

Mr. Marks was of the opinion that not much could be gained by troubling the manufacturers of pig-iron, but as practical foundrymen, the material which the gods saw fit to give them must be used. If large quantities of pig-iron were required it was possible to obtain to specification, but if one knew the source of the supply there is no difficulty in getting the manufacturers to supply one with an analysis from which one can make up mixtures. It was frequently stated that it is difficult to run high phosphorus irons with hematite, but this has been done for many years.

London Branch.

MODERN PROBLEMS AND DEVELOPMENTS IN ENGINEERING BRONZE FOUNDING.

By Francis W. Rowe, B.Sc., Member.

It is not the author's intention to deal extensively with modern methods of production in bronze foundry practice, nor with the details of the alloys used, as this phase of foundry work should be quite familiar to most. It is intended, however, to deal with specific problems and possible developments, particularly those which seem, in the author's opinion, to lack the attention they merit.

Those concerned with actual works production are always particularly impressed with the small amount of information available regarding the more commonly used alloys in industry. That such information, even of a purely scientific character, should be so meagre and scrappy, is a serious indictment against the academic research worker, especially when one considers the amount of time and money spent annually on non-ferrous research.

It is true that sterling work has been done in the past, but the present tendency is, with a few exceptions, for the academic research worker to devote his time to investigating alloys and alloy systems which do not find any application in industry and, what is more important, probably never will do. The author would be the very last to decry the possibilities and ultimate value of the work done in pure science, but the recent remark " that we are getting too much jam and too little bread " aptly seems to sum up the present situation. The works-metallurgist, whilst realising the urgent need for scientific data on industrial alloys, has not the time to devote to pure research, nor, if he had, would his findings, in the majority of cases, be available for others. To quote but one specific instance of this deficiency—the case of phosphor bronze. Even to-day there is no ternary equilibrium diagram for this widely used alloy. The only work in this direction is found in an

Italian journal for 1907. If only academic workers would realise that 80 per cent. of the world's production of non-ferrous castings consists of either gunmetal in some form, manganese brass or phosphor bronze and that the scientific data available on these alloys is small.

Fig. 1.—An Oxidised Bush, showing Intergranular Fracture.

Problems of Furnaces and Melting Practice.

The one phase of bronze foundry practice where the progress for the last 20 years has been practically negligible is the melting practice. From time to time new furnaces and new methods of melting are heralded, but, despite these, the coke fired pit furnace is still the favourite method of melting for casting. This is especially remarkable when one considers the extremely low thermal efficiency of this furnace. In the best cases it is not above 6 per cent. and more generally about 3 or 4 per cent. Table I shows the approximate thermal efficiency of the more common types of furnace. Both fuel oil fired and gas fired crucible furnaces have had a very fair trial in this country, but only in a few cases are they being operated to-day. They certainly possess some advantages over coke-fired furnaces, but it is difficult to operate them so cheaply, despite the many claims which have been made.

FIG. 2.—BEST SELECTED COPPER × 100 DIAS., SHOWING CuO EUTECTIC.

Coke-fired crucible tilting furnaces are much more common and these may be said to be a type which will stay for a long time. The efficiency is higher than a pit furnace, but more experience is needed by the furnaceman as the crucibles have a very short length of life, unless the furnaces are carefully operated.

The crucible costs are a very important factor in bronze melting. The average present-day costs of melting and casting a ton of metal in small quantities for small work is about 45s., of which about 14s. is for crucibles. Hence the many attempts of the foundryman to find a suitable non-crucible type of furnace. There can be no question that the crucible pit-fire natural draft furnace constitutes a method for melting which has not yet been excelled on the score of the quality of metal produced. The writer would not care to say that it cannot be equalled, but with other types of furnaces the danger of adversely affecting the quality of the metal is much more great and thus the skill of the operator needs to be corresponding greater.

Table I.—*Furnace Thermal Efficiencies.*

	Per cent.
Coke-fired crucible pit furnace-natural draught	3 to 7
Coke-fired crucible tilting furnace	8 to 13
Oil or gas-fired crucible tilting furnace ..	7 to 18
Reverberatory furnace	12 to 20
Cupola	30 to 40
Small electric furnace	40 to 65
Large electric furnace	60 to 85

Open type furnaces working with various fuels usually give considerably lower melting costs and are, of course, the only type used for melting large quantities of metal that is from 15 cwts. upwards. Excellent results can be obtained from these, providing the furnace atmosphere is kept just right—again a matter needing considerable skill—but these have yet to displace crucible furnaces for the majority of work.

The British foundryman has frequently been upbraided for his lack of enterprise in not adopting electric furnaces more extensively for non-ferrous work, but critics should remember that the seemingly more enterprising American is able to obtain electric power at competitive rates, and that also the non-ferrous foundryman is more sceptical on account of the many shortcomings of the electric furnace in steel foundry work, particularly when compared with the acid converter.

The choice of, and care devoted to, furnaces for melting non-ferrous metals do not yet seem to obtain the consideration they warrant in most foundries. Whilst the general trend of modern practice is to devote great care to analytical and pyrometic control, the importance of correct melting practice is not sufficiently realised.

Problems of Correct Melting.

It is not generally known how simple it is irreparably to ruin a bronze by incorrect melting practice. The dangers of oxidation during melting are far more prevalent than is often imagined. On account of the difficulty of detecting oxide in a bronze, its presence, even in extremely deleterious quantities, is often overlooked. Some of the most susceptible alloys to maltreatment in this direction are the alloys of the gunmetal class that is bronzes with or without small percentages of phosphorus and zinc.

Unfortunately, analytical results do not give any clue to the presence of oxide, and even careful microscopical examination may not give any definite evidence if the alloy contains lead or non-metallic impurities other than oxide. Probably the best guide to the presence of oxide in a bronze is the appearance of the fracture of a sample cast under good conditions as regards casting temperature, etc. Should the fracture be intergranular or show red specks, the presence of oxide is practically certain. Fig. I shows an excellent example of an intergranular fracture. The sample is from a consignment of war scrap—phosphor bronze bushes from gun limbers. The analysis of the particular sample is shown in Table II.

TABLE II.—*Analysis of Oxidised Bush.*

	Per cent.
Copper	86.7
Tin	10.5
Lead	0.71
Zinc	1.21
Iron	nil
Phosphorus	0.36
Arsenic	0.004
Antimony	0.002
	99.576

It will be seen that the analysis presents no unusual features although too much zinc is present for a good class phosphor bronze. The fracture, as will be seen, is completely intergranular and the dendrite formation of the separate grains is shown up remarkably well. The only unusual feature in the microscopic appearance of such a bronze is the presence of hair-like films usually starting from a patch of eutectoid and running to another patch or bordering a patch of eutectoid.

Cause and Prevention of Oxide.

The presence of such oxide is due primarily to faulty melting and mixing practice. The basis of all bronze is, of course, copper. Although electrolytic copper cathodes are fairly extensively used nowadays, the major portion of castings is produced with ingot copper. For casting, that brand known as "Best Selected" is generally purchased. Best Selected ingot copper usually contains 99.6 to 99.75 per cent. copper, the balance consisting of various impurities including oxide. The oxygen content varies from 0.05 to 0.3 per cent., and is easily visible under the microscope, as shown in Fig. 2.

The metal then is initially oxidised. That some further oxidation occurs in melting is inevitable, but careful practice will keep this at a minimum. Melting without a cover, prolonged melting, exposing the unmelted or partially melted ingots to an oxidising flame will all soon raise the oxide content to a highly undesirable level. Furthermore, one very seldom starts with all new metal in bronze-foundry practice—scrap generally forms from 40 to 70 per cent. of the charge—all of it containing more or less oxide. The question naturally arises, why not deoxidise the metal after melting? This is a far more difficult thing to accomplish than is generally realised. According to technical literature, phosphorus is one of the most powerful deoxidisers known. This widespread faith in the efficacy of phosphorus is touching but, unfortunately, misplaced. Whilst it is perfectly true that phosphorus will reduce cuprous oxide, it is not generally realised that it is of little value to reduce tin oxide. The writer has had numerous instances of the presence of large quantities of tin oxide present in bronzes containing anything up to 1.5 per cent. phosphorus.

In fact none of the commercially-used so-called deoxidants seems capable of removing tin oxide from a bronze. Phosphorus may be called the friend of the poor foundryman. It enables him to transform a pot of bronze which is so full of oxide that it is like treacle into a free-running metal, which, nevertheless, still contains its oxide and will give hopeless castings from the standpoint of strength.

The best way to deoxidise a bronze is not to oxidise it. No amount of "dope" will replace correct melting practice and make rubbishy scrap into new metal. In this connection the importance of adding the tin to a bronze, last thing of all, should be noted. Every precaution must be taken to preclude the possibility of tin oxide. The phosphor-copper or phosphor-tin or zinc or manganese copper or whatever alloy is preferred must be added before the tin, and stirred in and allowed time to react.

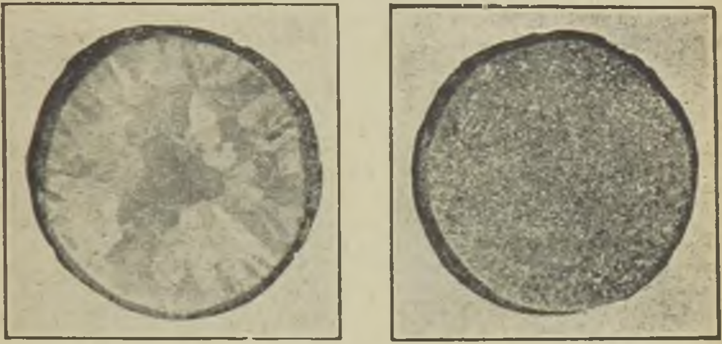


FIG. 3.—ETCHED MICRO-SECTIONS SHOWING THE INFLUENCE OF CASTING TEMPERATURE ON THE GRAIN SIZE.

Runners and Running and Pyrometric Control.

Probably the most important factor in the making of bronze castings is the method of running and feeding the castings. This is especially true in castings of any appreciable weight. There are one or two axioms which are easily stated and the truth of which will readily be admitted, but to carry these out in actual practice—with due regard to economical considerations—is frequently very difficult. One of these axioms is that the mould should be filled at every point with metal at the same temperature. The perfect achievement of this ideal is naturally difficult, but the manner in which some foundries run their castings throws light on their difficulty of obtaining a high percentage of really good work.

Another is that the runner should be so placed that the metal is agitated as little as possible inside the mould, and so that the metal does not flow with any force against the sides of the mould. The best results in bronze-founding practice are always obtained by running the casting as rapidly as possible consistent with avoiding undue agitation and scabbing of the moulds.

Whatever results are obtained in cast-iron founding small runners are of no value in bronze-foundry practice where good results are imperative. The subject of casting temperature is intimately bound up with the question of methods of running, and one cannot logically be discussed without the other. That the casting temperature of an alloy is an important point everyone now agrees, but mere discussion of casting temperature without reference to the size of the casting, the thickness of section, and the size of the runners is valueless and meaningless.

It has been the author's privilege during the last few months to visit a number of non-ferrous foundries—some up-to-date and some out-of-date—and he was rather pleasantly surprised to note that nearly every foundry had pyrometers; and if these were not used as regularly as one might think necessary, they were invariably used on heavy or important work.

The regular use of a reliable pyrometer in all bronze foundries is a practice which is to be strongly commended, as by this means one phase of bronze-foundry practice can be standardised and valuable data obtained. One point with regard to the fixing of casting temperature-limits perhaps deserves to be mentioned. The generally prevalent idea is that the heavier the section of the casting the lower the casting temperature should be. This is not always strictly true, as a very important factor is being neglected if only this aspect is considered. That is the distance the metal has to travel to the farthest point of the mould. It should be realised that once the metal has entered the mould the temperature falls with great rapidity, so that by the time it has travelled a short distance the temperature is very different from that of the metal in the pot.

FIG. 4.—ETCHED $(NH_4)OH + H_2O$ × 100 DIAS.

Thus in fixing the casting temperature this very important factor must be taken into consideration. The casting temperatures used for the bronze alloys lie between 1,000 deg. and 1,250 deg. C., the average being 1,100 and 1,200 deg. C.

Liquation, Segregation and other Problems.

One of the most serious troubles in bronze-founding practice in the past has been defects due to heterogeneity of castings. High-tin bronzes, particularly those containing phosphorus, are very liable to give trouble in this respect. Consisting, as they do, of two quite distinct phases, solidifying over a wide range of temperature, due consideration must be given to freezing conditions to obtain a homogeneous casting of good physical properties. Naturally the lighter castings do not present any difficulties in this respect, as immediately the casting is poured solidification takes place throughout, and there is very little possibility for segregation or liquation to occur.

With the ordinary tin bronzes the solidification commences at 990 deg. C., and is complete at 790 deg. C. With phosphor-bronzes the solidification commences about 960 deg. C., but the alloy is not finally set until the freezing point of the ternary eutectoid, namely, 620 deg. C. Thus the possibilities for liquation troubles to occur are greater with phosphor-bronzes than with plain bronzes or gunmetals. The effect of variations of casting temperature and rate of cooling on bronze constitute an almost unlimitable field for research, the fringe of which has only yet been touched. Only a few of the main effects can be stated with certainty. The lower the casting temperature of the bronze (other things being equal) the greater will be the Brinell hardness and the greater the density. Also the lower the casting temperature the smaller will be the grain size, as shown by etched microscopic sections such as those in Fig. 3. This is due to the rapid rate of cooling through the primary solidifying range, and corresponds with the small grain size shown by chilled castings. Low-casting temperature in bronzes gives rise also to greater segregation of the eutectoid, which is not often a desirable feature. When the eutectoid forms an almost continuous network or is segregated in large patches instead of being formed in smaller sized, isolated and evenly dispersed nodules, the alloy is considerably more brittle and weaker to shock. Figs. 4 and 5 show samples of bronze of the same composition which illustrate the effect of low-casting temperature on the eutectoid segregation. Variations in casting temperature have also a marked effect on the colour of the fracture of a bronze. Bronzes with 10 to 12 per cent. tin when cast at a high temperature (1,175 to 1,250 deg. C.) break with a golden-brown fracture, whilst those cast at a low temperature (1,075 to 1,125 deg. C.) have a greyish-white fracture. The appearance of fractured runners, etc., together with the microscopic appearance, and in conjunction with the size of the runner thus enables one to make a very close estimate of the temperature at which the metal was cast.

Where the strength of a cast-alloy is the primary consideration, it should be remembered that the conditions which tend to give a bronze of the greatest strength are rapid solidification from a fairly low-casting temperature and very slow cooling after solidification. Such conditions obtain in test bars attached to large, heavy bronze castings. A test bar attached to the bottom of the casting, and cast in such a manner as to solidify rapidly, will give very good results due to the slow cooling after solidification.

Tin-sweat.

This method is, of course, similar in some respects to casting a chill bar and subsequently annealing and slow cooling, which invariably gives higher test results than can be obtained by other methods. A comparison of the effects of various rates of cooling on strength is given in Table III, which illustrates the points enumerated above. One of the most familiar examples of liquation in bronzes is seen in high-tin bronzes, particularly those containing phosphorus. This is generally and expressively known as "tin-sweat."

TABLE III.—*Effect of Varying Solidifying Rates and Cooling on Admiralty Gun-Metal, Analysing Copper,* 87.44; *Tin,* 10.43; *Lead,* 0.27; *and Zinc,* 1.66 *per cent.*

Casting temp. Deg.	Method of moulding.	Maximum Stress. Tons per sq. in.	Elongation. Per cent.
1120	Attached to 15 cwt. casting.	21.8	27
1140	Loose green sand.	17.2	18
1140	Chilled and subsequently annealed.	23.4	32

Size of Test Bar in each case 1¼" round.

In its less harmful form it is seen to advantage on the runners of high-tin, high-phosphorus bronzes cast at high temperatures when the exudation from the runner may often be sufficient to cover the whole of the runner head. It is also fairly frequently seen on the top surfaces of castings after machining, grey hard spots generally having minute pellet holes all round the outside edge. These spots may be sufficiently extensive to cause rejection of a casting, and very often they extend deeper than is at first imagined. The author recently saw a case of "tin-sweat" on a large phosphor-bronze casting weighing about one ton, in which the actual "tin-sweat" was over 18 in. long by 2 in. to 3 in. broad, and was over ⅝ in. in depth.

Table IV.—*Typical Exudations from Bronze Castings.*

	Copper.	Tin.	Lead.	Zinc.	Phosphorus.
Casting ..	89.0	9.35	1.24	1.20	nil
Exudation ..	77.12	17.36	4.48	0.76	nil
Casting ..	88.03	10.70	0.33	0.46	0.16
Exudation ..	80.26	18.24	0.77	0.16	0.41
Casting ..	87.88	10.23	0.87	0.41	0.44
Exudation ..	78.82	19.29	1.40	0.29	0.92
Casting ..	86.11	12.54	0.21	0.16	0.89
Exudation ..	77.18	20.37	0.33	0.12	1.75

Table V.—*Analysis of a Large Phosphor-Bronze Casting Weighing* 19 *cwts.*

	Casting Per cent.	Exudation Per cent.
Copper	87.5	80.9
Tin	10.6	18.2
Lead	0.15	0.46
Zinc	0.30	0.45
Phosphorus	0.40	0.74

The "tin-sweat," in all cases, whether seen in the casting or on the runner, consists chiefly of what eventually becomes the delta eutectoid, and (if the alloy is phosphor-bronze) copper phosphide. The author has, at different times, had analyses made of such exudations from bronzes, and a sample of such analyses is given in Table IV. Table V gives the analysis of the exudation or tin-spot on the large phosphor-bronze casting mentioned above, together with the analysis of the main body of the casting. It is interesting to note that where the alloy contains lead a much larger proportion of lead is found in the exudation.

Cause and Remedy of Tin Spots.

The causes are too high casting temperature and insufficient feeding of the metal. The solidification of high-tin bronzes seems to proceed to two distinct phases—more distinct than one would imagine from the thermal equilibrium diagram. The alpha solid-solution of the alloys freezes, and the subsequent contraction of this network causes the still liquid portion of the alloy to be squeezed out.

If a heavy mould is poured at a high temperature and the runners and risers are so small that feeding is impossible, the liquid shrinkage will cause the metal to leave the top of the mould at the place where the metal is hottest (near the runner), and the subsequent cavity will be filled up by exudation of the low-melting point compound causing a tin spot. The remedy is to cast at a lower temperature, and if this is impossible because of the distance the metal has to travel, cast with as large a runner as possible in order to enable the casting to feed itself from the runner. The head of the casting should be both of large volume and good depth to give the requisite pressure head, and remain fluid the requisite time.

The reverse of this "tin-sweat" problem is also possible and interesting. If a piece of phosphor-bronze is heated up to 620 deg. C. the low melting-point compound will exude, and only this compound will exude until a very much higher temperature is reached.

The author has examined bronze bearings which have heated up and seized in service where the temperature attained has been high enough to cause this exudation, and the journal has been cemented to the bearing by this exudation.

In one instance the quantity exuded was sufficient to enable an analysis to be made, the results of which are shown in Table VI.

TABLE VI.—*Exudation from Seized Bronze Bearing.*

	Composition of bearing.	Composition of exudation.
Copper ..	84.09	72.48
Tin	13.87	21.59
Lead ..	0.74	4.98
Zinc	0.88	Trace
Phosphorus ..	0.030	0.030

Blowholes.

Blowholes are troubles which the foundryman will always have with him. In a well-regulated foundry, however, they should only form a small portion of the daily worries as the remedy is generally obvious and applicable. Probably the chief cause of blowholes in bronze-founding is cold metal. Very few commercial moulds are made which will not evolve a certain amount of gas when the hot metal is poured in. Provided, however, that a reasonable period of seconds elapses before the metal in the mould solidifies the reasonable amount of gas generated will not adversely affect the casting. But, if the metal is at such a temperature that it freezes as soon as it has filled the mould, the gas bubbles will remain as gas bubbles in the final casting, as the metal has not the chance to recover itself.

It must be admitted that certain metals and alloys have the exasperating habit of evolving gases at the moment of solidification. Pure copper is notorious in this respect, and many nickel alloys, unless carefully handled, fall from grace in this manner. It should, however, be a golden rule with foundrymen that whenever castings exhibit blowholes, the first thing that should be done is to try the effect of a casting temperature 50 or 100 deg. C. higher.

Manganese Bronze.

Manganese bronze—or to give it its academic name, high-tensile brass—forms an extremely useful series of alloys adapted for foundry work, although their limitations in several directions should be realised.

Properly made, they have better physical properties than any other metal or alloy in the cast state; tensile strengths of over 40 tons per sq. in. being obtained with careful practice, whilst still retaining a remarkable ductility shown by elongations of 20 per cent. or over. Probably the major portion of the manganese bronze produced finds its application in marine engineering. It is the alloy almost universally employed for propellers owing to its strength and toughness and satisfactory resistance to corrosion and erosion. It should, however, be mentioned that aluminium bronze propellers have been and are being tried for this duty, and may quite possibly become serious competitors in this direction owing to their extreme resistance to corrosion by sea water.

FIG. 5.—ETCHED $(NH_4)OH + H_2O$ × 100 DIAS.

The author has, at times, cut up castings made from manganese-bronze supplied to give anything from 35 to 45 tons tensile which have failed to pull 10 tons. The successful production of manganese-bronze castings is a matter requiring considerable experience often bitterly purchased, and is not to be lightly undertaken.

The hardening elements used by different firms vary considerably, but the examples given in Table VII represent typical practice. It is practically useless for a foundry which has not expert metallurgical knowledge and a chemical laboratory at its command, to attempt to produce really successful manganese-bronze castings as the effect of the hardening elements and alterations in composition are profound. The high shrinkage and other founding difficulties have prevented the more widespread use of this alloy for smaller castings.

TABLE VII.—*Typical Industrial Manganese Bronzes Analyses.*

	High grade.	Medium grade.
Copper	55.4 per cent.	58.5
Tin	Trace	1.3
Lead	nil	0.78
Zinc	37.6 per cent.	38.00
Iron	0.86	1.04
Phosphorus	Trace	Trace
Aluminium	2.50	Trace
Manganese	3.25	0.80

Physical Tests.

Yield point ..	21.4 tons per sq. in.	17.8 tons per sq. in.
Maximum stress	44.8 ,, ,, ,, ,,	37.6 ,, ,, ,, ,,
Elongation ..	24 per cent.	19 per cent.
Reduction ..	23.6 per cent.	20 ,,

Aluminium Bronze.

Most bronze-founders have at some time or other had at least an attempt to produce successfully sand castings in aluminium bronze. The remarkable physical properties given by this bronze and the apparent simplicity of manufacture form a great attraction. It is quite safe to say, however, that not many founders in this country could be found to undertake the production of anything like complicated sand castings in this alloy at a commercial price. The whole difficulty of aluminium-bronze founding may be summed up in the word "oxide." When some genius finds a really successful flux or deoxidant for this alloy then it is likely to become a serious rival to the ordinary bronzes.

Curiously enough, aluminium-bronze is far more successful as an alloy for permanent-mould castings. There are quite a number of firms in this country producing small, intricate castings in this alloy in cast-iron moulds. The achievements of our American friends in this direction are well known. Where castings of any appreciable weight or section—that is, when the thickness is over 1 in. or the weights over 50 lbs.—are to be produced by this method, the difficulties are rather great on account of high-liquid shrinkage of the alloy. It is reported, however, that in America castings of plain section up to 100 lbs. in weight are being successfully produced.

Alloys to Resist Corrosion.

One of the greatest problems connected with modern brass-foundry work is the production of a commercial alloy to resist corrosion. Judging from current technical literature and trade advertisements, one is apt to think that the corrosion problem is nicely settled now that stainless steel is available, but, unhappily, it is not so.

Whilst stainless steel represents a metallurgical achievement, little short of marvellous, combining as it does an alloy of remarkable physical properties with great superiority in resistance to corrosion to ordinary steels, yet for serious corrosion-resisting duties in very few cases is it superior to or even equal to such commercial non-ferrous alloys as the nickel-copper group typified by the alloys known as Monel metal and Corronil.

For feebly-corrosive mediums of a non-acidulous character, especially when erosion and abrasion occur, stainless steel is the best metal yet produced. There is, however, a very large field for an alloy which can be handled fairly easily in the foundry and which has good anti-corrosive properties.

Such an alloy should have also fair strength and good machining properties. Many of the cast nickel-chromium-copper alloys give very excellent anti-corrosive properties, but the difficulties attendant on casting these alloys into anything but the simplest shapes are very great.

Generally speaking, the aluminium bronzes are more resistant to corrosion than the ordinary bronzes, but here again the difficulties of founding prevent their widespread use. The cast alloys of copper, nickel and aluminium, with between 5 and 10 per cent. of the latter metals, are comparatively simple to cast, and besides showing remarkable resistance to corrosion in some media, give excellent physical properties. Such alloys as the copper-silicon and copper-silicon-manganese, also present distinct possibilities.

Possible Future Developments.

It is extremely presumptious for anyone to attempt to prophecy what bronze-founding practice of the future will be like. One of the comparative certainties is the great extensions that are likely to be made in the use of aluminium-alloy castings—particularly die castings and permanent-mould castings for small work. The cheapness, lightness and comparative ease with which such castings can be made by those methods will result in time in the majority of small non-ferrous castings being made in such alloys. In this connection, particular mention should be made of the aluminium-silicon alloys, which have probably a brighter future before them than any other aluminium alloy yet developed. The development of non-ferrous alloys having really good anti-corrosive properties and suitable for casting purposes is long overdue. No alloy to resist corrosion is likely to have a wide use unless it can be handled in the foundry with comparative ease. Alloys containing percentages of nickel between 5 and 15 per cent. to replace tin-bronzes are likely to become common unless, of course, the Dutch financiers decide to sell tin to the foundries at £100 a ton.

If all our mooted water-power schemes come to satisfactory fruition or any of the bi-weekly newspaper stories of cheap electricity ever result in power at a farthing a unit, we shall then see wholesale adoption of electric furnaces.

Vote of Thanks.

THE CHAIRMAN (Mr. V. C. Faulkner) said that this was the fourth of a series of lectures which had been delivered under the joint auspices of the two bodies. The first lecture was by Mr. S. E. Wells, the second by Dr. Longmuir, the third by Mr. A. H. Munday, and the fourth was by Mr. Rowe, who was a member of both societies. They attached a good deal of importance to these lectures, because the Institute of Metals, taken as a whole, treated rather of the academic side of metallurgy, whereas the Institute of British Foundrymen dealt with the technical and practical side, but they met on definite technology, of which Mr. Rowe was a very good representative, being a man who was familiar with the latest academic thought, and also with practice in the shops.

Dr. J. L. Haughton (Chairman of the London Section of the Institute of Metals), proposing a vote of thanks to Mr. Rowe for his lecture, said he was sure they had all listened to it with the very greatest pleasure. It was a real treat to have a lecture such as this, by a man who combined both scientific and practical knowledge in a way which had been made so very obvious to them. Speaking for the members of the London Section of the Institute of Metals, he said it was always a great pleasure to them to have these joint meetings with the Institute of British Foundrymen, and they had always been very fortunate in having excellent lectures on those occasions. Mr. Rowe's lecture stood out as a very successful and a remarkably interesting one, and he had great pleasure in proposing a vote of thanks to Mr. Rowe.

Mr. Wesley Lambert (Past President of the London Branch of the Institute of British Foundrymen), who seconded, said he had enjoyed the lecture very much indeed. There was one proposal he would like to make to Mr. Rowe, namely, that in his reference to manganese bronze, he should delete the word "grade." It would be better to talk of high "tensile" and medium "tensile" than of high and medium "grade." At his works on the following morning they would be casting a very large propeller, weighing 28 tons, and he could assure them that he would not attempt to get anything like a figure of 46 tons tensile, because he would consider it most dangerous to put such a metal into a large propeller.

The vote of thanks was accorded with acclamation.

Birmingham Branch.

MALLEABLE CAST IRON.

By D. Wilkinson, Member.

The successful manufacture of malleable iron castings involves two distinct processes :—(1) The production of a casting which is hard, brittle and white in fracture; and (2) the modification, by heat treatment, of this hard and brittle casting so that it becomes soft, tough and ductile.

If the final product is to be of a good grade, the requirements of the second process call for definite limitations in the first. Not every white, hard and brittle casting can be malleablised. It is an easy matter to produce two castings between which the eye may not be able to detect any great difference, but which the annealing furnace will readily prove to be entirely different from each other; one retaining its brittleness under treatment, the other becoming ductile.

To produce the castings, furnaces of several types may be used; but this Paper will be confined almost entirely to castings produced from the cupola. A brief reference only will be made to one other type of furnace. For cupola-melted metal the following points should be noticed :—(1) The whole of the carbon must be in the combined form; (2) the phosphorus should preferably be under 0.06 per cent.; (3) the manganese should not exceed 0.2 per cent.; (4) silicon, while varying according to the type and size of casting should not exceed, say, 1 per cent. With this maximum in mind it may, for ordinary work, be kept as high as is consistent with obtaining a perfectly white fracture in every part of the casting. If the highest strength and ductility is required 0.5 per cent. should seldom be exceeded; and (5) sulphur, providing the pig is normal, need give little trouble. Excellent malleable castings are regularly made with as much as 0.45 per cent. of this element present. It may be noted a high sulphur should not be associated with a very low silicon, or difficulty may be experienced in the anneal. Also the higher manganese should accompany the high sulphur.

Grading.

Too much care cannot be given to grading the iron. For analytical control nothing but a complete analysis of each consignment of pig-iron is of real value. Partial analysis often proves to be a short, thorny road to the wilderness. As an example, a single experience of the pre-war days, which foundrymen are sometimes inclined to look back upon as the golden days when all pig-iron was good, can be cited. Two consignments of West Coast refined hematites were received under the following specification:—Silicon: under 1 per cent.; sulphur and phosphorus under 0.035 per cent. On arrival the complete analyses were found to be:—

	T.C.	G.C.	C.C.	Si.	Mn.	S.	P.
A	3.96	3.30	0.66	0.75	0.162	0.023	0.009
B	3.89	2.75	1.14	0.74	1.150	0.035	0.031

"A" was an all-grey iron with a fairly open fracture. "B" was a mottled iron of the sort called in malleable foundries "spotted grey." The complete analyses show the difference between the irons very plainly; but partial analyses, taking only silicon, sulphur and phosphorus, would be entirely misleading. The silicons are identical and are correct for the production of good malleable. The percentages of sulphur and phosphorus certainly vary; but the highest figure is so low that they may be ignored with safety. But neither of these irons would make good malleable castings. While the fracture of "B" would be correct for certain purposes, the high manganese would prevent successful annealing. With "A" where the manganese is correct, an all-white fracture could not be obtained, and any greyness in the casting is fatal to ductility after annealing. The analyses reveal no reason for the difference in fracture. The only element with any appreciable variation is manganese, which varies by nearly 1 per cent.; but neither experience nor research tells us that this amount of manganese will change a grey iron, with an open fracture, into a mottled one. Inspection of the fracture would instantly reveal the difference; and instances such as this form a strong argument in favour of retaining fracture as one method of grading.

It would be an easy matter to multiply examples similar to the above, but enough has been put forward to show the extreme care required to grade pig-iron so that good malleable castings may be regularly produced. It is safe to say that wherever records of analyses of refined irons are kept, an inspection of these records will produce instances where every sort of fracture, from all white to all grey, have had approximately the same silicon content; although in most cases the sulphur and total carbon contents would reveal the reason for the difference; while in the above example there is nothing in the analyses to account for it. For these reasons, a complete analysis, giving not merely the total carbon, but the combined and graphitic carbon also, is essential if maximum safety is desired.

Recognising that uniformity, while desirable, cannot be obtained, the following method of grading, for cupola-melted malleable, can be recommended as one which will prove reliable.

Each consignment of pig-iron, as it arrives, is stacked separately and fully analysed. When the charges are being made up in accordance with the analyses, instead of transferring the iron to the cupola platform immediately it is broken, let it be broken the day before it is required and each lot piled separately near its own stack with the fractured surfaces exposed to view. The fractures are then examined and any abnormal ones marked with chalk. These abnormal fractures are either distributed evenly through the charges, kept back to make up special charges, or rejected completely as judgment dictates. It may be noted that a fair amount of latitude in composition is permissible; and, by using a method similar to the above, the extreme variations that sometimes occur, and which always give trouble, can be definitely avoided. A cupola charge is so comparatively small that any decided variation in the pig is liable to be transferred to the casting with consequent trouble in the anneal.

This method of grading unites all that is good in the old style practice with the best of modern practice. It should not be forgotten that the old-style malleable foundryman, despite his handicap, made a success of his work. There are firms who have been producing good malleable castings with regularity for nearly 100 years who even to-day do not possess a laboratory, and in which none of the staff possesses any considerable metallurgical knowledge. There are also firms, equipped with laboratories replete with the latest scientific appliances and staffed with men of high metallurgical attainments, who have abandoned the manufacture of malleable iron and are now purchasing it, in some cases, from the very firms who work by the so-called "rule of thumb." No scientific attainments can replace the skill which comes from the careful, prolonged and patient observation of the facts of everyday experience. But the greatest success will be obtained by the combination of wide technical knowledge with the practical ability only obtained by a close steady application to daily routine.

Cupola Practice.

The cupola practice may be considered good if the metal is hot and fluid. Speed of melting and low coke consumption, compared with hot, fluid metal, are of secondary importance. White iron, owing to its lower silicon and manganese content, is more susceptible to oxidation in the cupola than is grey iron; and when in this condition it not only gives trouble in the castings, but it freezes with great rapidity, skulling up the ladles and only about half filling most of the moulds. As a consequence great care and skill are necessary if a minimum coke consumption and a high rate of melting is to be obtained, and it is hardly wise unduly to economise in the cupola at the expense of the castings.

Foundry Practice.

Compared with grey iron practice the special points to be noted in malleable founding, while of great importance, are not numerous. White iron, having a higher contraction than grey, is more susceptible to shrinkage cavities and cracking. Successfully to meet these difficulties affords ample scope for ingenuity and skill. Shrinkage cavities are prevented by attention to the filleting and contour of the pattern, the provision of substantial feeders, a thoughtful disposition of the gates, and by chills. A feeder is preferable to a chill, unless it is quite certain a chill will eliminate the cavity and not merely move it to other parts of the casting. In general, a sounder product is obtained by using several small gates running into a thin part of the casting than by using a larger gate in a thicker part. When the whole of the metal enters the casting in one place and that place is a comparatively heavy one, the local " hot spot " thus produced is very susceptible to shrinkage. By breaking up the " hot spot " and locating it in a thinner part of the casting, greater uniformity in freezing is secured and liability to shrinkage holes is reduced. With regard to pattern design all internal corners should be filleted, and, where possible, an angle in the pattern should be replaced with a curve.

Cracks result from several causes. Sometimes they are started by shrinkage cavities, and in these cases the elimination of the cavity will remove the crack. At other times they are caused by the resistance of the mould, or the cores, to the free contraction of the metal.

Here the remedy is obvious. The worst cases result from unskilful design, and where this cannot be altered it is sometimes a troublesome matter to produce sound castings. There are two periods during which cracks form as the casting cools from the molten condition. As the metal freezes it passes through a pasty stage, and any opposition to free contraction during this state results in the tearing apart of the semi-solid particles, with the formation of a crack. After the metal has completely frozen, any considerable variation in section will induce irregularity of cooling and contraction, and the stresses thus set up may lead to cracks or even to complete fractures.

Attention to gating and chilling will frequently overcome this second difficulty. Where these fail, the addition of a thin bracket or web to the casting will sometimes prove successful. The bracket must be so proportioned that it will cool and contract more rapidly than the casting, and it must be so located that the stress induced by its contraction will oppose and neutralise the stresses induced by the irregular contraction of the casting. If these two ends are attained the opposing stresses will cancel out and the cracks or fracture will be prevented. It will be seen that considerable judgment is required to succeed in preventing cracks by bracketing. If these measures fail, the only thing to be done is to muffle the hot casting. Immediately it has solidified it must be taken out of the mould and placed in a muffle previously heated to bright redness. The heat of the muffle should be kept up for a little time, and it should then be cooled very slowly, and the casting not taken out until it is cold enough to handle. When carefully carried out, muffling seldom fails to secure success.

Cracks resulting from the first-mentioned cause —those occurring while the metal is in the pasty stage—are prevented by attention to pattern design, by chilling, or by bracketing. It is perfectly obvious a crack of this nature cannot be prevented by muffling. The casting cannot be taken from the mould until it has completely solidified, and by that time the crack has already formed. An alteration in the contour of the pattern will usually overcome this trouble. Where this cannot be done, a chill or a bracket must be used. When using a chill care must be taken not to make it too large, or another crack may form beyond the edge of the chill. A large chill may cause so rapid a freezing and contraction of the part to which it is applied that the adjoining wall of the casting, being still in a semi-solid condition, will be unable to withstand the resulting stress, and so will crack. One or more brackets carefully located and proportioned will frequently be found to be the easiest and best method of preventing this trouble. The brackets may be cut out after annealing.

An Experiment with Black Heart Malleable.

Before passing on to the annealing process the writer would like to mention an experience he had during the war with so-called unsuitable iron while producing malleable castings from a Siemens open-hearth furnace. During the time the shortage of iron suitable for malleable was acute a consignment of soft, grey hematite had been sent to the works. The silicon was 2.85 and the manganese 1.1 per cent. The firm considered it totally unsuited for use, and it was put on one side. While the writer was with the firm he suggested the iron should not be allowed to stand while hematite was so scarce, and obtained permission to try it for the production of malleable. The furnace had a capacity of 2½ tons, and a charge was made of the soft hematite with 10 per cent. of steel scrap. When the charge was melted, new annealing ore, carefully calculated to the amount required to reduce the silicon and manganese to the desired percentage, was added, a little at a time, to the slag. The heat proceeded in exactly the same manner as the earlier stages of a steel-melting heat, and before the last portion of the ore was added, test pieces were cast, carefully cooled, broken, and the fracture examined. No difficulty was experienced in limiting the ore additions to the exact amount necessary to reduce the silicon to a figure sufficiently low to give a completely white fracture. By the time the silicon had been reduced to 0.75 per cent. the manganese was found to be 0.3 per cent. The slag was then allowed completely to exhaust itself of oxide, when the metal was tapped and cast. By avoiding a strongly oxidising flame during melting the oxidation of the carbon was minimised, and the resulting metal, after annealing at 750 deg. C., yielded a good, tough blackheart malleable. The fracture of the hard castings was perfectly white, and could be distinguished in no way from the ordinary fracture of a hard casting. The whole consignment of iron was used in this manner.

Annealing.

The castings being made, they are cleaned and prepared for the annealing process. The oven in which this operation is carried out deserves careful consideration, but to investigate the various designs now in use would unduly prolong this Paper.

The manner in which the castings are packed in the annealing pans is a matter of importance if distortion during the process is to be kept at a minimum. The writer has more than once heard it said that it is essential to surround each one completely with the packing material, and to prevent them touching each other, if good annealing is to be secured. But he has never found this to be necessary. When associated with a malleable foundry his practice was, where the size and shape of the castings permitted, lightly to wedge them in shallow layers across the pans, filling the hollows and interstices with packing material, and ramming it down with short bars so the castings could not move.

The packing material is usually red hematite ore. The new ore is mixed with spent ore from a previous operation in proportions which vary according to the size and grade of the casting and the position occupied in the oven. The proportions vary from equal parts to one in twelve or fourteen. The strongest mixture is used for the cooler parts of the oven and for the larger and harder castings. It is usual to expose the spent ore to the action of the air and weather, moistening it with sal-ammoniac and water. This weathering re-oxidises the reduced ore, so an economy in the amount of new ore required is obtained.

The consideration that ore is an oxide of iron once led the writer to try the oxidised scale that forms on the outside of the pans as a packing material. The scale was broken small, sifted, and used in the same way as ore. The results, on the whole, were satisfactory, although the elongation of the test pieces was slightly lower than usual. With ore, up to 8 per cent. elongation was very frequently obtained; with scale, 6 per cent. was seldom exceeded. This reduced elongation was considered to be the result of the greater impurity of the scale as compared with the ore. For some years this material was used with success for cheap and unimportant castings, although ore was always used for important work.

All the pan joints should be luted inside and out, and made as completely airtight as possible. Defective luting is responsible for much spoiled work. It will be found an advantage to mix about 10 per cent. of the finest of the dust sifted from the spent ore with the fireclay mixture used for this purpose. This admixture considerably reduces the cracking and falling off of the outside luting during the process. It probably acts by forming a little ferrous silicate, which, being plastic at the annealing temperature, yields without breaking to the expansion and contraction of the pans.

The ideal annealing oven is one in which a uniform temperature can be maintained in every part from the beginning right through to the end of the process. It is to be feared this oven is still somewhere in the future. It is not impossible to construct, for laboratory use, a small furnace in which a uniform temperature can be maintained for an almost indefinite period, but to build and maintain at a definite heat a furnace large enough to hold a couple of dozen or more stacks of annealing pans, each 6 ft. high, is a problem of a different order. The annealer whose ovens do not vary from the roof to the floor by more than 10 to 15 deg. may count himself fortunate. Again, radiation will always prevent the outer stacks of pans attaining the same temperature as the inner ones. Careful firing will minimise these variations, but, even with the greatest care, complete control of the natural forces opposing uniformity cannot as yet be secured.

In view of the impossibility of obtaining a uniform temperature, it is fortunate that annealing will permit a fair latitude in this respect without seriously impairing either the strength or the ductility of the product. Unless an oven is badly designed or carelessly fired, there should be no difficulty in maintaining a temperature with a maximum variation of not more than 30 to 35 deg. C. between any two parts. It is not contended that an oven can be kept within these limits without trouble, but with good design, constant repairs and intelligent firing, even narrower limits are attainable.

The bringing up of the oven to the full annealing temperature of about 970 deg. C. should be done slowly. There is a temptation to save time by forcing the firing while the oven is cold, but few things are more productive of irregularity than too steep a temperature gradient at the beginning of the anneal.

Sufficient time should be allowed for the heat to penetrate to the centre of the stacks, so that a uniform expansion and increase of temperature may result. If the heating up is too rapid, the pans, which receive the full brunt of the flame, will expand away from the castings inside them. This gives rise to a double evil. The air-space between the expanded pan and its contents slows down the heat transference to the castings; since while the space lasts heat is transferred by radiation only, and not by radiation plus the conduction that occurs when the pan and its contents are actually in contact. In consequence there is a possibility of some of the castings not being properly annealed when the oven has run its full time. Also, as the castings begin to heat up, their expansion causes a settling down and a filling up of the increased pan space with a liability to some of the castings cracking, owing to interruption of their free expansion. When, later on, at full heat the carbon precipitation occurs, the lower layers will not have sufficient room for their final permanent expansion, and distortion will occur. A rate of heating sufficiently slow to maintain a uniform increase of temperature and expansion right through each stack of pans is an excellent preventive of under-annealing, distortion and oven cracking. Forty-eight hours is not too long a period to take in bringing an oven up to full heat.

As the temperature rises above 850 deg. C., its rate of increase should be still further slowed down. This is to prevent any part of the oven over-running the maximum temperature. Unless care is exercised at this stage, some of the upper pans, which receive the full brunt of the flame, heat. Overheating of this character, unless immediately checked and reduced, produces badly annealed castings which, while not burnt, are not strong and ductile, but possess a fracture known colloquially as "rotten," an expressive and illuminating term descriptive of the result of overheating at the commencement of the anneal. The want of ductility is directly due to the premature precipitation of the carbon by overheating and to the flaky form carbon precipitated under such conditions always takes.

When the upper part of the oven reaches 970 deg. C. the increase in temperature should be stopped by adjustment of the firing and the dampers. At this period the variation of heat throughout the oven should be as little as possible; and in no case, if entire success is to be obtained, should it exceed 35 deg. This temperature should be maintained as evenly as possible until the annealing is finished and the time for cooling arrives.

Heat Control.

It is necessary to have some method of determining the temperature at which the oven must be held if the operation is to be a success; and this fact at once leads to the consideration of some form of pyrometer. As every foundryman knows, the eye, when trained by long experience, acquires a considerable facility in comparing and judging temperatures.

It is a common experience when regularly inspecting furnaces to turn to the pyrometer not so much for information as for confirmation of an impression already formed in the mind, and to find the pyrometer confirming that impression. But when accurate information can be readily obtained it is not wise to rely entirely upon judgment, however well trained it may be; and the assistance of some definite method of measuring the temperature of the oven is a necessity.

It is not easy to lay down the best method of securing pyrometric control of annealing temperatures. A radiation pyrometer gives excellent results with some furnaces, but the atmosphere of an annealing oven, which should consist of a slowly-moving smoky flame, interferes so much with the correct focus of the instrument upon the pans that low temperatures are frequently registered by it. If this type of instrument be adopted, it is usual to insert a closed fireclay tube through the wall of the oven and to focus the pyrometer upon the closed end of this tube. This cuts out the smoky flame, and when allowance is made for the lag in rise and fall of temperature, due to the tube, very reliable results may be obtained.

If a thermo-couple placed inside the oven is used it is necessary to guard against registering a fluctuating flame temperature instead of the true temperature of the pans. The only satisfactory position for a thermo-couple is inside one of the pans, where it will register the actual heat of the material undergoing treatment. But fixing it in this position is rather troublesome, and frequent renewals are usually required. The writer's preference is for a radiation pyrometer focussed upon the end of a built-in closed tube. When workmen have become accustomed to this type of instrument and to the lag introduced by the fireclay tube, it will be found very trustworthy. Needless to say, whichever instrument is adopted, it should be a registering one, so that the night firing may be checked.

It is in the highest degree necessary to guard against the error of working only to the pyrometer. The tendency is to consider all is well if the record is following the usual track. The pyrometer should be fixed at a point that readily comes up to heat; and the correct method is to use this location as a standard; and by attention to the fires and dampers to bring the remainder of the oven to uniformity with it. One accurate pyrometer is all that is needed; the trained eye, guided by the pyrometer, will readily determine variations in the remainder of the oven. A correct record should never be accepted as an excuse for poor annealing, and the conjunction of the two is by no means unknown.

Silver as Pyrometer Control.

As an occasional check upon the accuracy of matching the temperature shown by the pyrometer the silver melting test is useful. This is a very old test for annealing temperatures. Boyden, who is said to have introduced the manufacture of malleable castings into America, left on record his observation that the malleable annealing temperature coincided with the melting point of silver, and in at least one instance this test has been in occasional works so long that the time of its introduction has been forgotten. A piece of silver, preferably hammered into a thin ribbon and bent into a rough ring, is placed on a small fireclay dish and inserted in the part of the oven it is desired to test. Silver melts at 962 deg. C., so it is evident that if the correct annealing temperature has been established the ring will be melted. After a few trials it is fairly easy to estimate the approximate temperature by the rate at which the melting occurs. This test is sometimes used instead of a pyrometer, and if care be taken to maintain the silver in a state of purity by an occasional cupellation, it gives an exceedingly reliable indication.

It is also useful as a check upon the pyrometer to show when it needs attention and calibration.

The length of time the oven is maintained at heat may vary according to requirements. For castings of an ordinary grade in which the highest ductility is not required, 48 hours' bringing to heat, followed by 60 hours at heat and a slow cooling, will give good results, provided a suitable composition is obtained in the hard casting.

If maximum ductility is required the silicon and sulphur content of the castings should be kept down and the period at heat lengthened. With a silicon of 0.5 to 0.6, a sulphur between 0.2 and 0.25 and period of 72 to 84 hours at heat, followed by slow cooling to 600 deg. C., excellent ductility may be obtained. The longer anneal reduces the carbon content more than usual, and, providing the upper limit of 970 deg. C. is not exceeded, a very ductile malleable results. A standard works bend test for this annealing treatment was a bar 9 in. long by ⅜ in. dia. These bars regularly bent to 180 deg. round a ½ in. radius without the least sign of a crack appearing.

The Chemistry of Annealing.

The reactions by which the carbide of iron in a hard casting is decomposed during annealing, its carbon being partly removed and partly deposited as temper carbon, are undoubtedly much more complex than they are usually considered to be. The commonly accepted explanation is as follows:—

As the oven comes up to heat, the oxygen of the air enclosed in the pan, diffusing through the skin of the castings, combines with the carbon of the cementite it finds there forming CO_2

$$(1)\quad 2O_2 + 2Fe_3C = 3Fe_2 + 2CO_2.$$

As the ore is heated up it is decomposed into mixed oxides and oxygen, and this oxygen also reacts with the cementite and forms CO_2. The mixed oxides remaining are of a variable composition, so that it may be better to leave the numerals indefinite and write the formula Fe_xO_y. With increasing temperature, a small amount of the furnace gases containing a proportion of CO_2 and CO will diffuse through the pans, and the ore will oxidise the CO to CO_2.

$$(2)\quad Fe_x\,O_y + CO = Fe_x\,O_{y-1} + CO_2.$$

By the time the oven is up to heat a fair amount of CO_2 will be present in the pans. As this gas diffuses into the castings it reacts with the cementite:—

$$(3)\quad 2Fe_3C + 2CO_2 = 3Fe_2 + 4CO.$$

The ore immediately adjoining the castings oxidises this CO, as it diffuses outward, into CO_2 in accordance with equation (2). The cycle of reactions (2) and (3) proceeds slowly but continuously, having as an ultimate issue the removal of carbon from the outer part of the castings.

The precipitation of temper carbon is usually considered to result from the unstable condition of the cementite. This instability is inherent, and is increased by the action of the silicon present.

When cementite is maintained for a sufficient time at a sufficiently elevated temperature it slowly coalesces into nodules, and finally arrives at a condition of equilibrium by decomposing into iron, in the state of ferrite, and carbon. The carbon, owing to the mechanical opposition of the iron, is unable to coalesce into flakes, but remains, *in situ*, in patches of temper carbon.

Recent research has brought to light facts which appear to modify these views. At the autumn meeting of the Iron and Steel Institute in 1923 a Paper was presented by Honda and Murakami on "Graphitisation of Iron-Carbon Alloys." Working on a pure white iron with a silicon content of only 0.063 per cent., these investigators appear to have proved that graphitisation is the result, not of a movement of cementite towards equilibrium when under the influence of heat, but to the presence of traces of oxides of carbon in the alloy and to a well-known catalytic action which occurs when the oxides of carbon and iron are in contact at an elevated temperature.

In the upper regions of the blast furnace a well-established reaction occurs, due to this catalytic action, which may be represented by the following equation:—

$$(4)\quad 2CO = CO_2 + C.$$

The carbon monoxide decomposes, forming carbon dioxide and depositing solid carbon. This reaction only occurs in the presence of iron, upon which the carbon is deposited. The investigators appear to have proved that this catalytic action occurs at temperatures as high as 1,100 deg. C. When it occurs within an iron-carbon alloy, the resulting dioxide will at once react with the cementite it finds there, as shown in equation (3), and the newly-formed monoxide again undergoes decomposition by catalytic action, as shown in equation (4). So the cycle of reactions will continue; and as a final result there is the reduction of cementite to metallic iron by reaction with the dioxide, and the deposition of solid carbon in a finely divided form by catalytic action between the monoxide and iron.

If these facts are applied to the annealing of malleable iron, the reasons for the removal of carbon from the outer part of the casting and its precipitation in the interior part become clear. At a high temperature there is, at the outer part of the casting, a system capable of chemical action, containing oxides of carbon, iron, carbide of iron, and a large excess of mixed oxides of iron in the ore.

At ordinary temperatures these bodies would remain in contact, without change, indefinitely, but at the annealing temperature chemical affinity comes into play, and, knowing the composition of the bodies present, it is possible to predict the direction of the various reactions towards equilibrium. The excess of oxides in the packing will determine the movement towards a simpler system consisting of carbon in its maximum state of oxidation—that is, carbon dioxide—iron, and the excess of mixed oxides, with the disappearance of carbon monoxide, carbide of iron, and a portion of the mixed oxides of the packing. Hence the removal of carbon from the outer part of the casting. As the gases penetrate further into the casting, they pass beyond the oxidising influence of the packing, and so the point of equilibrium will change. Chemical action would now establish equilibrium between carbon monoxide, carbide of iron and iron were it not for the catalytic action which occurs under these conditions, decomposing the newly-formed monoxide into dioxide and carbon.

So we have the continued alternate chemical and catalytic reactions until the carbide of iron disappears and equilibrium is established between the monoxide, carbon and iron.

The result is that in the annealed casting the greater part of the carbon is concentrated in the centre of the section in a very finely-divided form, while the outer part of the section is almost carbon free.

The partial removal of carbon from the centre of the casting is also accounted for. At the annealing temperature part of the carbide goes into solution in the iron, and diffusing outward, comes into the range of the oxidising influence of the ore, and so is removed.

It is evident that the action of manganese and sulphur in retarding annealing is by interference in the reaction between the dioxide and cementite; while the action of silicon is to facilitate this reaction. The carbide of iron appears to be perfectly stable under heat, providing there is a complete absence of the oxides of carbon.

Yet further light on the mechanism of annealing may be obtained from recent researches on the action of hydrogen on steel. During the last few years several Papers on this subject have been read before the Iron and Steel Institute, and it is definitely established that hydrogen, especially when it is moist, will decarburise steel at a temperature of 950 deg. C. Its action is:—

$$(5)\quad 4H_2 + Fe_3C = 3Fe_2 - 2CH_4.$$

When it is considered that the ore used in annealing is usually moist, it is evident the hydrogen resulting from the decomposition of the moisture will also have an action on the malleablising of cast iron. As shown by several published analyses of gases taken from annealing pans, both hydrogen and methane are always present in them. It must be borne in mind that the equilibrium pressure between the two gases H and CH_4 will determine the amount of carbon removed by this agency. But it must also be remembered that the complex interaction of the components actually present, and the reversible reactions that occur under a varying equilibrium, may have important but as yet unknown results upon the process. A continual regeneration of hydrogen from the hydro-carbon gases is not impossible, and it may ultimately be found that the moisture content of the ore has a definite bearing upon the success of the process.

DISCUSSION.

Opening the discussion, the Branch-President (Mr. T. Vickers) commented on the decline of the malleable iron industry in this country, and thought there must be some definite reason for it. There was a time, he said, when this country were the largest exporters in the world; now it occupied about the fifth position in output. Great Britain manufactured about 60,000 tons of malleable iron per annum, compared with America's about one million tons. It employed something like 6,000 men in the malleable iron foundries, against approximately 35,000 employed in America. One source of satisfaction was that America owed its success to the initial work of an Englishman, Seth Boyden, who left the Bilston area for America and started their malleable iron work. This was the beginning of America's success. It was extraordinary how varied was the practice, and malleable iron founders needed more information as to the working of their annealing ovens. As to packing, some packed exceedingly fine, and others favoured very coarse packing; some packed in a loose way, and others as tightly as possible. There ought to be some definite rule as to which was the better practice. Further, they needed precise information on such matters as the temperature of the oven, the time of annealing, and the rate of cooling. It was remarkable that there was no really good English book for the guidance of the malleable iron founder. They had to go to America for their information. In these circumstances Mr. Wilkinson's lecture was particularly useful.

Mr. H. Field, referring to the weathering of the ore, which was said to be an economy, did not think such economy was necessary, as the difficulty seemed to be to get old ore. It might almost be said that they ought to hasten the spending of the ore so as to accumulate a good stock. In the Walsall and Willenhall area they were constantly being asked if old ore could be supplied. Regarding recording pyrometers, Mr. Field feared that where there were six or eight annealing ovens, to have them all fitted with recorders would necessitate an outlay which was beyond the means of the small iron founder. One question which Mr. Wilkinson did not dwell upon was that of economy in annealing pans. Of all the expenses in the malleable iron foundry there was none which seemed so wasteful as the continual scaling of annealing pans during the process. There seemed to be a tendency for malleable castings to get heavier. He considered that by being asked for sections which were too thick the malleable industry was being done a considerable injury.

Mr. E. R. Taylor said the metallurgist could be of very great assistance in the malleable iron trade, which seemed to be slow in coming into line with scientific progress. There must be no distrust, however, between the metallurgist and the man in charge. In the malleable iron trade there seemed to be no end of tests applied in the way of bending and twisting, but it was desirable that they should be standardised, Some effort had been made by the British Engineering Standards Committee to standardise certain test bars in the malleable trade, such as the bend and tensile, and specifications called for a bend of 45 deg. in white heart. In that case the test bar must be of a definite size—$\frac{3}{8}$ in. thick and 1 in. broad. That was a very useful step forward, and was an attempt to formulate some standard test to which people could work. As regarded elongation, it seemed to him it would be very difficult to get, Some people said they could get 8 per cent. every time, but if they did, something else was bound to suffer. He found it easy to get 20, or even 25, tons tensile, but elongation began to fall off so severely that they were liable to find themselves outside the specification.

Mr. A. Parsons inquired as to the length of time after the heat-up that it took to anneal, and how long castings should be left in the furnace after the annealing was complete, to cool down before being drawn. He was referring to castings which were not over half-an-inch thick.

The Chairman, alluding to physical tests, pointed out that in America they obtained 25 tons per sq. in. easily, with 20 per cent. elongation.

On the motion of Mr. J. B. Johnson, seconded by Mr. F. C. Edwards, a cordial vote of thanks was passed to the lecturer. Mr. Edwards, referring to patterns, emphasised the importance of good, big fillets being put in, because with white iron there was greater possibility of shrinkage cracks.

Replying upon the discussion, Mr. Wilkinson expressed surprise that there should be any difficulty in obtaining old ore. When he was in a malleable foundry, he said, they used regularly to throw it out. He agreed that the expense of introducing pyrometers was considerable, but pointed out that even then it was an economy if by their introduction bad malleable castings were avoided. Many firms lost a considerable amount by defective annealing, and this might be obviated by using pyrometers. He did not agree with Mr. Field's observations on the subject of the thickness of malleable iron castings. The great variety of test bars was one of the evils of the trade. It would be a great advantage to have them standardised. To obtain really good elongation, the annealing must take time, after which 35 hours should be allowed for the cooling down. The pans should not be drawn until it was possible to just touch them with the hands. He had a decided preference for annealing by gas. Gas was under better control; they could heat with more regularity and maintain the heat with less trouble than was possible with coal.

Scottish Branch.

SOME ASPECTS OF FOUNDRY COSTING.

By John Spittal.

On approaching this subject of foundry costing it is pointed out that these remarks are not addressed particularly to cost accountants as such, nor is it the intention to put forward any fully detailed scheme of costing, but an endeavour will be made to interest the moulder and his foreman in this department of the foundry organisation, and to outline some general principles which govern the question of foundry costs from a practical standpoint.

We are past the days now for considering whether the foundry really requires an efficient costing department or not, because most employers have long since realised that a properly run business cannot afford to be without one. Those in the position of knowing will agree that the lack of co-operation between the pattern shop and the foundry is reflected almost immediately in the cost records, and that but for these records, the undesirable conditions often referred to may go on for some time unsuspected.

One has to consider not only the actual mistakes which occur owing to the absence of sympathetic co-operation—these mistakes usually come into evidence during the progress of the work through the shops when they have to be put right—but there is also to consider the general production efficiency in the foundry suffers to a very marked degree, because before the job reaches the foundry, one department has passed on its work to the next, without troubling very much what interpretation the other may put upon the details, or what difficulty may be encountered in the production of the work in the departments subsequent to its own. It is here that the cost accountant, who realises the service he can render the management with detailed costs, will so arrange his scheme of work that comparative costs can be produced at any time, setting forth the production efficiency of one class of work, where designs are adopted having regard to the capabilities of labour and the facilities otherwise available, as against similar work where through inefficient co-operation, these considerations have not been taken into account. When conditions exist which retard the moulder in the efficient performance of his work, and these can be expressed in money terms, it will be found that the subject assumes an altogether different aspect, and in all probability not only the design of the patterns, but their construction also, will receive more sympathetic consideration, from the moulder's point of view.

There is an unhappy idea in the minds of many moulders—not excluding sometimes their foremen—that the cost department (whatever its functions may be) is not their friend, and the less it gets to know of what goes on in the shop the better it will be for all concerned. That is an altogether mistaken idea, but at the same time one must admit that the moulder is not wholly responsible for this unfortunate attitude, and there have been, no doubt, many occasions where the moulder has been thought at fault, when he was really working against conditions over which he had no control.

Where Economies May be Effected.

When costs are high on a particular class of work and it is found that the direct wages are perhaps more than they should be, it is certainly not good policy to consider the reduction of the wages cost as the first step towards economy. It is generally agreed that that should be the last resource, because on investigation, it probably may be found that the man is working with unsuitable gear or with shoddy patterns, while on the other hand it might be the case that the man is on a class of work to which he is at first unaccustomed. It will be seen therefore that all cost statements should be examined with care, as one can be quite easily led to wrong conclusions, and in this connection it may not be out of place to remind those in charge of foundries, that it is much the better way, that their criticism of costs is first discussed with the accountant before the men actually on the job are approached on the matter.

The work of the cost department covers an important requirement in all business establishments, and in a foundry concern, where castings of a fairly wide variety are produced, it is necessary to have a suitable system of costing in operation if the business is to be a success. In such a system the principle on which the oncost charges are allocated should be such that each job or each group of work bears only its own legitimate share. Foundry costs raise problems peculiar to themselves, and in no other department of an engineering establishment are the same difficulties encountered. The reason is obvious, of course, that whereas the foundry is actually producing all kinds of articles by bringing them into shape and being from the raw material in the form of pig-iron and scrap, the machine shops and other departments are merely carrying out the finishing details on work already produced by the moulder. Even in the smithy and structural shops the material there worked upon, *e.g.*, M.S. plates and sections, are already manufactured before entering these departments. It can be appreciated therefore how the foundry has problems in their manufacturing costs that do not arise in any of the other departments, and in order to obtain satisfactory results the method of costing the foundry output requires to be carefully considered. In a general engineering works having their own foundry it will be found advisable to separate the foundry so far as costing is concerned from the other departments, and with a little reorganisation this can be accomplished quite satisfactorily.

The foundry section of the establishment should comprise all the departments concerned with the production of the casting from the point where it leaves the drawing office to the point of its delivery either to the machine shops or to the despatch department, and it would therefore include:—(1) Foundry planning; (2) pattern shop and pattern stores; (3) the foundry proper subdivided as follows: (A) cast-iron section; (B) nonferrous section; (*a*) Greensand moulding; (*b*) Drysand and loam moulding; and (*c*) coremaking; (4) dressing shop; and (5) foundry office.

One of the principal duties of the planning department is to aim at complete co-operation between the designer in the drawing office and the moulder in the foundry, also between the pattern shop and the foundry. The planning department therefore studies the requirements of the designer always from the foundry point of view, with the object of ensuring that the work coming into the foundry is such that the moulder can be reasonably expected to carry out in an efficient manner. When the details of the work are definitely fixed, this department will pass on to the patternmaker all the necessary particulars relating to the design and construction of the patterns, not forgetting that it is possible to have a design which is technically right but commercially wrong. The cost department would be in the position of giving details of the cost of previous work of a similar nature for the guidance of those concerned, so that the work may be designed on economic lines.

Importance of Accurate Records.

It is customary in all special jobs to give to each unit a definite part number, and in all standard work to give a definite pattern number, and these details should be noted in the time records taken in the foundry, so that when any departure is made from the standard or the original design, necessitating the employment of a different method of moulding, the separate cost can be obtained. The same arrangement, of course, is carried out in the engineering shops, thus giving the cost department the necessary information for providing the cost of any particular part of the complete job. The workman can therefore appreciate the fact that if the time-clerk appears to be too particular about these seemingly needless details there is a reason, and both the moulder and his supervisor can do much towards the accuracy of the costs without going out of their way to do so. When reliable costs are available the employer can concentrate upon that class of work which his foundry is best suited to produce cheaply. He can also see what jobs are likely to be unremunerative while the order is still in progress, and so get matters adjusted if possible. In turning attention to foundry costs, it will be at once apparent that the various processes by which castings are produced vary to some extent in cost. The three processes in general use are, of course, greensand, drysand.

ELEMENTS OF FOUNDRY PRODUCT COSTS.

(1) METAL COST.			(2) DIRECT WAGES COST.			ONCOSTS.
Brand.	Weight.	@ £ s. d.	Total Hours.	Class.	Amount.	(3) MELTING COSTS: (a) WAGES:—
						Labourers.
S.						Cupola attendants.
T.				Moulding £		(b) Fuel.
W.						(c) Stores.
Y.				Closing £		(d) Upkeep of plant.
Z						(e) Power cost.
				Coremaking £		(f) Depreciation.
						(4) DRESSING COSTS:
		£		TOTALS .. £		(a) Wages of dressers and sand-blast operators.
						(b) Stores.
ADD.:						(c) Upkeep of plant.
	Melting loss at 4.6%	£				(d) Power cost.
						(e) Depreciation.
						(5) GENERAL SHOP CHARGES:
	— per cwt.					(a) Indirect labour.
						(b) General stores.
						(c) Power cost.
....						
MELTING LOSS thus:—						(d) Repairs and renewals.
		Weight.				(e) Loose tools.
Pig-irons, etc., used ..						(f) Foundry staff and management.
Less returns (shop scrap)						(g) Depreciation.
						(6) DEFECTIVE PRODUCTS.
Net consumption ..						
						(7) ESTABLISHMENT ONCOSTS:
CASTINGS OUTPUT ..						(a) Staff and management.
						(b) Taxes, insurances, etc.
Melting loss ..						(c) Depreciation.
						(d) Commercial oncosts, advertising, etc.
	—4.6%					

CHART 1.

and loam moulding, and it is not a difficult matter to arrive at the cost of each group if a carefully prepared scheme is adopted. Such a scheme would necessarily require to provide for the collection of all items of cost relating to metals, labour and oncost charges, and to allocate these correctly to the three groups of work named, *i.e.*, greensand, drysand, and loam. In many foundries where only a few loam jobs are undertaken, the drysand and loam groups are classified as one, leaving only the two groups to be dealt with.

The following items comprise the production cost of the foundry output as follows :—(1) Metal cost; (2) direct wages; (*a*) moulding; (*b*) closing; (*c*) coremaking; (3) melting costs; (4) dressing costs; and (5) general shop charges, comprising: (*a*) indirect labour; (*b*) general stores; (*c*) power costs; (*d*) repairs, renewals and maintenance; (*e*) loose tools; and (*f*) foundry staff and management; (6) defective products; and (7) establishment oncosts, which are (*a*) office staff and management; (*b*) rates, taxes, and insurance; (*c*) depreciation; and (*d*) advertising, etc.

Before going into the question of how the sums expended in the production of the castings are distributed over the work produced, the various items of expenditure just enumerated will be considered.

Metal Cost.

This refers to the cost of the various metals or brands of iron required to make the castings. There are various methods of arriving at this cost. In some foundries it represents the cost of the molten metal in the foundry ladle, *i.e.*, the expense of the melting is also included. Personally, the author prefers that the metal costs should be only what it purports, and as melting is a distinct process in the making of the castings, it will be found best to keep this under a separate account. The metal cost for the iron output would be therefore arrived at by pricing the consumption of the various brands of iron and scrap; to the overhead rate per cwt. is added the melting loss, represented by the amount of waste matter, etc., in the pig-iron, usually taken about 5 per cent., and adjusted at the close of the month when the stock returns are available. The systematic control of the cupola has been frequently discussed at foundry meetings, and it is gratifying to find an increasingly large number of foundries all over the country where the cupola is treated with that respect to which it is entitled. No one knows better than the foundryman that the cupola has a nasty way of reminding one when its importance is temporarily overlooked. This control of the cupola has assisted the accountant in many ways, principally because he can now obtain accurate returns for every cast. Each charge of metal is weighed, its composition being clearly stated, so that at the end of the day's melt the accountant knows exactly the tonnage of the various brands of iron which have been used, the weight of coke consumed, and the amount of fluxing material, etc., introduced. When the metal cost is arrived at in the manner described, the effect of any fluctuation in the price of the iron or any particular brand of iron used is always apparent; but this could not be said if the melting cost was always included, as one then might often find it to be the case that the molten metal cost was the same for two consecutive months; whilst as to the fact in one of the months iron was probably at a lower cost, the consumption of fuel or some other item was higher than formerly.

Direct Wages.

The second item, direct wages, is the amount expended on moulding, closing and coremaking for the month, against the various orders on hand. In dealing with this part of the subject, it should first of all be decided what method of time recording is to be adopted. In the large majority of shops these records are taken daily by the foundry time clerk going to each moulder and getting details of his work for the day, and although this may be a quite satisfactory arrangement in many foundries, something different may give much better results in other shops. A good arrangement where it can be conveniently carried out is to provide job cards for all orders coming into the foundry. Each card represents a definite "job" to a certain machine or a certain workman. These cards are arranged in the foreman's office in such a manner that he has constantly under review the various classes of work coming forward classified into suitable sections relating either to the different machines or to the various charge hands in the shop. The cards can be further arranged in order of priority, so that the more urgent work gets earlier attention. They are issued to the supervisors early in the day for the following day's work, so that the pattern store may be advised what is required in the way of patterns, and the supervisor can see also that the necessary cores are forthcoming in good time for the man employed on closing the moulds. The core department should be working at least a day ahead of the moulder, and where standard work is in constant demand the supervisor in the core department can always fill in odd minutes in such work, the cores thus made being kept in the core store until requisitioned. These job cards give all the information the workman requires in order to proceed immediately with his work, and are particularly serviceable in dealing with repetition work, the number being made each day being shown, also the balance required to complete the job. The card also carries the record of bad castings in the foundry, giving under symbol reference the cause of rejection, and in this way a complete history of the job from start to finish can be seen, whilst the number of rejects and the cause are kept under the notice of the moulder during the progress of the job towards completion. In some cases a moulder may have two or three cards representing his day's output, whilst on the other hand one card may last for several days. The foundry clerk checks the number of moulds made at the close of the moulding shift, and enters on the card the details already referred to, transferring the particulars to the workman's weekly output record. This record states whether the job is in greensand or in drysand, and gives generally all the information required for costing purposes, the wages on each job being extended separately, the total for the week agreeing with the gross wages earned. In this way complete agreement is maintained between the wages account in the general ledger and the amounts entered through the costs, as shown in the wages analysis. This analysis will be referred to again under the heading of indirect labour.

Melting Costs.

The third item, melting costs, deals with the pig-iron and scrap as received from the yard stock until delivered at the cupola spout. The items comprising this cost would therefore include: (*a*) Labourers' work, breaking the pig-iron and scrap, also weighing the iron and coke charges for the cupola; (*b*) cupola attendants; (*c*) fuel; (*d*) stores, refractory materials, limestone, etc.; (*e*) relining cupolas and upkeep of plant; (*f*) power costs; and (*g*) depreciation.

The total expenditure ÷ output of castings gives the rate per cwt. for the melting cost.

Dressing Costs.

The fourth item, dressing costs, include:—(*a*) Total wages expended in this department; (*b*) general stores; (*c*) upkeep of sand blast plant, etc.; (*d*) power cost; and (*e*) depreciation.

In regard to the allocation of this expenditure the author has never found it a practical proposition to deal with this as a *direct* charge, *i.e.*, taking the actual time the dresser is employed on each casting. In order to give full liberty for encouraging the output of work, the foreman should be able to clear up his day's cast in as straight ahead manner as possible, leaving it to the foundry despatch department to collect, apportion and weigh up the castings. There are foundries to-day where the large proportion of the foreman dresser's time is employed apportioning the work for his men so that the time may be lifted with some degree of job sequence, finding the orders to which the castings belong, even weighing the castings and making out the daily output, all work which has really nothing in common with dressing a casting or supervising others so engaged. In some foundries the expenditure on dressing is allocated at an overhead rate per cwt., but there is great doubt as to the correctness of this method. One can personally observe work in almost any foundry where the weight of the casting caused the dressing cost to work out at about 15s. when only half an hour was required for the job. On the other hand, one has seen castings where the rate per cwt. brought out the dressing cost at a few pence, but the actual time taken was two hours. As a general rule, it will be found that the allocation of the dressing cost on a direct wages basis brings out a much more reliable cost, for, after all, it is a very reasonable conclusion to arrive at, that the longer the moulder takes to mould a job the more core work there is, the dresser will spend a correspondingly longer time at his part of the work. It would appear, therefore, that the allocation of this expenditure in proportion to the direct wages on the job is the correct procedure.

General Shop Charges.

The fifth item, general shop charges, includes all those items of oncost already enumerated, and deal only with expenditure over which the foundry manager has control. The first item under this heading refers to indirect labour. By indirect labour is meant, of course, all labour not directly engaged on a definite productive order. The moulder and his assistants are engaged directly producing certain castings; such labour, therefore, would be classified *direct*, as distinct from *indirect* labour, which comprises, for example, the men employed at sand-mixing, electric cranemen, etc., who are helping production more or less indirectly, although nevertheless essential. The method of dealing with indirect labour presents no special difficulty. It may be necessary in some foundries to lift this time in the same manner as with direct labour, but it may also be arranged by means of suitable grouping the names of the workmen on the pay roll, and by departmental totals. In any case, an analysis of all indirect labour should be kept each week and compiled monthly, so that in the event of this item being questioned at any time, it can be shown how the labour has been employed. As the indirect labour costs in the foundry form a substantial percentage of the total foundry cost, it is obviously necessary to keep control over this item, and the accountant should be in the position of showing how the money has been actually expended.

The complete wages analysis comprising all classes of labour should show the proportions against the greensand and drysand departments, also the core department separately, and would be prepared somewhat on the following lines:—

A. *Direct Wages.*—(1) Moulding; (2) closing; and (3) coremaking.

B. *Indirect Wages.*—(1) Skilled labour employed indirectly:—(*a*) Supervision; (*b*) apprentice training and schoolroom; (*c*) sundry work making test bars, etc.; (*d*) experimental work; (*e*) overtime allowances; and (*f*) lost time through breakdowns, etc. (2) General labour in foundry:—(*a*) Supervision; (*b*) general labouring; (*c*) electric cranemen; (*d*) sand preparation; (*e*) pouring; (*f*) cleaning up and shop preparation; (*g*) drying stove attendants; (*h*) storeman; (*i*) blacksmith. (3) Core department:—(*a*) Supervision; (*b*) pasting and storing cores; (*c*) core stove attendance; and (*d*) sand mixing and preparation. (4) General:—(*a*) Cupola attendance; (*b*) brass melting furnacemen; (*c*) dressing and sand blasting; and (*d*) repairs and maintenance of plant.

The grand total of this weekly analysis agrees with the wages account in the financial books.

The Cost of Experiments.

In looking over the various items mentioned under the heading of indirect labour, two of these may call for special remark, viz., experimental work and overtime allowances. Regarding experimental work, this falls naturally into two groups. (1) Experimental work undertaken by the firm with a view to adopting or improving upon certain designs of machinery or gear; and (2) experimental work carried out in the foundry for the purpose of arriving at correct methods of production under specific conditions.

Dealing with the first class of experiment, it is customary to reserve a definite sum in the annual accounts for the purpose mentioned to cover the estimated expenditure during the year. Obviously the cost of these experiments cannot be entered as a charge against the foundry output, therefore a specific order should be passed to the various shops, including the foundry, for every job of this description decided upon. The foundry, in common with other departments, would carry out the work in precisely the same manner as if the order was for an outside customer. The cost department would deal with the expenditure on the completion of each experiment, and also at the

Messrs...........................   *No*...............

Specification...   *6th December*, 1924.

DETAILED APPROXIMATE EXPENDITURE IN PRODUCING ORDINARY CASTINGS IN GREENSAND.

Description. Cast Iron. G.S.	Weight, each	Total Weight.	Rate.	Metal Cost.	Direct Wages.		Oncosts.		Total Estimated Cost.
	Lbs.			£ s. d.	Class.	£ s. d.		£ s. d.	
Castings	112	1	5/–	5 0 0	Moulding ..	2 10 0	Melting ..	1 17 6	
					Closing ..	0 10 0	Dressing ..	2 0 0	
					Coremaking	0 15 0			
Oncosts :—									
A.—Indirect Labour :									
1. Supervision in Core Department								0 0 10	
2. Pasting and Storing Cores								0 4 2	
3. Core stove attendant								0 1 8	
4. Sand preparation in Core Department								0 1 8	
5. Supervision in Foundry								0 2 6	
6. General labouring in Foundry								0 8 4	
7. Electric cranemen								0 2 6	
8. Sand preparation								0 5 0	
9. Pouring								0 2 11	
10. Cleaning up and shop preparation								0 6 8	
11. Sundry work—test bars, experiments								0 1 3	
12. Storekeepers, watchmen, etc.								0 1 4	
3. Maintenance Staff ; Plant and patterns								0 2 0	

B.—GENERAL STORES, ETC.:								
14. General Stores—Core Department							0 9 6	
15. Do. —Foundry							0 3 0	
16. Coal dust and blackings							0 0 10	
17. Heating and ventilating works							0 0 5	
18. Fuel for Core stoves							0 4 2	
19. Sands							0 12 6	
C.—POWER COST							0 16 8	
D.—REPAIRS, RENEWALS AND MAINTENANCE							0 4 7	
E.—LOOSE TOOLS							0 5 0	
F.—FOUNDRY STAFF AND MANAGEMENT							0 6 8	
G.—DEFECTIVE PRODUCTS							0 6 8	
H.—ESTABLISHMENT CHARGES:								
Office staff and management Rates, taxes and insurances Depreciation Commercial oncosts, advertising, etc.							1 16 8	
Totals	1		£5 0 0	—	£3 15 0		£11 5 0	20 0 0
								=20/– per cwt.

PERCENTAGE OF TOTAL COST.

METAL COST	25.0 %
DIRECT WAGES	18.75%
TOTAL INDIRECT WAGES	22.5 %
ALL OTHER EXPENDITURE	33.75%

CHART 2.

end of the financial year. It is probable that such work, when completed, may be transferred to a productive order and subsequently sold, and in that case the accountant would debit and credit the accounts affected accordingly.

The second class of experiment relating to methods of production is really a shop expense, and is consequently a direct charge against production. A point arises as to whether this expenditure should be charged against the work necessitating the experiment, or against the output generally, and in this connection it will be found the better way, it is thought, if each job is decided upon its own merits. If the experimenter is to acquire knowledge which other people possess, but is not known to the foundry concerned, then the foundry ought to bear the expense, and not the customer. When special work is carried out, however, to meet specific conditions laid down by the customer, and the ultimate benefit from the experiments is confined to that class of work, it is evidently a matter for mutual arrangement between the foundry and the customer. It is a melancholy reflection that castings are still being purchased by British engineers from the Continent which could be produced in British foundries if only this spirit of reciprocity existed between the engineering and foundry interest. It also stirs our national feelings somewhat when it is realised that pig-iron required for making these castings is exported from our own shores.

Regarding the items for overtime allowances, it will be observed that these are shown separately, the total for the month being dealt with as a shop oncost charge. There are, of course, special instances, such as a breakdown repair job, where the circumstances justify the charge being made direct to the job. As a general rule, however, it is not a good principle to charge overtime allowances to the job on which the overtime is wrought when it has been occasioned by general pressure of work. These allowances often reach a formidable sum on a contract job, and in many cases it will be found that other work passing through the shops at the same time has been fortunate in almost completely escaping overtime. When the cost of this overtime is spread over the whole output, the net effect on the individual order is scarcely perceptible, but that could not be said if the whole cost was borne by one or two jobs. These would naturally come out much higher in cost than they should, and this might easily lead to a future inquiry being quoted, quite unnecessarily, at an enhanced price, resulting possibly in the loss of the order.

The next item under general shop charges is general stores. The consumption of these materials is another matter of some consequence. and a proper system of receipt, accommodation, and issue of all stores is a decided advantage in every shop. It is also one of the best preventives against waste and leakages, apart altogether from the benefit derived from a costing point of view. All the materials purchased for the foundry are suitably classified in the stores' ledger, the receipts and issue of materials being entered daily, an abstract of the issues being made at the end of the cost-week, and sent to the cost department. This abstract shows separately the materials used in the green sand, dry sand and core departments, so that the output from these departments would be debited accordingly.

The sixth item of costs deals with defective products, that frightful bugbear of every one having anything to do with foundries. It is an old saying amongst foundrymen that those foundries which make no bad castings never made a good one, and seeing that all foundries make good castings, there should be no timidity in dealing with the bad ones. Foundry wasters should be all sent forward to the dressing shop to be cleaned, and immediately passed on to the mortuary for the daily "post-mortem" examination. Some rejects, however, will not arrive at the dressing shop, as, for example, in the case of a "run-out." It has also been known, however, that other "rejects" mysteriously disappear, never to be recognised when they come to life again, as lively as ever, at the cupola spout the following afternoon. This method of handling bad castings is happily becoming less frequent, for every foundryman is aware that this is not playing the game in accordance with the recognised rules. It certainly does not help to reduce costs, and will never make any improvement on the output per man hour of good castings.

The foundry clerk should compile a daily list of moulds closed and cast, typed copies being sent to those concerned, including the foundry despatch office, which will then be on the outlook for the castings from the dressing shop. Castings which fail to come forward should, of course, be accounted for in the list of bad castings. As a general rule, these rejects are charged against the order to which they belong, an exception being made with a special casting being dealt with for the first time, in which case any wasters resulting from experiments to ascertain the proper method of gating, venting, size and position of risers, etc., are reckoned as a shop expense under the heading of experimental work. When the method of production is once established, the rejects are charged in the ordinary way against the job.

The castings rejected from the machine shops and test rooms have been already invoiced to the customer, or charged to the job, when they were despatched from the foundry as presumably good castings. On their return to the foundry the castings are examined and their full value credited to the customer or to the job, as the case may be, and debited to the defective products account. This account will, of course, be credited with the value of the metal in the scrapped castings, the balance, which represents the loss, being dealt with as a shop expense. There are three ways of charging this, viz.:—(I) When there is more than one moulding shop in the establishment the loss is borne by the particular shop in which the casting was made; (II) as a general foundry oncost spread over the combined outputs of the foundry department; and (III) as a special charge against each particular class of product to which the castings belong.

There may be points of advantage in any of these methods or in a combination of two of them, but a hard and fast rule cannot be laid down, as the conditions in one foundry may be quite different from the one across the street, where an entirely different class of work is produced.

Establishment Oncosts.

The seventh item, establishment oncosts, does not interest the foundry manager so much, as these are more or less standing charges over which he has no control. They include rent, rates, taxes, insurance, office management, etc.

Core Department.

In the core department the wages expended in making the cores are charged direct to the various jobs for which the cores are required. The total expenditure, including sand, fuel for drying stoves, general stores, indirect labour, depreciation, power and light, etc., is completed, and allocated on a percentage basis of the direct coremaking wages.

Pattern Shop.

In some foundries the expenditure on patterns does not enter into the casting cost, but is an additional charge, similar to machining, etc. The output from the pattern shop is generally classified as follows:—(I) Special patterns made specially for customers' requirements are charged direct to the job; (II) new patterns required for a new design of product, being additional to existing standard products, are charged to capital expenditure; and (III) repairs and maintenance of standard patterns are charged to the foundry output.

The expenditure in the pattern shop is allocated on the productive wages basis, and the daily time records for the workmen will show to which of the three classes the work belongs. The items of oncost will include:—(I) All indirect work and non-productive labour in the shop; (II) accommodation and storage of patterns—wages of storeman and materials used in pattern stores; (III) timber and general pattern shop requisites; (IV) repairs and renewals of pattern shop tools; (V) pattern shop staff—foreman and assistants; (VI) proportion of power and light cost; and (VII) depreciation.

The only item here which may be specially referred to is timber. This should be requisitioned from the storekeeper in writing, giving the job for which the material is required. The timber cost is usually a fairly heavy one, and should be handled in a similar manner to the materials issued from the general stores.

Compiling Monthly Costs.

Assuming now that the machinery for collecting the various elements of cost is available, we may proceed to consider how the monthly costs are compiled. In some foundries it is necessary that the costs records be completed immediately after the castings are despatched, whilst, in other places, the returns can be completed at the close of the month and the output priced accordingly. When the costs are required immediately on despatch, and this condition applies to the bulk of foundry output, the following arrangement has given satisfactory results. The metal cost and the direct wages were always readily available, but the other items of expenditure were fixed at definite rates, and the oncosts charged partly on a wages basis and partly on a weight basis. The system provided for showing separately the sum charged as "oncost" against each order, and these were totalled monthly, taking into account, of course, the work and progress. At the close of the month the costs were completed in the usual way, and the actual cost of the month's output was obtained. As the estimated oncost rates were always fixed with a margin of safety, it invariably occurred that the sums charged as "oncosts" were in excess of the actual figures. The balance in hand was transferred to an appropriate account, and held in reserve for the slack month of the year, when the output was under normal. Briefly stated, the position is that when one has plenty of work and the costs are consequently lower than usual, the benefits are not passed on to the orders executed during the busy months of the year, so that when the dull period comes along one is able to go more keenly into the market, or to venture in other directions for work to keep the men employed, for it is only when costs are kept normal, or under normal, that a period of trade depression can be survived. The general complaint to-day, however, is that instead of having, perhaps, three quiet months in the year, that unfortunate condition has extended to the whole twelve. It will be understood that the author is dealing with the subject under normal conditions.

How should the oncosts be allocated when completing the costs at the end of the month, so that each job bears its true proportion? It is principally on this point that the utility of foundry costing depends, and until a general and sympathetic movement is made in the foundry trade to put their costing systems on a correct basis they will continue getting along "somehow," in spite of the method by which costs are arrived at and prices arranged by many foundries at the present time. How often one finds it to be the case that special parts of a job, usually presenting some difficulty, are offered to outside jobbing foundries in the expectation that the rate quoted will be not more than 18s. per cwt., because the overhead rate of the castings runs out about that figure. It may be that one of the foundries offering for the work has a rough and ready method of costing, and takes on the job at 20s. per cwt., because their output for the past month was calculated to be a little lower than that figure, whilst, as to the actual fact, the position probably was that only 30 per cent. of the output cost this sum, the remainder coming out at rates varying from 14s. to 35s. per cwt. The casting taken at 20s. may possibly be costing 30s., but the estimating department is not aware of the fact, and when the end of the financial year comes round the lean results are generally attributed to "not having enough weight" in the output, or to someone not working as he should. There is perhaps some truth in both ideas, but had there been a correct method of costing and estimating for the work the results would have been much more satisfactory for all concerned. It may be argued that the work was taken at 20s. per cwt., because the foundry round the corner was prepared to take it up at that price if the first declined. It is for this reason that some definite step should be taken to adopt generally throughout the trade a revised method of costing, freed from academical and cumbersome details. Such a system is not beyond the capabilities of the average foundry accountant, and in this connection the author would strongly urge all engaged in this work to become thoroughly familiar with the practical work-a-day atmosphere of the foundry, to keep an eye on the technical developments of the industry and also keep in touch with the practical ideas of those actually on the moulding floor, so that the costing department may keep abreast of the times. This could not be better achieved than by regular attendance at the meetings of the Institute of British Foundrymen and a careful perusal of the trade journals.

Foundry Oncost Charges.

Dealing now with the allocation of the foundry oncosts, a careful study of the various items will convince one that in certain of these the services given have relation to the *weight* of the casting (*i.e.*, on a weight basis), whilst other items have a distinct connection with the time spent on the job, which for the present purpose we will call a *wages* basis. Reference has already been made to the melting costs and the dressing costs, on which it was advocated that the former are allocated on a weight basis and the latter on a wages basis. Again, take sand as an example. Foundrymen generally recognise, no doubt, that the more metal that goes into the making of a casting the greater quantity of sand will be required, therefore the allocation of this expenditure on a weight basis would seem to be the correct procedure. Then there is also the labour preparing the sand, to which the same argument would apply. As one examines the list there are other items, such as electric crane drivers, pouring, shop preparation, etc., so that the oncosts consequently separate themselves into these two sections referred to, *i.e.*, on a weight basis or a wages basis. When all the items have been extended to their respective columns they can be summarised so that there are at most only three calculations to make in allocating the oncosts:—

(I) At a certain rate per cwt.; (II) at a percentage on direct wages on each job, and (III) dealing exclusively with the core department, the expenditure being allocated as a percentage on the coremakers' wages on each job.

The effect of adopting these classified rates of oncost on the estimated price of the castings is apparent from the two examples in each of which the line A (Table I) shows the application of an overhead rate for oncosts, and the line B shows the classified rates. The figures are taken from

Table I.—*Effect of Classified Rates on Oncost.*

First Example.

	Weight.				Metal Cost.			Direct Wages Cost.			Oncosts.			Total.			Per Cwt.
	T.	C.	Q.	lb.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	
(A)	1	0	0	22	6	1	2	1	1	0	7	12	0	14	14	2	14/7
(B)	1	0	0	22	6	1	2	1	1	0	5	0	5	12	2	7	12/-
								Second Example.									
(A)	2	15	0	10	16	10	6	16	18	3	20	12	6	54	1	3	19/8
(B)	2	15	0	10	16	10	6	16	18	3	55	14	0	89	2	9	32/5

the same month, only for obvious reasons they represent no firm or foundry in particular.

In the first example, which represents plain heavy work without cores, it is seen that the flat oncost rate brings out the cost at 14s. 7d. per cwt., whilst the classified rates give the cost as 12s. per cwt. The ultimate effect would be that the foundry would be quoting for work 2s. 9d. per cwt. more than they could have done, but were not aware of the fact so far as the costs were concerned. This foundry, therefore, runs a serious risk of losing work they could possibly get and turn out at a profit.

In the second example, which deals with light and intricate castings involving a considerable amount of core work, it will be seen that the overhead rate brings out the cost as 19s. 8d. per cwt., as against 32s. 5d. per cwt. under the classified rates. The position here is the reverse of the first example, as the foundry would be basing their quotation for work at 19s. 8d., which was really costing 32s. 5d. per cwt. to produce, consequently they would, in all probability, get as much of this class of work as they felt inclined to take, but someone would be buying it from them at a price less than the cost of production. This foundry, then, must look around for castings having more "weight," in order to get the balance of costs adjusted, but the outstanding fact remains that customer A is paying something towards the loss incurred in producing the castings for customer B. Anything more unsatisfactory in the realm of costing can scarcely be imagined, and the time for putting our costing arrangements on a sound basis is long overdue.

Another point of interest where the classified rates are in operation is that the estimating department will generally be found in sympathy with a system of estimating where the oncosts are calculated on both weight and wages, as when only the one basis is used (whether weight alone or wages alone), and a mistake is made in underestimating either the weight of a casting, or the time allowed for the job, the loss incurred in calculating the oncost is much greater.

Other trades have adopted with marked success what may be termed universal rules for costing their particular products, and it seems regrettable that the movement in this direction in the foundry trade is lacking of that energy usually displayed in other matters. The author was particularly interested in an article which appeared in The Foundry Trade Journal of November 13 last, entitled "German Method of Costing in Foundries." This article deals with a booklet which has been issued by the German Union of Iron Foundries, and which aims at providing a sound basis of costing for most of the important foundries in that country. There can be no doubt that the German foundrymen have been studying this question of foundry costs with extreme care, and they have apparently seen the necessity of adopting a definite system for all their foundries to work upon. They have even prepared calculating tables for estimating the cost of castings, and have separate tables for various districts where different economic conditions prevail. The method they set forth, however, is open to some criticism, especially in the manner in which they lump together the overhead charges for dry-sand and green-sand work, and one would conclude from a perusal of the system that the heavy cost of preparing dry-sand moulds is borne equally by the output of both green-sand and dry-sand castings, and also that the entire cost of the core making is distributed over all castings whether they involve core work or not. In any case, the German foundrymen have taken united action upon a matter of first importance so far as their commercial efficiency is concerned, and this action is bound to be of great assistance to them in so directing their energies that an increased and more profitable business will result.

In conclusion, the author has endeavoured to interest foundrymen in those matters that concern the commercial side of the foundry business, particularly in regard to foundry costing, and although he has not submitted a mass of detailed specimen forms, he trusts, nevertheless, that foundrymen will appreciate the necessity of the costing department in every foundry, and that each one will do what he can to assist, but do nothing to hinder its efficiency, for it is only by each department pulling together and putting in all their weight that the success we strive for can be achieved.

DISCUSSION.

Mr. Elliot said he thanked Mr. Spittal for his very interesting Paper. With regard to the practice of a clerk going round the shop collecting particulars, he agreed with Mr. Spittal that a system of time cards as outlined in the Paper was much better. That system was, in his opinion, the most accurate and therefore the most satisfactory. He also agreed that the method of basing the oncost partly on a wages and partly on a weight basis was nearest the truth. Oncost was, of course, very much a matter of approximation. He thought that Mr. Spittal's Paper had given the meeting a general idea of the accountant's work in connection with a foundry, and that it would help to clear away the suspicion that the accountant was only there to find somebody out.

Mr. Affleck, Branch President, said he had had some experience of the benefit of a costing system in foundries where there was a great variety of castings made. In the first instance in his experience that a costing system was applied in the foundry it was applied in a fairly elaborate manner. Practically every class of casting was dealt with in detail, and at regular intervals there was placed before him a series of figures relating to these castings. He found that while the ultimate cost came out at, say, about 35s. per cwt., some were as high as 70s., and others again as low as 25s. If one had not the actual cost before him, he might be inclined to quote on an average rate. They might get the job and have less money on it, but they would prevent someone else getting it who could do the job at, say, a moderate rate and yet not lose on it. Referring to costs, he said he had scarcely ever investigated a case of high cost where the moulder was to blame. It was rather some fault of the plant. The handling of the sand was an important item in costs, and he had seen some figures which brought out a rate of 20 per cent. of the cost being involved in the handling of sand. The large proportion of the cost which this item represented had been appreciated on the Continent, but he did not know to what extent it had been appreciated in this country. In one large foundry which he had visited on the Continent they had installed expensive plant with a view to lowering the cost of handling sand. When he saw that plant it was not working owing to some mechanical difficulty, but the installation of such plant showed that they appreciated the difficulty connected with this question. With regard to costs generally, he had found that the more detail they went into in getting out costs the more it would cost them to do so, and therefore the balance must be struck somewhere. So far as his experience went, they had started out with a very elaborate scheme. and when they had got a certain amount of information they contracted the scheme somewhat and then took only a certain number of classes. That, of course, was a compromise between a very costly system and a very simple system. To arrive at actual costs, however, he believed would greatly benefit the foundry trade, competition would be fair, and the engineering trade would benefit also.

Mr. Spittal was accorded a vote of thanks for his Paper.

Sheffield Branch.

SMALL WORK MOULDING IN GREEN AND DRY SAND.

By J. D. Nicholson, Member.

INTRODUCTION.

When reading literature or hearing Papers relating to sand moulding, a certain amount of latitude must be allowed because there are, in foundries and foundry work, numerous instances continually arising which help the various operations of moulding. The object of my Paper is to emphasise the important features in green and dry sand moulding, which must be adhered to, to produce reliable moulds and sound castings—together with some practical hints.

The illustrations are simple with a view to showing effectively the principles desired, so that they may be carried out under more exacting circumstances. The Paper deals with small work, such as would come under the term jobbing castings, and the base sand used throughout is Erith yellow loam. For green sand work it is used in the new or green state, whilst for dry sand work it passes through a process of milling.

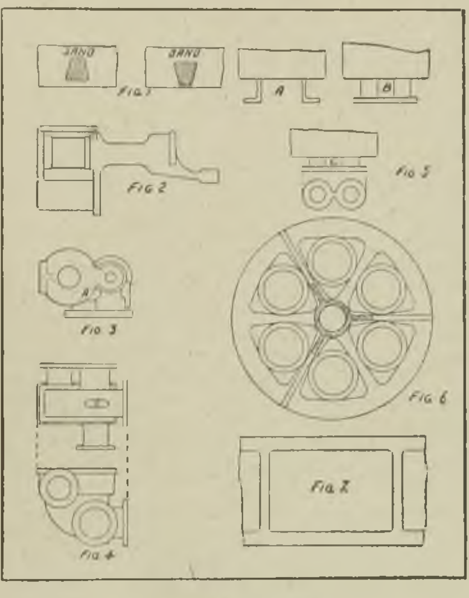
Moulds of either sand may be made successfully in many cases by unskilled labour, yet one is often confronted with numerous types of patterns, the making of tackle for and the moulding of which calls for the highest skill of the foundrymen. The continued advance in the many branches of engineering tends to various, and usually intricate, additions to patterns.

The Moulder.

A moulder employed upon a large mould may be so engaged for several days, but that is not the case with the small-work moulder, who is required to produce several moulds of different designs every cast, both in green and dry sand, each mould claiming separate attention and foresight, method of moulding, parts of pattern to be loosened, type of box available, position of runner and risers, also care of machined parts.

Cleanliness and individuality are qualities which should be acquired by every moulder. A lack of mental calmness has caused many a day's work to fail to reach expectations.

A moulder regularly engaged upon one type or section of mould knows its individual peculiarities, yet a person thus employed is too near standardisation which, although it may be necessary, is not good for producing efficient craftsmen.



General Moulding.

Good facilities for moulding should be maintained. These will not only benefit the employer, but will raise the spirit of the foundrymen in what is universally considered as a dull, rough occupation. By facilities is meant abundance of old sand, good condition of boxes, and quantity of tackle, such as loose box bars, lifters, grates and loose irons.

Whilst turnover methods are preferable, yet occasions arise when floor-moulding must be done.

Jobbing work causes constant handling of boxes and those with stove-dried moulds receive severe handling when removing their castings. Foundries making their own boxes might give due consideration to box thickness rather than strengthening pieces.

A useful item may be to have several sizes of box parts with one standard depth. One would then decide instantly the number of parts any mould would require. Middle parts being without bars, yet possessing holes for loose bars when required, which holes also encourage mould drying, venting and vent passages.

Top and bottom parts are preferable with straight bars cast in. Bottom-part bars, cast less deep, allow the box to be used for a top part if necessary, thereby removing the inconvenience of a flat-bottomed drag. Lugs cast upon all boxes would prove convenient. For hand-work, numerous makes of light, strong boxes are available.

Wood for box bars is permissible with green sand work, but discretion must be used for its use in dry sand. With repetition work or regular castings, boxes may have their bars made to eliminate the use of lifting tackle. Lifters should correspond with the depth of boxes frequently in use, and of the hanging variety. If a lifter is not hanging over a box bar, it is dangerous to allow it to protrude above the sand. A moulding box 26 in. sq., 12 in. deep, should hold in with dry sand without any definite tackle, except a lifter in a protruding piece of mould.

This size is reduced when using green sand to about 18 in. sq. Above these two dimensions grates wired up may be used to make sure of a hold-in. Grates are broken to suit the shape of the pattern. With dry sand, straight irons, wired-up, may be used as an alternative, with the addition of lifters as the holding. Several patterns require a special grate cast, which should be provided in good time previous to commencing the mould.

Deep lifts must have their grates stayed to the top box to prevent any falling away when turning over. It will have been noticed that grates have a narrow side and a broad side (Fig. 1). It is preferable with prominent pieces of mould to use grates having the narrow side down. This allows the sand to bind entirely round the grate. Otherwise the sand underneath the flat side has nothing to hold it save the clay-water. The grate being tapped down makes this piece of sand hard, and is also overburdened with clay. When drying in the stove, the heat encourages this piece of sand to leave the grate and often does so when molten iron reaches it.

In a green sand mould it is well known that liquid iron and excessive clay matter do not agree. Both cases result in what is termed scabbing. Sloping or recessed joints may be covered with wet brown paper or sea-sand. Both give good partings. The former being desirable when accuracy or absence of fin is essential. Pieces of patterns which give a very straight lift may have brown paper placed against the side to help a good lift.

The ramming of moulds should be done in such a manner as to ensure soundness being obtained. Hard-rammed moulds resist the exit of gases and generated steam, whilst soft parts produce swellings upon the casting. Sound ramming, providing the pattern is good, will give good lifts with top and bottom parts. It facilitates finishing and makes the mould more reliable.

To overcome ferro-static pressure, increasing as depth of mould increases, one must increase ramming pressure accordingly. The effect of pressure should also be borne in mind when making femmer cores, and also when boxes are being clamped together previous to turning over in order to cast "end-up."

The handiness of oil-sand cores lends itself favourably to coring out awkward parts of a pattern as frequently presented by modern designs. Nevertheless, outstanding or protruding pieces of mould well surrounded with metal are often met with. They should be treated similarly to a core when ramming up the mould either by inserting a row of fine ashes, or, in a dried mould, a piece of wax vent string, thus ensuring a ready exit for accruing steam and gases.

Dry Sand Moulding.

Whatever facilities are used for drying dry-sand moulds, they must be efficient. The majority of faulty castings may be put down to damp moulds. Everything possible should be undertaken during moulding which will encourage the drying of the mould, and also hasten the exit of generated steam and gases formed during filling the mould.

The following may be noted as in favour of and detrimental to a dry-sand mould:—(1) Mixing old sand by hand is laborious and sometimes the mixture receives too much water; (2) too hard ramming retards drying. The grains of sand being too compact affect the porosity, thereby reducing the escape of gases arising from the metal and sand, and perhaps causing them to remain in the iron; (3) narrow places, webs or brackets may have a row of fine ashes or a wax vent string; (4) the free use of a $\frac{3}{8}$ in. vent wire upon bottom and top parts previous to turning over. This facilitates the exit of steam when in the stove and during casting. A similar method may be employed with large brackets between flanges, by using a runner stick or tube about two inches from the mould face and removing it when finished ramming, and (5) excessive application of water when finishing will show cracks on the mould face on its return from the stove.

Scabbing and buckling usually arise from steam forcing the sand into the iron. A scab is rough through sand washing away when the iron reaches it. A buckle happens some time after the iron has passed the part, and is caused by generated steam in the sand having no escape except through the mould face which it forces into the iron to varying depths.

The accompanying diagrams are included for the purpose of demonstrating the foregoing by specific cases:—Fig. 2, for example, is a front elevation of a reversing engine cylinder body, whilst Fig. 3 shows an end view, exhibiting a difficult piece of sand marked A, in which it is preferable to insert a wax vent. Fig. 4 shows a discharge chest with two flanges moulded in the bottom; and in Fig. 5 three views of the bottom parts of valves are shown:—A illustrates a valve with two feet, which are, at times, cored out. A row of ashes between them would benefit the bottom face of the mould; B may be treated in the same manner, whilst C, being very narrow—about 2 in. only—the inserting of a wax vent would have a beneficial effect.

Of course, irons are embedded in this piece, care being taken they do not spring.

The last four illustrations serve to show how the iron, reaching the bottom flanges, first causes steam and gases to rise to the mould face, resulting in scabbing or buckling if not counteracted. This fault is susceptible in all flat-bottomed valves and chests. In all cases the steam generated must have an outlet downwards or at the box edge.

Referring to views B and C, loam cakes may be used to form the bottom edge of the flange instead of making a joint and parting. The fact must not be overlooked, however, if provision be made for separating boxes when stoving, the mould will receive a more effective drying. The ramming of top parts is often commenced by smearing the joint with loam and bedding grates, etc., upon it, to provide for a sound joint with the top part, yet it may be avoided when stove-drying.

A handy operation is to add some new sand to wet loam and mix with the hands until a little stiff. This may be applied to accurate facing pieces, pockets, joint brackets and prominent pieces on patterns. A good sound draw with the pattern will be received. These places should be first dampened and dusted with parting sand as in coremaking.

Fig. 6 shows where it may be used upon a head valve with its numerous thin facings. The same operation is desirable with places similar to the bottom flange of a water box shown in Fig. 7. This is about 14 in. deep and floor-moulded. Having removed the screws from the bottom flange, a little parting sand may be sprinkled at the inner edge of the flange. Removing this during finishing with the edge of a trowel preparatory to their withdrawal will facilitate their removal. No fear need be entertained with respect to pieces of mould falling when withdrawing the flange.

Narrow facing strips as found upon flanges which are awkward to blackwash will be skinned satisfactorily if a little coal dust or dry blacking be added to the sand at these parts.

Green-Sand Moulding.

Moulding with green-sand is the branch of founding which requires the utmost skill of the moulder. A good green-sand moulder is a valuable asset, and one who will readily adapt himself to the circumstances required to be adopted with any quality of moulding sand.

It is remarkable the difference in results obtained from various moulders, clearly showing that, although all are seemingly carrying out the selfsame operations, there is a difference somewhere which acts for or against the casting.

With many classes of moulding little respect need be taken of the condition of the old sand, nevertheless many types of moulds require the sand to be in a suitable condition. Green sand receives much burnt core-sands whilst removing castings from boxes.

Where any fair amount of green-sand work is carried out, although several things may be in the way as regards possessing any satisfactory plant for cleansing, renewing and mixing old sand, such plant would provide a sand uniform in quality and dampness, besides saving considerable skilled time and energy.

The success of a suitable installation may be compared to the simple operation of riddling sand. If one were to pass a quantity of sand through a half-inch riddle, it will be seen less water is necessary to bring it to working condition as compared to mixing with a shovel, the reason being that damp clots are broken up and evenly distributed among the mass.

Without efficient means of mixing backing sand the risk is taken of wet clots coming too near the facing. This is possible, for when filling in around a pattern the shovel is tilted towards the pattern, the heavy damp pieces falling against the facing.

The quality of the facing sand is the main feature in green-sand work. The mixing must be in trustworthy hands and under strict supervision for uniformity of bond and dampness.

Generated steam being very prominent, its easy escape has a large bearing upon the soundness of the casting. A too-damp facing-sand causes doubtfulness, whilst a dry facing needs the application of a supply of water when finishing to bring it into bonding condition for smoothing. Possibly too much may be used.

Venting may be relaxed when sands are of a good permeability. The sand to which these remarks refer having a low permeability, it is necessary further to increase porosity by the unlimited use of the vent wire and drying of certain parts. The use of the vent wire has fallen greatly into disuse.

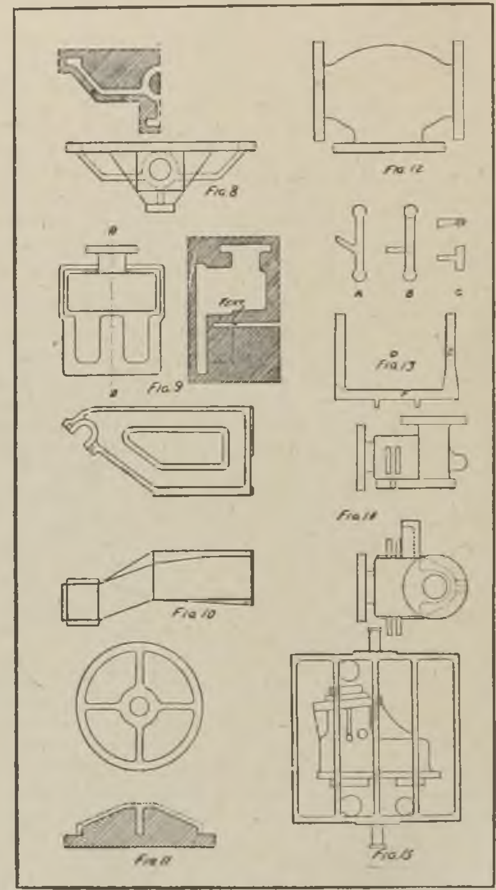
Occasions arise when a turnover method is not possible, necessitating a pattern to be moulded in the floor. Numerous moulds made this way cause large volumes of gases to be formed, requiring for their exit a definite passage, or even an outlet for a core-vent. For this a bed of cinders is made about 9 in. below the bottom of the mould. The size of bed and quantity of ashes depends upon the size of the mould, also the speed necessary for their escape. The easier the escape, the better for the mould. A pipe is inserted from the bed to the floor level for a final outlet. Paper should cover the ashes to prevent sand mixing with them, and a partial choking of the bed. All moulds, more especially small valves, tee-pieces and globe valves, should be well vented with the ⅛-in. vent wire. Commotions set up while filling the mould must free themselves sharply, otherwise they become entrapped in the quickly freezing iron, only to be discovered when machining or under test.

The commotions which take place may be seen when casting an open sand packing ring 12 in. deep, 3 in. thick, or by looking carefully down an open riser during filling the mould.

Moulds with branches in top parts or having pieces of mould as shown between the flange and body in Fig. 8 should be moulded with care. This is a view of a high-pressure slide valve, also a mould sectional elevation. When nearing the flange, it should be laid in position and rammed underneath instead of ramming up full and knocking it down to position. This knocking down may make it too hard, thus encouraging scabbing, which in parts like these require little encouragement, owing to gases and steam rising from mould face to mould face.

Excessive dampness here evolves an excess amount of steam in the flange, which, if it does not escape through the sand or riser, will lodge itself in the flange, the result being a blowhole in the casting. Porosity at these parts is assisted by pieces of straw laid in the sand, the vent wire, and slightly drying with a hot iron.

Fig. 9 shows an auxiliary discharge chest with a mould section, the mould of which is benefited by the addition of a stream of ashes. Gases generated



when the iron enters the bottom fly upward through the sand and through the easy ash passage. The gases from the sand between the vent and the flat mould face having an easy exit, give way to the pressure exerted by the iron. Without this passage the tendency is to make for the flat mould face. Upon the iron reaching here, a bubbling takes place, causing the face of the mould to lift away where the gases break through.

Fig. 10 shows a weigh shaft bracket, a type of pattern, if it is not possible to turnover, requires skill and care when made in the floor. It is about 4 ft. 6 in. long, 18 in. deep, and moulded as shown in front elevation. In the plan a large piece of mould will be seen which will become well surrounded with iron, making it prone to scabbing. The making of these moulds requires the inserting of a cinder bed.

For the floor-moulding valves brackets smaller than the one previously shown, or slab plates 6 ft. × 2 ft. 6 in. × 3 in. thick, no cinder bed is necessary. The bottom of the hole should be well opened up before commencing to work from the desired level, thus assisting the downward escape of gases.

The use of facing may be eliminated when making thin moulds such as thin flat plates, bodies of narrow pipes or top parts of large pipes.

Gases from facing sand retard the flow of the iron, and in pipes may affect cohesion of the metal at the tops.

Moulding with milled green-sand must be done with extreme care. Although it possesses the much-desired bond for green-sand work, its permeability is very low. Light tooling must be done, as scabbing easily appears. It is excellent for moulds which are preferably skin-dried, when it results in a good mould face.

Shortage of floor space accounts for the making of moulds in a hot hole and with hot sand. These ought to be finished off as quickly as possible. The facing sand becomes very dry, and although water may be applied, it is difficult to finish. Scabbing is encouraged by too much tooling, especially upon flat or curved surfaces.

The pile or glaze made agitates the iron, which results in bringing away a piece of the face. Fillets upon joint brackets should not be made too large. Large fillets not only affect the crystalline arrangement, but encourage sponginess. This is more easily encountered in dry sand work, as the casting cools slower, and generally undergoes a more critical test.

Fig. 11 is a view of a pump bucket cover and mould section to illustrate prominent pieces of mould. These, also flat tops made with old sand, pieces of mould subjected to the continual beat of the iron, and joint brackets, may be smeared with plumbago as a preventive for resisting the scorching effect of the iron.

Discretion must be used when applying plumbago to mould bottoms owing to the great retarding effect it produces upon the flow of the iron.

Many successful varieties of runners are to be found for the running of moulds. The straining of moulds is more often met with in green-sand work than in dry sand. Fast pouring accelerates straining, also blowing in risers, owing to steam and gases not being able to free themselves sufficiently quickly. Such blowing is often accompanied by the scabbing of flanges if the riser is upon a flange. Obviously, large thin castings should be run quickly, and in this instance due consideration must be given to the dampness and porosity of the sand used.

With the work with which the subject deals, it is preferable to use a runner which will fill the mould gradually. This allows steam and gases to find their exit through the sand and outlets provided for them; also any commotions taking place in the mould will free themselves in the gradually rising metal.

Fig. 12 is a view of a globe valve. Any bubbling taking place in this mould failing to free itself, may lodge itself in the body, and not be found until under test.

There is always a possibility of a small amount of dirt being carried down the downgate with the first rush of the metal. As a precaution, the joint runner may be extended a little farther than where it enters the mould—a kind of receptacle—or, better still, if the joint runner is not cut in the top part, sand may be cut out above this as a further preventive.

Fig. 13 illustrates a few designs of runners. A is one of the most common type; B has the runner cut in the top joint and where it enters the mould in the bottom; C shows why a runner should be deeper at the mould edge to prevent the edge washing; D is almost similar to B, and is preferable for moulds made in dry sand, which must produce a casting entirely free from dirt or slag owing to the high test they generally receive; and E is a scum-gate twice as wide as the down runner, thus allowing any scum freedom to accumulate instead of choking the bottom, with the possibility of some entering the mould. The breaking of the piece F when removing the casting is simple proof.

Unless supervision is strict, the occasion sometimes arises, through shortage of box space, of a mould having a drop runner upon a flange or part of a body. A round pin is more satisfactory here than a flat one. Flat and square down-runners set very much more quickly than round ones. This cuts off any chance of escape of the bubbles which are continually found when a flat gate has been broken off a casting. Round gates can be worked more effectively if further attention is required after filling the mould.

With dry sand moulds it is seldom necessary to close the risers. The nature of green sand sometimes makes closed risers a necessity, yet it is of the utmost importance they be allowed freeness to be eased by the touch of the metal. More especially with small valves, with which it is essential to run metal through after having been eased, thus freeing any blows which may have failed to escape. The failure to ease a riser often results in a defect in a flange.

Fig. 14 is a view of a mud box which possesses many weak pieces of mould, and one where all risers should be eased. Moulds having large flat surfaces, prominent pieces of sand or femmer cores, require their risers to be securely closed. This affords a pressure to be exerted all over the face of the mould, forcing the gases through the sand and artificial means of escape instead of rushing through the mould, out of the open riser, and blowing away pieces of mould or drawing down flat top parts.

When closing dry sand moulds every precaution must be taken for dampness or steam arising from any of the constituents used whilst coring up. These may be clay for touching purposes, or too damp sand when making up prints. Special regard to this is necessary with oil sand cores.

Fig. 15 shows a top part with holes above core prints, giving a clear view for the vent to be made up without any fear of the metal entering. If the core be upon a spindle or made of sand or loam, it is preferable to bring the vent away horizontally or vertically. Cores of oil sand allow one greater freedom.

In jobbing work, chaplets play an important part in the success of a casting. Continual adding or removing of branches from patterns makes it impossible to have a core in one piece; consequently, many loose cores are encountered.

On no account should a pressure casting have a double chaplet. A stalk chaplet of suitable strength will prove satisfactory. Blowholes, which sometimes occur round chaplet nails, may be caused through the small impression or button made upon the sand being hard, as they are often made without any sand being eased out.

Gauze chaplets are suitable in mould bottoms, but one must use discretion for their use to resist uplifts. In a green sand mould they may rest upon a metal prod or flat-headed nail inserted level with the mould face.

It is not possible to advise anything definite in the making of moulds for superheat work or internal combustion castings. A few points which might be adhered to are:—A dry mould, quick running, large risers and an entire absence of anthing which will produce dampness or blowing of the metal. The numerous unsound castings met with in this class of work too clearly suggest much research has yet to be undertaken.

In conclusion, the author desires to express thanks to his employers, the North-Eastern Marine Engineering Company, Limited, Wallsend-on-Tyne, for their kindness in allowing him to give this Paper, and also to their laboratory for assistance in preparing slides, etc.

Lancashire Branch
(BURNLEY SECTION).

THE EXAMINATION OF METALS.

By W. H. Poole (Member).

What is Science?

The dictionary definition of *Science* is the state or fact of knowing. It is knowledge or cognisance of something specified or implied. It can mean with wider reference—knowledge more or less extensive as a personal attribute.

A man of Science is one who possesses knowledge in any department of learning—or trained skill in any art or craft. In more modern use—he is a man who has expert knowledge of some branch of science and devotes himself to its investigation. It will be agreed that these terms are quite wide, and do not make too vital a separation between classes. A skilled craftsman can therefore be rightly considered as a scientific workman.

One often hears the term "Rule of Thumb," and this is often put as a description of a highly practical type of foundryman. Rule of thumb is also said to be a method or procedure derived entirely from practical experience without any basis in scientific knowledge—a roughly practical measure. In experience the gift of eyesight plays a valued part—so much so that it is necessary to emphasise the use of it. Eyesight is the power or faculty of seeing. It is the use of the eyes—to look, gaze, view or make observations. Now, how does the use of eyesight affect practical experience?

The metallurgist to be efficient must develop these senses. The development of sense perception to aid scientific deduction is reciprocal. Anyone studying, say, geology or botany naturally improves their vision. The value of the practical foundryman's observation is of immense importance in his craft. Carefully to note details of special phenomena cannot be over emphasised. There is an immense added value found in one's work if a deeper insight is made into the scientific aspect of foundry problems. Too often deductions are made with too little keen observation and thought on the problem.

Insight can be taken as a deeper knowledge. The original notion appears to have been " internal sight," that is with the eyes of the mind or understanding.

The dictionary defines internal sight to mean understanding or intelligent wisdom—mental vision or perception. It can also be taken as the fact of penetrating with the eyes of understanding into the inner character or hidden nature of things. It is a glimpse or view beneath the surface. So one can use their eyesight, but " insight " into a problem is required to get to the root of it.

Too many people use their eyesight without thinking much at the same time. How can the foundryman get full value of his eyesight and deep insight at the same time? Many say, " Wider practical experience," and this really implies " more knowledge." However, when knowledge is attained, it is up to the progressive man to make every use of it.

The study of metallurgy or co-operating with men specially trained in this will help any foundryman to adopt deeper reasoning on the many foundry problems met with. No thinking foundryman will make a gulf between himself and the scientific man, but he will link up and thus find his own knowledge of added value to him.

The metallurgist has his microscope, his " fracture definer," which is an optical instrument consisting of a lens or combination of lenses suitably adjusted by which objects are so magnified that details indistinct or invisible to the naked eye are clearly revealed.

Professor Dewey has said: " The future of our civilisation depends upon the widening spread and deepening hold of the scientific habit of mind." It has also been said that: " Knowledge is certainly precious to us, because we shall never have time to complete it." So it should be appreciated that a deeper study into the many foundry problems met is of vital importance to every foundryman.

Graphite.

One of the most important of reactions, and one that has a vital effect on the strength and structure of cast iron, is that of graphitisation. The study of this phenomena is a large one, and leaves a large field for study.

The flaky form of graphite, showing large flakes or patches, is associated with weakness. By rubbing very grey iron with the finger one can note the shiny graphitic coat. This is quite different from the graphite present in malleable iron, which is nodular in formation and an absence of the flake formation. The temper carbon resulting from splitting up by heat of cementite exhibits this nodular form.

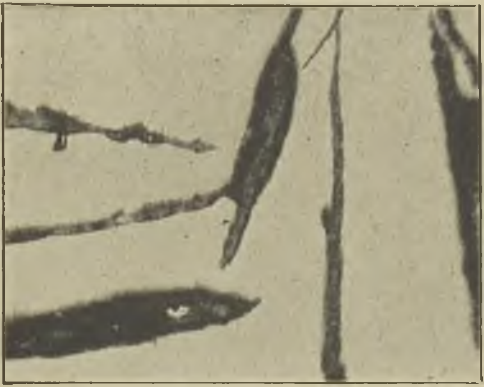


Fig. 1.—Pig-iron Cooled very Slowly under Slag. Not Etched. Magnification, 120 dias. Graphite Formation.

In the case of grey iron, it is important to control graphitisation, and this is done by considering many factors such as analysis of the mix, melting conditions, rate of cooling and type, size and section of casting.

The control of the analysis has its effect on graphite formation, and, as is well known, silicon plays its part. As an illustration of the effect of cooling on graphite formation, a sample of No. 3 foundry iron was very slowly cooled, over a period of many days—the resultant pig giving a structure as shown in Fig. 1. This is very interesting as showing a pig with the carbon all in the graphitic form, with no combined carbon. The silicon was 2.63 per cent. in this sample.

It is interesting to note the iron or ferrite crystals surrounding the graphite flakes. This micro (Fig. 2) shows the iron phosphide lakes, and from this segregation of phosphorus is plainly depicted. It is seldom in foundry practice that the cooling is so slow that no combined carbon results. Such a slowly cooled pig gave graphite plates in some cases nearly ¼ in. sq., with a resultant pig that was weak and easy to break.

Fig. 2.—No. 3 Pig-iron Cooled very Slowly under Slag. Etched Nitric Acid. Magnification, 120 dias.

In comparison with this sample, a piece of white iron before malleablising (Fig. 3) shows the carbon all in the combined form—as cementite.

On annealing the iron carbide splits up into graphite or temper carbon and iron, giving a structure that is soft yet tough (Fig. 4). The background shows a pearlitic structure, and the metal is very strong.

As a comparison of the effect of slowly cooling pig-iron, a sample of pig-iron of the same brand is shown in Fig. 5, that has been rapidly cooled immediately after casting. This sample is of much interest to foundrymen. In sampling a batch of pig, a number of pigs were found that were too hard to drill—yet gave a good No. 3 fracture in appearance. The analysis of the pig gave:—Total carbon, 3.85; combined carbon, 0.50; graphite carbon, 3.35; silicon, 2.04; sulphur, 0.023; phosphorus, 1.10; and manganese, 1.80 per cent. The pig is of the high manganese type, associated with high total carbon.

Whilst there is nothing in the actual analysis to explain such hardness, the micro photograph clearly shows a martensitic structure, and was the result of quenching the pigs on the pig bed at a critical temperature around 700 to 800 deg. C. Fig. 6 shows a remarkable star formation of graphite, and this is persistent throughout the whole structure.

The chilling of this sample had the opposite effect to that shown by slow cooling, but the pig had had time enough cooling through the higher temperature range to permit of graphitisation as shown.

Much has been written on pearlitic cast iron, which is a product of "control of analysis" and "cooling of metal." As an example of this, and showing how such material has been made, a sample of very tough scrap was examined (Fig. 7). This was an old tyre from a steam roller made 25 years ago.

This gave on analysis:—Total carbon, 3.16; graphite carbon, 2.60; combined carbon, 0.56; silicon, 1.71; sulphur, 0.15; phosphorus, 0.87; and manganese, 0.42 per cent.

The micro clearly shows the emulsified plates of ferrite and cementite, and explains the very tough nature of this sample. A patch of phosphide eutectic can be seen. A tensile test cut out of this sample gave 18.8 tons per sq. in., in spite of being cut from a thick flange.

As has been stated, graphitisation of iron is a most important point to study. The sample of pig-iron containing no combined carbon has been noted, and, as stated, this condition is not found often in foundry castings. Cast iron, however, will, if heated repeatedly, give a condition when all the combined carbon or carbides will be broken up with resultant formation of graphite.

A sample of scrap (Fig. 8), taken from an old vat, found its way into a foundry. An examination of this showed a badly burnt and oxidised condition. The effect of using this scrap in fairly large proportion in a mix gave badly gas-holed, chilled and dirty castings (Fig. 9).

FIG. 3.—WHITE MALLEABLE PIG-IRON. ETCHED NITRIC ACID. MAGNIFICATION, 100 DIAS.

The analysis of the casting was:—Total carbon, 2.99; silicon, 2.13; sulphur, 0.13; phosphorus, 1.20; and manganese, 0.34 per cent.

The high sulphur and unbalanced condition with low manganese are noteworthy. This could be largely, if not wholly, corrected by the use of higher manganese in the mix and attention in fluxing and melting.

The burnt scrap exhibited distinct burning, and oxide formation through sections 1 in. thick, and the use of such scrap was condemned for many purposes.

To revert to graphite in cast iron, one vital point as to the physical condition is the amount and form of the graphite flakes. The manner in which the continuity of the otherwise ductile matrix is broken up by the graphite affects the physical condition. So very coarse highly graphitic iron is brittle and lacks ductility because of the presence of numerous plates of graphite, as the relative weakness of the matrix is then noted. Graphite, because of its low specific gravity, will occupy a relatively large per cent. of the bulk of the metal. Thus, 3 per cent. graphite contains by volume 12 per cent. of that element.

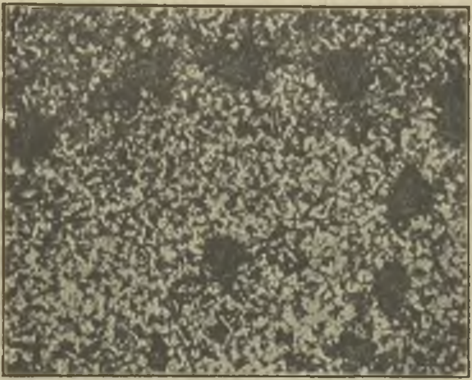


FIG. 4.—ANNEALED MALLEABLE IRON. ETCHED NITRIC ACID. MAGNIFICATION, 120 DIAS.

The rate of solidification of the metal, and thus cooling conditions, has its influence on the shape and size of the graphite flakes as well as the matrix structure.

The sample shown in Fig. 10 of centrifugal cast iron shows clearly the fine condition of graphite with a 3.42 per cent: total carbon iron, with 1.9 per cent. silicon.

To illustrate this, a sample of open No. 1 highly phosphoric pig was spun into a mould to give a section 1 in. thick. The graphite was very finely divided and the phosphide eutectic exceptionally fine.

Kish.

The formation of kish has been noted in pig-iron, and such graphitisation is sometimes noted in foundry work. This is noted as fine flaky particles of graphite oozing through the molten metal and escaping in the air. It is essentially graphite resulting from the instantaneous graphitisation of primary cementite. The exact mechanism is not very certain, but the momentum of the reaction is such that the graphite is able to break through the surface tension and rise into the air.

Fig. 5.—Open and Close Pig-iron with the same Silicon Content.

With the metal superheated no separation takes place, but begins with falling temperature. This formation of "kish" can be noted in blast-furnace practice, especially when the metal is running very hot and the silicon high. Such pigs show a "kishy" metal, and in use in the cupola require hot melting and such conditions as will assist in the solution of this graphite.

It is interesting to note the rapid "cooling off" of such kishy metal. In the case shown, the metal mix in use had been successfully used for some time with one type of coke, and the "kishy" castings resulted on a change of coke. Two predominant factors were noted:—(*a*) very hot melting, and (*b*) very high fixed carbon coke (93.5 per cent.).

FIG. 6.—PIG-IRON TOO HARD TO DRILL. STAR FORMATION. GRAPHITE MARTINSITIC STRUCTURE. ETCHED NITRIC ACID. MAGNIFICATION, 120 DIAS.

An analysis of the mix showed an increase of 0.37 per cent. carbon by the use of this new coke, giving 3.72 per cent. total carbon in the iron The mix was hardened up, and less new coke used to counteract this.

It is possible that the time factor in cupola melting may not always be sufficiently long fully to take up the graphite in very kishy pigs, and a nuclei left in the metal for rapid graphitisation on cooling after tapping. An experiment with very kishy pigs was made, putting 10 cwt. of a very grey pig through the cupola at the end of a blow. The furnace was melting very hot indeed, and this last charge was tapped out. The metal tapped was so grey that graphitisation was noted at the spout, and the metal rapidly chilled. The coke bed was examined, and some pieces of "sponge" were found that were full of "kish," the coke also being coated with this.

FIG. 7.—PEARLITE AND PHOSPHIDE EUTECTIC. ETCHED NITRIC ACID. MAGNIFICATION, 960 DIAS.

Much investigation remains to be done to correct up actual blast-furnace conditions, and resultant quality of pigs and the usage in the foundry cupola.

A recent case examined of cracked castings was finally traced back to a batch of pig of quite good chemical analysis, but of peculiar physical condition. The pig clearly shows the presence of oxide on micro examination.

Cupola.

The foundryman here has one vital spot in his practice. Eyesight plays its part, and without keen insight is apt to mislead. It is true one can see if the iron is hot and fluid, but it requires more thought to know if the very best is being obtained from the plant.

It is remarkable the amount of variation in cupola practice, and, before one can compare results, so many factors must be considered. In fact, each plant must be judged on its own merit. After all the interesting and valuable data already written is considered, it is not desirable to go into technical details.

Fig. 8.—Burnt Cast-iron Scrap. Etched Nitric Acid. Magnification, 120 dias.

Do foundrymen work their cupolas to suit the blowing plant? So many foundrymen change and alter their furnace practice from the wrong standpoint. Very often the engineer puts in the air plant, and the cupola is worked by putting on so much bed, charge coke, and try it out. If not hot enough, more coke, and so on until a stage is reached where hot melting is found. This is obviously necessary.

The essential point is to know the air supply and the volume of air delivered. The pressure conditions are a function of the cupola design, etc. To alter the internal design and charging of the cupola to suit the air supply is often likely to lead to poor economy. Whilst knowing the scientific limitations of blast meters, the use of such is invaluable in cupola practice. Pressure conditions are secondary to volume, though obviously bound up with it. The thermal working of a cupola is now worked out to a nicety, and there is available a quantity of useful data, which has appeared in the technical press.

FIG. 9.—GASSY CASTING MADE OF BURNT SCRAP.

Assuming 30,000 to 35,000 cub. ft. per ton per hour is required, the requirements can be judged. But this is at a suitable pressure, and with correctly balanced charge to coke, should give good melting. This sounds easy, but undoubtedly some deeper insight into these conditions well repays the time spent.

Keep an eye on the cupola—the zone position and condition, the coke usage, and especially the slagging conditions.

The general tendency is to use too little flux. Fluxing plays an important part in melting processes. Slagging time is a point to be considered, especially on a long blow.

Scrap.

It is a difficult problem to control outside scrap, but more attention can be given to this than is usual. It is suggested that scrap should be classified as much as possible, particularly domestic scrap if more than one mix is made. So the foundryman has to keep his eyes opened to control the many foundry variables. The metallurgist can be an invaluable help in "looking into" problems, and it is this co-operation that will give a combination likely to keep foundry practice up to date.

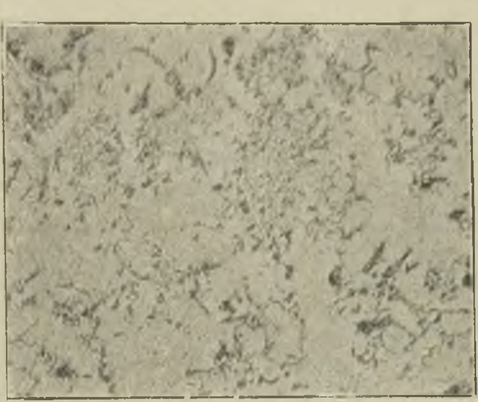


Fig. 10.—Graphite in Centrifugally Cast Piston Ring Not Etched. Magnification, 120 dias.

It is interesting to note that Germany before the war, after reducing the population to the same scale as in England, employed 50 chemists in industrial work to every six here.

Heavy Core Oil Tests.

Using one type of core oil, the mixture tried gave the following results:—The tests are an average of 12 cores in each case. The tensile tests were on a core made to 1 in. square, similar to a concrete test, but with special precautions with the jaws used on the machine.

The time given was such as to get a similar colour to that noted by the foundryman when baking in the usual way.

Tensile Test, 1 *in. Square.*

Time of Baking	23 mins.	38 mins.	60 mins.
Temp. of Baking	240° C.	240° C.	240° C.
Tensile test	55 lbs.	111 lb.	79 lb.
Colour	Light brown	Nut brown	Dark brown

Compression, 2¾ *in. Cube.*

Time	60 mins.	75 mins.	90 mins.
Temp.	240° C.	240° C.	240° C.
Compression	0.66 tons	1.10 tons	0.86 tons
Colour	Light brown	Nut brown	Dark brown

The colour "scheme" was taken from the usual method of judging in the foundry, and these figures refer only to the type mix in use. The comparative results are, however, of interest. A question of value was a comparison of emulsifying the oil—compared with the usual method of mixing the raw oil to sand damped and sieved to mix.

Made and baked under the same conditions, the emulsified mix containing 1.9 per cent. by weight of oil, compared with the other mix containing 3.1 per cent. by weight of oil, gave:—

Tensile, 1 *in. square.*

Emulsified oil mix	361 lbs.
Usual mix	281 ,,

Compression, 2¾ *in. Cube.*

Emulsified oil mix	3.46 tons.
Usual mix	2.75 ,,

The value of using emulsified oil is marked. To obtain the most satisfactory use of any core oil, careful attention to baking time and temperature, to suit the particular oil and type of cores, must be given. These points do not always receive the attention they merit.

Newcastle Branch.

THE STRUCTURAL COMPOSITION OF CAST IRON.

By Arthur Logan, Member.

Two years ago Mr. C. Gresty, in a Paper entitled the "Examination and Photography of Cast Iron under the Microscope,"† stated: "Nowadays most metallurgical Papers are illustrated by photo-micrographs, and it is probable that the average foundryman, not being a trained metallurgist, would more fully appreciate and understand the illustrations if he were familiar with the methods by which they are obtained. The object of the Paper is to describe practical microscopic work as applied to cast iron, and to show how the various constituents of the metal may be distinguished. *It is not proposed to deal with the theoretical side of the constitution of cast iron. . .*"

The objects of the Paper as set forth in the introductory remarks just quoted were admirably achieved. The Paper is a clear and concise account of the photo-micrography of cast iron; but obviously, treating the subject in a comprehensive manner, it was impossible to deal with the theoretical constitution of cast iron. It has always seemed to the present author, therefore, that if a further chapter could be added dealing with this side of the subject in a simple way, then the foundryman would be in a much better position to understand and appreciate something of the subtleties of this complex material.

This, then, is the justification for the following Paper," "The Structural Composition of Cast Iron," which is to be regarded as being in some degree a second chapter of the first-mentioned Paper. The object of this second portion, to express it in a single sentence, is to enable the foundryman to understand why slight differences of chemical composition can have so large an influence on the iron. The foundryman may

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† See The Foundry Trade Journal, April 5, 1923.

think that the structural composition of cast iron is not his concern, but it is. It is the vital concern of every foundryman, consciously or unconsciously. Everyone who mixes iron, whether by analysis or by fracture, does so to control, or to try and control, the structural composition.

Examination under low powers, of the polished but unetched specimen, will only reveal the graphite and possibly the manganese sulphide constituent, both of which are revealed in Fig. 1. It will clearly show physical defects, however, such as a tendency to "sponginess," draws, dirt inclusions, etc. The graphite is free carbon. Carbon exists in cast iron in both the free and the combined condition. Up to approximately 0.8 per cent. combined carbon will be present structurally as pearlite, which consists of alternate plates of relatively pure iron known as ferrite, and plates of the compound iron carbide (Fe_3C), which has three atoms of iron to one of carbon. Fig. 2 illustrates the appearance of

FIG. 1.—UNETCHED MICRO OF CAST IRON SHOWING GRAPHITE AND MANGANESE SULPHIDE.

pearlite at high magnifications. Any excess of combined carbon over 0.8 per cent. will exist as free iron, which is known as cementite.

Apart from carbon, cast iron contains four other things which are present in quantity. These are silicon, phosphorus, sulphur, and manganese. Although these things are all that are generally taken into account, cast iron contains small amounts of many other elements. Probably the one occurring in the greatest quantity is titanium, which is often added at the blast furnace as a deoxidiser. Some brands of pig-iron also contain appreciable amounts of some of the following:—Arsenic, copper, nickel, tungsten, chromium, vanadium, aluminium, etc., to say nothing of dissolved gases such as hydrogen, nitrogen, oxygen (possibly also in combination as dissolved iron oxide), carbon monoxide, carbon dioxide, sulphur dioxide, etc.

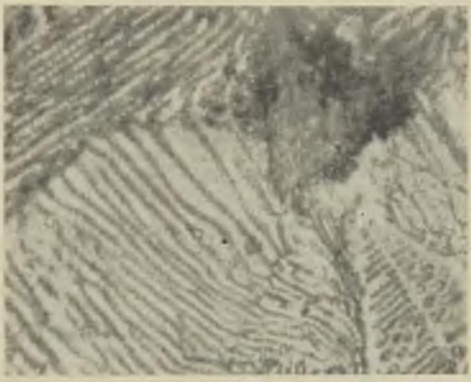


FIG. 2.—PEARLITE AT HIGH MAGNIFICATION.

How the Elements Exist.

The silicon enters into solid solution with the iron, and is therefore invisible. It is invisible in the same way that sugar dissolved in water is invisible. It is there, but cannot be seen. The phosphorus present exists as a phosphide eutectic. It is easily recognised under the microscope. This phosphide eutectic is the last thing in the iron to solidify, and it is consequently squeezed about as solidification proceeds, thus giving rise to its characteristic formations. In normal iron, the whole of the sulphur present will be combined with manganese, and will be present in the form of small globules of manganese sulphide. The remainder of the manganese present combines with carbon to form manganese carbide, which acts in a similar way to iron carbide, and is indistinguishable from it. Thus graphitic carbon, combined carbon, silicon, phosphorus, sulphur and manganese are found in the structure as graphite, pearlite (composed of the iron and manganese carbides), phosphide eutectic, and manganese sulphide.

The foundryman is now in a position to recognise the different constituents under the microscope. Considering these elements singly and ascertaining what their influence is, and what happens during cupola melting, it will be supposed that an iron contains 1.9 silicon, 0.8 phosphorus, 0.10 sulphur, and 0.8 per cent. manganese, and is charged into the cupola. As is known, various changes occur.

EFFECT OF CUPOLA MELTING.

Carbon.

Iron has the power of dissolving carbon, which power increases as the temperature is raised. Case-hardening, for example, is an instance of carbon actually being absorbed by solid iron. The silicon has been referred to as being dissolved in iron as sugar dissolves in water. Carbon can be imagined to do very much the same thing in molten iron. Cold water dissolves a certain amount of sugar; if the water is heated, more sugar will dissolve. If the water is maintained at a constant high temperature and more sugar added, a point will be reached when no more will dissolve, this being known as the saturation point. If now the water is allowed to cool, sugar will be thrown out of solution, as the water, being at a lower temperature, has a lower saturation point. A parallel happening occurs in the case of iron and carbon—that is, molten iron constantly trying to saturate itself with carbon.

Iron going down through the cupola is heated, gradually increasing in temperature until it arrives at the top of the melting zone, where a very rapid increase of temperature takes place. As the outer layers of the piece of iron reach the melting point, they trickle away down through the hottest part of the melting zone, thereby becoming superheated. In this condition it is greedily trying to absorb more carbon, and, indeed, conditions are very favourable. There is iron at a high temperature, in small drops, every particle of which comes into intimate contact with carbon (coke) also at a very high temperature. The lower the carbon in the iron charged into the cupola, the greater the tendency to absorb carbon. The only thing lacking at this stage is time, and here, apart from composition, is practically the only chance to control the absorption of carbon. The more rapid the melting and the shallower the melting zone, the less time will the little drops of superheated iron have to absorb carbon. The

Figs. 3 and 3a.—Graphite Distribution in the Same Casting.

molten iron collects in the well of the cupola, still in contact with coke, but now on a falling temperature gradient. It is possible that more carbon is taken up whilst waiting to be tapped, but, on the contrary, it may be that some irons actually lose carbon at this stage.

Graphitic Carbon.

Suppose that the iron after its passage through the cupola contains 3.5 per cent. total carbon.

Fig. 4.—Phosphide Eutectic Network Structure.

This carbon, whilst the iron is molten, is all combined with iron, and is held in solution. The actual temperature at which an iron commences to solidify will vary according to its composition, but the main solidification will occur round about 1,130 deg. C. Just immediately after solidification, the iron carbide, which is not very stable in the solid form at high temperatures, starts to split up into its component parts. That is, $Fe_3C=3Fe+C$. This liberated carbon is the graphite. The iron is still semi-liquid when the first graphite forms, so that it is able to grow readily; therefore, the first or primary graphite is large. As the iron continues to cool, more graphite is thrown out. The amount of graphite thrown out will depend upon the total carbon held by the iron, the percentage of silicon, phosphorus, sulphur and manganese present, and especially upon the rate of cooling. This latter is largely a matter of section and size of casting; also initial casting temperature and temperature of mould. Cooling continues down to about 940 deg. C., when the phosphide eutectic solidifies, and the whole mass is then solid. Graphite still continues to be formed right down to about 700 deg. C., but naturally this graphite, forming in the now completely solid material, cannot grow so easily, and is consequently small in size. It is known as secondary graphite. If specimens from different castings and castings from different sources are examined it will be seen that the graphite can vary considerably in amount, size, shape, and distribution, each different variety having its influence on the physical properties of the iron in which it occurs. Fig. 3 illustrates this clearly.

Fig. 5.—Typical Sulphur Print of Cast Iron.

Suppose that in iron under consideration, which had 3.5 per cent. total carbon when it left the cupola, 3.0 per cent. of this has freed itself as graphite. This figure is 3.0 per cent. by weight, and does not represent the area or volume occupied in the iron. Grey cast iron has a specific gravity of about 7.15, and graphite about 2.2, so that every 1 per cent. of graphite by weight represents about 3.25 per cent. by volume; thus 3.0 per cent. graphite by weight actually represents 9.75 per cent. by volume. In other words, almost 10 per cent. of the bulk of the material forming a casting consists of small spaces or cracks filled with powdery graphitic carbon. The importance of keeping the graphite under control will be appreciated when it is regarded in this light. Although the graphite percentage may be identical in two irons, it does not follow that the volume occupied by the graphite will be the same in each case.

Combined Carbon.

The remainder of the carbon in the iron not liberated as free or graphitic carbon is converted into pearlite at about 700 deg. C. This pearlite consists of alternate plates of almost pure iron (ferrite) and the compound iron carbide (cementite), in the proportion of seven parts of ferrite to one of cementite.

The atomic weight of iron is 55.84, and carbon 12. Therefore three atoms of iron and one of carbon would give a formula weight of 167.52 + 12 = 179.52. Therefore every 12 parts of combined carbon would equal 179.52 parts of cementite. In this case the combined carbon is 0.5 per cent., so that by simple proportion this gives 7.48 per cent. cementite. Pearlite consists of seven parts ferrite to one of cementite, so that 7.48 multiplied by 8 gives the amount of pearlite, which is 59.84 per cent. A simpler way of arriving at this figure (providing the amount of combined carbon is less than 0.8 per cent.) is to multiply the percentage of combined carbon by 120. Thus 0.5 multiplied by 120 equals approximately 60 per cent. pearlite, which is near enough for practical purposes.

Silicon.

A certain amount of silicon is oxidised and passes into the slag during melting. Commencing with an iron containing 1.9 per cent., probably

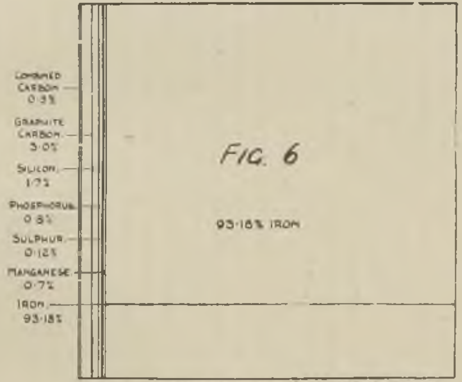
0.2 per cent. would be lost in the cupola, the iron finishing with 1.7 per cent. The loss of silicon depends upon the conditions prevailing in the cupola, hard driving and much excess air increasing this loss. The silicon forms a silicide of iron, and this is held in solution by the remainder of the iron. Assuming that it is FeSi that is formed, then 1.7 per cent. silicon will form 5.1 per cent. iron silicide.

The effect of silicon is to reduce slightly the solubility of carbon in iron, and to promote graphitisation. That is, increasing the silicon tends to lower the total carbon, but increases the amount thrown out as graphite. The very considerable effect of silicon in this latter respect is very well known. Everyone would know what to expect in two similar irons, one of which contained 1.0 per cent. silicon and the other 2.0 per cent., for instance. Both the effects mentioned can be obscured or prevented by the influence of other things.

Phosphorus.

Phosphorus has also the effect of lowering the carbon saturation point of iron, and although it is apparently without direct effect on the condition of the carbon, it has the indirect effect of lengthening the solidification range, and thereby allowing the formation of large, coarse graphite. The amount of phosphorus going into the cupola remains unchanged during melting, and the finished iron will contain practically the whole of the phosphorus charged. Phosphorus has a very considerable effect on the fluidity of the iron. The reason for this is that it combines with iron 1.0 per cent. of phosphorus, forming 6.4 per cent. iron phosphide (Fe_3P). This iron phosphide in turn forms a eutectic with more iron, and it is this phosphide eutectic, with its melting point of about 980 deg. C., which gives fluidity. In an actual cast iron the phosphide is not solid until about 940 deg. C. The eutectic of grey cast iron consists, according to the late Dr. Stead, of approximately 90 per cent. iron and 10 per cent. phosphorus. The particular iron under consideration would therefore contain 8 per cent. phosphide eutectic It should 'be noted that in strong irons

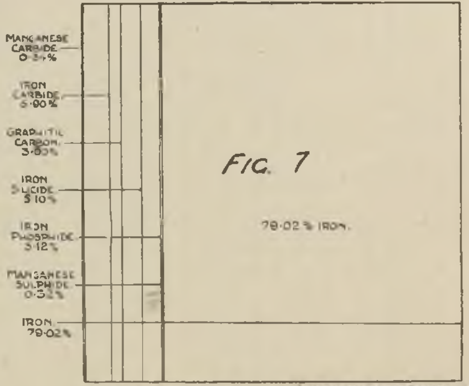
FIG. 6



GRAPHICAL REPRESENTATION OF ULTIMATE ANALYSIS OF CAST IRON.

0·3% COMBINED CARBON
3·0% GRAPHITE CARBON
1·7% SILICON
0·8% PHOSPHORUS
0·12% SULPHUR.
0·7% MANGANESE.
93·18% IRON (BY DIFFERENCE)

FIG. 7



GRAPHICAL REPRESENTATION OF PROXIMATE ANALYSIS OF CAST IRON.

0·54% MANGANESE CARBIDE Mn_3C.
6·90% IRON CARBIDE Fe_3C.
3·00% GRAPHITIC CARBON
3·10% IRON SILICIDE $FeSi$.
3·12% IRON PHOSPHIDE Fe_3P.
0·32% MANGANESE SULPHIDE MnS
79·02% IRON.

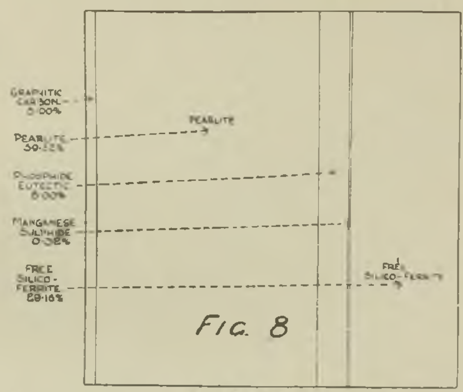


FIG. 8

GRAPHICAL REPRESENTATION OF
STRUCTURAL COMPOSITION OF
CAST IRON
(BY WEIGHT)

3.00% GRAPHITIC CARBON.
59.52% PEARLITE.
8.00% PHOSPHIDE EUTECTIC.
0.32% MANGANESE SULPHIDE.
29.16% FREE SILICO-FERRITE.
(BY DIFFERENCE)

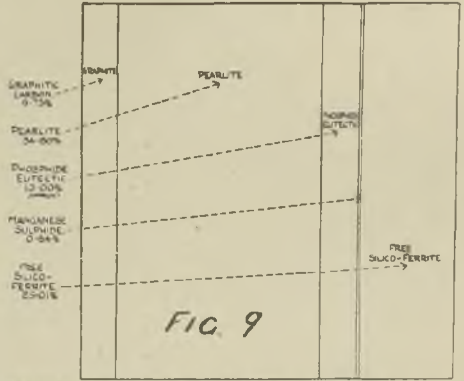


FIG. 9

GRAPHICAL REPRESENTATION OF
STRUCTURAL COMPOSITION OF
CAST IRON.
(BY VOLUME.)

9.75% GRAPHITIC CARBON.
54.60% PEARLITE.
10.00% PHOSPHIDE EUTECTIC (APPROX)
0.64% MANGANESE SULPHIDE.
25.01% FREE SILICO-FERRITE.
(BY DIFFERENCE)

the phosphide is generally found to be arranged in a network formation as shown in Fig. 4.

Sulphur.

During the descent through the cupola, and especially on standing in the well awaiting tapping, cast iron picks up sulphur from the coke. The amount picked up is variable, depending upon the conditions of melting and upon the sulphur content of the coke. Probably an average gain would be about 0.02 per cent. In the iron under consideration the final sulphur content might be 0.12 per cent. Sulphur exists in cast iron as manganese sulphide, every 0.10 per cent. sulphur forming 0.27 per cent. manganese sulphide. Thus 0.12 per cent. sulphur would be equivalent to 0.324 per cent. manganese sulphide. Sulphur alone, in the absence of manganese, has a very pronounced effect on the carbon, but when at least twice as much manganese is present, manganese sulphide is formed, and the influence then is only apparently the local influence of the hard crystals of manganese sulphide. These hard crystals are believed to be good from a wearing point of view.

Sulphur has rather a bad name in the foundry—unjustifiably so in the author's opinion (that is, when kept under control)—and it is the scapegoat for many troubles for which no other reason can be assigned.

A very practical method of judging the approximate amount of sulphur present is to take a sulphur print. The piece of iron to be tested is machined or filed flat, and then polished with emery—the finer the finish the better the result. Photographic bromide paper is then soaked in dilute sulphuric acid and pressed into intimate contact with the surface, and wherever a globule of manganese sulphide exists, it will leave a corresponding brown mark on the photographic paper. If the conditions are standardised and adhered to, an idea of the amount of sulphur present and its distribution can readily be seen. A typical sulphur print is shown in Fig. 5.

Manganese.

Manganese is generally not present in cast iron in greater quantity than 1.5 per cent., and is usually below 1.0 per cent. Manganese has a great affinity for carbon, and high-manganese irons tend to pick up carbon in the cupola. Manganese is slightly oxidised during melting, ordinarily about 0.1 per cent. being lost.

The effect of manganese is directly opposite to that of silicon, which lowers the carbon saturation point and promotes graphitisation. Manganese increases carbon absorption and opposes graphite formation. The reason for this is thought to be that having formed manganese sulphide with all the sulphur present, the remainder of the manganese unites with carbon, forming manganese carbide, which is much more stable than iron carbide at high temperatures. Manganese is therefore regarded as a hardener, but where insufficient manganese is present in a high-sulphur iron, the addition of more manganese will then have the effect of softening the iron. The iron under consideration would probably finish with 0.7 per cent. manganese; 0.2 per cent. of this would form manganese sulphide with the sulphur present, and the remaining 0.5 per cent. would combine with carbon, forming 0.54 per cent. manganese carbide.

Ultimate, Proximate, and Structural Composition.

It will thus be seen that chemical analysis alone gives only the ultimate amounts of the elements present in the iron. It does not indicate how these elements are united with the iron, nor what part they play in the actual structure, which is really the most important point of all. Knowing the chemical analysis, however, it is possible by calculation to build up the proximate composition, and thereby obtain an idea of the compounds present in the iron. These are shown in Table I.

The proximate composition, however, still does not go sufficiently far, and it is desirable to ascertain what the structural composition is. The manganese carbide and iron carbide together form the cementite, which, with seven parts of ferrite, forms the pearlite, which is seen under the microscope. The iron silicide is dissolved throughout the whole of the ferrite, and consequently cannot be seen. The phosphide forms a eutectic with more iron. The sulphur exists as manganese sulphide distributed throughout the mass in little globules;

so that the actual structural composition by weight is as shown in Table I. The different constituents have different specific gravities, so that it is necessary to correct these figures to realise the amounts as actually seen under the microscope. The corrected figures showing the composition of the iron by volume are also shown in Table I.

The whole of these facts are summarised graphically in Figs. 6, 7, 8, and 9. It will be seen that in place of the 7.0 per cent. or so of elements which this iron contains, 75 per cent. of the mass is occupied by constituents formed from the carbon, phosphorus, sulphur and manganese. Of the 75 per cent., 54.6 per cent. is due to the combined carbon in the form of pearlite.

FIG. 10.—CAST IRON FREE FROM FERRITE.

Carbon is practically the most important thing in cast iron. The other elements are important indirectly, inasmuch as they affect the amount and condition of the carbon in the final product.

Effect of Changes of Composition.

It will be obvious now that slight changes of ultimate composition will produce drastic changes in structural composition. The retention of a little over 0.2 per cent. more carbon in the combined state, for instance, would be sufficient to take up the whole of the free ferrite, and the matrix would then be completely pearlitic, as is shown in Fig. 10. Very slow cooling might cause practically the whole of the carbon to be freed as graphite, in which case the matrix would then consist of nearly all free ferrite, and, in addition, the material would be further weakened by the presence of a large amount of free graphite.

TABLE I.—*Showing how the Constituents in Cast Iron can be Considered as Existing.*

ULTIMATE ANALYSIS. %		PROXIMATE COMPOSITION. %	
0.50	Combined carbon.	0.54	Manganese carbide.
3.00	Graphitic carbon.	6.90	Iron carbide.
1.70	Silicon.	3.00	Graphitic carbon.
0.80	Phosphorus.	5.10	Iron silicide.
0.12	Sulphur.	5.12	Iron phosphide.
0.70	Manganese.	0.32	Manganese sulphide.
93.18	Iron (by difference).	79.02	Iron (by difference).

STRUCTURAL COMPOSITION. (BY WEIGHT.) %		STRUCTURAL COMPOSITION. (BY VOLUME.) %	
59.52	Pearlite.	54.60	Pearlite.
3.00	Graphite.	9.75	Graphite.
8.00	Phosphide eutectic.	10.00	Phosphide eutectic (approx.).
0.32	Manganese sulphide.	0.64	Manganese sulphide.
29.16	Free silico ferrite.	25.01	Free silico ferrite.

These figures are obtained by assuming the undermentioned specific gravities.

SPECIFIC GRAVITIES.

Specific gravity of final iron	7.15
,, ,, graphite	2.20
,, ,, pearlite	7.8
,, ,, manganese sulphide ...	3.55
,, ,, phosphide eutectic—assumed to be a little less than cast iron.	

Increasing the silicon content would have a similar effect; in fact, any slight change in ultimate composition produces a corresponding, but very much greater, change in structural composition.

Structure and Physical Properties.

The physical properties of cast iron depend entirely on the structural composition and arrangement, so that any change in structural composition is followed by a change of physical properties. As set forth previously, structural composition depends upon chemical composition, but, in addition, it is also influenced by thermal conditions, so that it is possible to have a difference of structural composition, and therefore of physical properties, in two similar castings poured from the same ladle, but possibly at different temperatures and cooled at different rates. It is even possible to have differences of structural composition in a single casting, of which a cast-iron propeller is the classical example. In one such propeller which the author has examined the total carbon was practically the same at the tip and boss, namely, 3.76 per cent. The tip, however, had 0.62 per cent. of this in the combined form, but at the boss practically the whole amount existed as free graphite.

Cast iron may be considered as a very impure steel of a carbon content equal to the combined carbon content of the iron, but that the continuity of the matrix is broken up in all directions by little cracks filled with powdery graphite. The strength of the iron, therefore, is primarily dependent upon the amount of graphite present, and secondly, on the strength of the matrix, which in turn is dependent principally upon the amount of combined carbon present.

Consideration of the Graphite.

Assuming equal amounts of graphite in two irons, the one which has it in the finest possible form will be stronger than one where the graphite occurs in large flakes. This fact is self-evident and needs no elaboration. (See Fig. 3.)

Another factor is the arrangement of the graphite flakes. Some irons have the graphite arranged in very definite "groups," and here again it is evident that this formation, irrespective of size of flake, will make for strength. This arrangement is associated with the phosphide "network" previously mentioned.

Coarse graphite, apart from being a source of weakness, is the cause of " porosity " or " weeping " of castings on water test. The graphite flakes act as channels along which liquid or gas can penetrate.

The liability of such castings as internal combustion engine cylinders and liners, etc., to " grow," is to a great extent determined by the graphite for this reason. Fig. 11 illustrates a piece of cast iron which has been in contact with corrosive mine water. The action of the graphite in providing channels along which the corrosive fluid, or oxidising gas can travel, and eventually disintegrate the whole material, is clearly shown.

A point touched upon earlier was that two irons with identical amounts of graphite by weight might have different amounts of graphite by volume. As the volume is the major concern, this would be equivalent to the iron containing more graphite, and being, in consequence, weaker. It is not possible at the moment to produce any direct proof of this, although the author has tried in many ways to find a method for the accurate determination of the amount of graphite present by volume. From observation, practically all irons appear to have more graphite by volume than the amount calculated from the specific gravities of graphite and cast iron. For instance, assuming 3.0 per cent. of graphite by weight represents approximately 10 per cent. by volume, then what may be termed " synthetic graphite structures " have been prepared, representing exactly 10 per cent. It will be obvious from a comparison of Figs. 12 and 13 (which both contain 10 per cent.) that the apparent amount present depends to some extent upon the state of division—the finer the state of division, the larger the apparent amount. However, taking the more finely divided specimen and comparing it with an actual cast iron containing 3.0 per cent. graphite by weight (Fig. 14), it will be seen that the iron appears to have much more than 10 per cent. by volume.

This is partly accounted for by the fact that it is impossible to prevent the edges of the graphite flakes being slightly worn away and rounded off during the polishing; so that the graphite of any iron must appear under the microscope to be a little worse than it really is. Even so, the apparent increase of graphite due to polishing should be comparable in all specimens, and would not account for two irons of similar percentages of graphite by weight showing apparently different amounts by volume. It is certainly a point which requires further investigation, as it is of very practical importance, having some bearing on so-called " inherent qualities."

FIG. 11.—ILLUSTRATES THE PENETRATION OF CORROSION BY MEANS OF THE GRAPHITE FLAKES.

Considering again the combined carbon, it can be fairly safely accepted that other things being equal, an increase of combined carbon up to approximately 0.8 per cent. (with corresponding decrease in graphite) will give a stronger matrix; hence the great amount of publicity during the last year or so, concerning " Pearlitic Cast Iron." Pearlitic cast iron is simply iron where the whole of the matrix or ground mass consists of pearlite.

Pearlitic cast iron is no one's secret or patent, although the methods to ensure its automatic production may be. The phosphide eutectic is hard and brittle, so that both the tensile and transverse strength will decrease as the amount of phosphide increases.

It follows from the foregoing that the strongest irons are those which contain a minimum amount of graphite in the most finely divided form and preferably "grouped"; and having in addition, a completely pearlitic matrix with only a small amount of phosphide eutectic present.

FIG. 12.—GRAPHITE STRUCTURE OCCUPYING 10 PER CENT. OF THE VOLUME.

Composition and "Inherent Qualities."

Cast iron is a very complex material, and its study has been almost neglected until quite recent years, so that even now there is much to learn concerning it. Despite this, however, cast iron is governed by ordinary laws, and possesses no supernatural qualities. It has been the custom in the past for some foundries to rely on certain stereotyped mixtures or brands of iron. These possibly were found by experience to suit the particular class of casting made. Either because of excessive credulance, or very probably through fear of the consequences, any change from the mixture was to be avoided. In this connection, blind belief in the superior qualities of certain irons has undoubtedly been deliberately fostered by iron producers and agents for purely commercial purposes. Possibly in the case of the stereotyped mixture, where efforts were made to try and improve or cheapen it, and the experiments failed, these failures would be put down to inferior qualities of the new irons used; whilst in reality it would be nothing more or less than unsuitable chemical composition. This is possibly one of the ways in which the "inherent quality" theory originated.

Another and more modern school adhere to the belief that certain irons have inherent qualities which influence the graphite, so that a large coarsely graphitic iron, even on remelting, will cause the resulting mixture also to have coarse graphite, even going so far as to say that large coarse graphite persists through the cupola.

The whole crux of the situation can be summed up in the following:—If a foundryman takes any mixture of irons, melts and casts it, then any other mixture of irons melted and cast under identical conditions, and with exactly the same composition, will have identical physical properties. The difficulties in the way of doing this, however, are enormous; in fact, it is almost impossible in the scientific sense. It is difficult enough to analyse and control the four elements, silicon, phosphorus, sulphur and managanese; but when in addition the control of the amount of total carbon and its formation into certain amounts of graphite and combined carbon is sought, then the difficulties increase greatly. Assuming that it was possible accurately to control the melting, pouring temperature, and rate of cooling, and that one finished with two irons of identical amounts of combined carbon, graphitic carbon, silicon, phosphorus, sulphur and manganese, then these two irons would have exactly similar physical properties. If they were not absolutely identical, then one would have to look further. There is no accurate method of estimating dissolved iron-oxide in cast iron, nor, indeed, is it absolutely certain that iron-oxide can actually be present in cast iron. It is not known whether or not nitrogen is absorbed during manufacture and subsequent melting; or if so, in what form it exists, and what its influence is. Then what is the effect of occluded gases such as hydrogen, carbon monoxide, carbon dioxide, sulphur dioxide, etc.? Again, the estimation of small amounts of arsenic, copper, nickel, chromium, tungsten, titanium, vanadium, etc., is very tedious and difficult, yet these things must have an influence. It will be appreciated how difficult a thing it is to produce two irons, in the scientific sense, exactly alike. Yet people constantly assert, and apparently believe, that by running the same mixture through the cupola months on end, iron

Fig. 13.—Graphite occupying 10 per cent. of the Volume (compare Fig. 12).

of identical and consistent quality will be produced.

Practical Considerations.

If every foundry were able to control the exact composition of the iron in use, foundrymen would very quickly have an end of the "inherent quality" theory. Like sulphur, it is a good excuse for something which is not understood. The more perfect the control, the more consistent in every respect will the final product be.

Having entered into the theoretical side of the structural composition of cast iron a few of the practical considerations for the production of high-quality iron will be considered in conclusion.

Remembering the statement made earlier, that strong iron will have a minimum amount of graphite in a finely divided state in a pearlitic matrix, and containing only a small amount of phosphide—how is this to be achieved? Obviously the first step towards a low graphitic carbon is a low total carbon. This simple, fundamental fact is practically the whole secret of strong iron, yet its production in the cupola is one of the most difficult problems to be solved. It is almost useless buying high-priced, low total-carbon pig-irons, and by melting in an ordinary way, expect to get low total-carbon castings. The extent to which low total-carbon iron picks up carbon in the cupola can be gauged from the fact that if charges of steel and ferro-silicon alone are put through, the resulting iron will show almost 3 per cent. total carbon. It is seldom possible in ordinary working, to get below about 3.2 per cent. total carbon in the cupola. The problem is one which the author has not yet solved to his own satisfaction, and it is hoped to have the experiences and opinions of others on this very important point.

The silicon content should be regulated according to the section of the casting. The following figures can be taken as a very rough guide :—

½-in.	section	...	2 per cent. silicon.
1 in.	,,	...	1.7 per cent. silicon.
1½ in.	,,	...	1.5 per cent. silicon.
2 in.	,,	...	1.3 per cent. silicon.

The amount of phosphorus permissible will depend upon a compromise between strength and fluidity. For strong iron, at the most, no more than 0.5 per cent. phosphorus should be present, and no more than 1 per cent. should be present in any casting.

The actual amount of sulphur is not very important, and if round about 0.10 to 0.12 per cent. will be satisfactory, providing about 0.7 to 0.8 per cent. manganese is present.

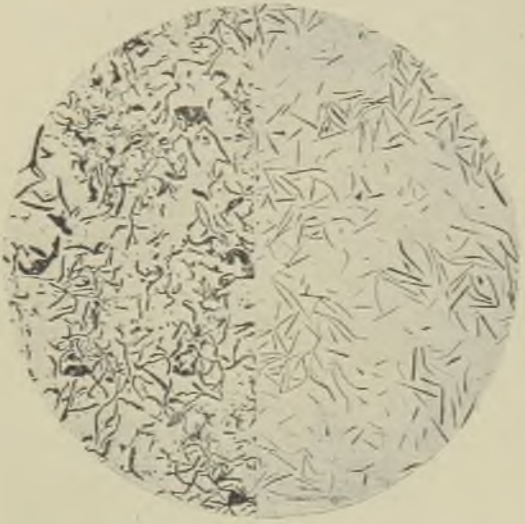


FIG. 14.—THE LEFT MICRO APPARENTLY CONTAINS MUCH MORE THAN 10 PER CENT. GRAPHITE.

Hot, rapid melting is considered to be essential, as also is a high casting temperature. Careful skimming of the ladle before casting is a point which should not be neglected. Dusting the clean surface of the molten iron with fine parting sand after skimming, is a little refinement which has been found to be worth the trouble. The effect of this is to form a crust which effectually holds the small globules of slag and manganese sulphide which continually keep rising to the top. The use of pouring basins with accurately fitting plugs is a further refinement which pays.

Control of composition is not easy. It is only possible by means of much systematic routine analysis; but it will have to come, for the advance of the Diesel engine, and the tendency to cut down section and weight, will make it imperative if the foundries of this country are to hold their own. It is not claimed that by its adoption troubles will instantaneously vanish for ever, and that 20-ton testbars will be the order of the day; but its use will certainly shed a light where previously darkness held sway.

Scottish Branch.

THE CONVEYANCE OF MATERIAL IN THE FOUNDRY.

(With Special Reference to the Production of Light Castings.)

By J. M. Primrose (Member).

When one considers the amount of material handled in the average foundry daily, it is surprising to find that so little attention has been paid to the question of the conveyance of material. The wheelbarrow has been superseded in some foundries, but in others it is still the main or the only means of conveying all materials. The necessity for substituting some other system for the mechanical handling of materials is therefore important if foundrymen are to reach the efficiency demanded by the engineers and get to a point to please them. In a light castings foundry, melting 30 tons per day, the material handled is, in round figures, 255 tons, made up of 5 tons coke, 30 tons pig-iron and scrap, 10 tons new milled facing sand, 30 tons molten metal, about 10 tons gates and runners, 20 tons castings, and allowing 1 ton of sand per moulder, which is understated, say, 75 tons sand handled twice, the total stated is reached. Eliminate some of the time employed in handling part of this bulk, and a rise in the output of castings will soon be observed.

The work performed by the unskilled men in the shop (if there is such a person as an unskilled man) amounts to roughly 105 tons, comprising coke, pig-iron and scrap, milled sand, molten metal, gates, and castings, and it should not be difficult to invent some system which will at least reduce the non-productive labour.

Demands of Various Sections.

Commencing with the cupola, pig-iron and coke are mainly man-handled, first from the truck, then to barrows on to the platform and charged to the cupola. All the men work hard, and it is difficult to see therefore where this can be reduced. One method is to have a sufficient number of trucks to enable two men to fill them up in the morning and leave them free to charge the furnace, thus setting free during the casting period two men, who can be better employed at that busy time inside the shop. Another method is that of the self-charger worked by one operator with a magnet and drop-bottom boxes for the coke. But the idea which appeals most to the author for a foundry of the size mentioned is a mono-rail running round the yard and having carriages fitted with scales for weighing. For speed and utility this method will outstrip most other systems. The rail could be run over the wagons and be used for unloading. If scrap is used, it will enable the ironfounder to buy unbroken scrap, which can be broken in the yard, as it ought not to be difficult to design an elevated part of the system to allow of ball and monkey to be brought into operation and the scrap broken up more cheaply than at present. Each foundry, however, has its own particular problem, and therefore no two systems can be altogether alike, but this Paper will have served its purpose if it shows the necessity for introducing labour-saving devices.

Sand Handling.

To deal with milled sand is a one-man job, and the only thing possible is to remove hard work, so that a moulder unfit for heavy work owing to age or other cause can be employed, if all the weight is put on the runway. The employment of boys is not advocated, as blind-alley occupations are undesirable.

Transport Facilities.

At present molten metal is conveyed throughout the shops in bogies which take two and sometimes three men to pull. Here a mono-rail can ease the burden and enable one man to take the metal to any part with twice the speed, less danger, and no hard work. A boy of 14 has been known to convey a ladle containing 10 cwts. of metal a distance of 170 yards in less than two minutes. Gates, runners, and castings can be dealt with as one operation, and, of course, the first two go back to the foundry and the last to the dressing shop. Labourers are often seen staggering with barrows loaded up with gates if the barrow contained 3 cwts. A mono-rail truck would take a ton and cover the ground in a quarter of the time, whilst the man would be as fresh as when he started to push it. This also applies to castings, and no road barrow or truck can improve upon it, whether hand or mechanically propelled. The necessity can be summarised thus—reduce carrying, eliminate delay, remove all strenuous operations by substituting mechanical for manual labour.

Economies Effected.

The first economy is increased production. Ease and rapidity of handling material enables moulders to devote more time to actual production, as the system removes and places material where it is required with a minimum of labour, and allows the skilled man to expend his energy in the most economical way. The removal of moulding boxes to and from the shop floor to the yard is carried out so easily that it is not necessary to hamper moulders with boxes not required, owing to the lack of labour, while the ladles in use can be reduced from 30 to 50 per cent.

Cost of Installation.

With reference to labour costs, it is not the purpose of this Paper to give facts and figures regarding any particular shop. This item really belongs to the management, but if one man is eliminated at 40s. per week, that would allow of an installation costing £1,000, taking money at 5 per cent. and allowing 5 per cent. for depreciation per annum. It is therefore not difficult for anyone to work out a system to suit his own shop, and calculate roughly the cost of installation. A shop equipped with labour-saving devices for conveying materials can command the best class of labour—if moulders, they are able to earn a better wage with less fatigue because of facilities in the shop—and if labourers, better working conditions owing to the elimination of heavy lifts, enable them to work to the best advantage. The facility with which all waste material may be removed gives a cleaner shop and floors, thereby assisting foremen to reduce waste to a minimum.

Important Considerations.

In any mono-rail system it is imperative to avoid junctions and points. As far as possible, design the system in circles joined up by junctions in as few places as possible, without, of course, injuring the continuity. It is advisable not to run mono-rails over the centre of bays worked by travelling cranes, but where this must be done, a movable bridge should be used, so that the efficiency of the crane is unimpaired. Crank mono-rails should be run wherever possible over moulders' places to prevent heavy lifts and to enable casting to be done by overhead rail with the hand ladle. The system should be arranged in such a way that the rails are free when casting commences and kept for the metal trolleys only until the cupola is dropped.

Each shop has its own problems and hence must adopt its own system, but whether a single rail or H-beam mono-rail is used, one thing is certain —present-day methods in this country must disappear if British foundries are to keep abreast of other countries in the race for the world's trade, and the key industry of all engineering must not lag behind.

DISCUSSION.

Mr. Affleck, Branch-President, in opening the discussion, referred in complimentary terms to the Paper read by Mr. Primrose. With regard to the subject of the Paper, he said, that in the foundries of a great many automobile manufacturers in America the system of the moving platform was being adopted. While in light-castings work the mono-rail was very good, for a mixed class of work, he thought, the moving platform would be better. It seemed to him that there were some cores that the only safe way to carry was on a hand-barrow. One system he had seen at work was what was called in the States the "mule." That was an engine and chassis. The apparatus was about 6 or 8 ft. long. It could be attached to bogies, and took the place of a horse, but there was power and speed behind it. This "mule" was used for taking coke into the foundry, taking castings into the dressing shop, etc. One thing about overhead transport that struck him was that it was best to keep it away from the men working on the floor. It was a disturbing thing to those engaged in fine work. Mr. Primrose referred to the effect of good transport on labour, and he (Mr. Affleck) agreed with him. He believed that if they could eliminate donkey work they would improve the class of workmen employed in the foundries very materially.

Mr. Gardiner said the handling of material in the foundry was the be all and end all of the management. Where wages could be eliminated the cost became cheaper and commodities could be sold cheaper. That meant more demand and more employment. Personally he was more in favour of a jib crane, because with it one could pick up anything from any point in the yard and deposit it at the place where it was wanted. He had had considerable experience, and he found that a jib crane worked very well.

Mr. Laurie said he had also come to the conclusion that he was very well served with a jib crane. When they had to work two or three different brands of iron, which were usually distributed over the yard, these had to be collected. Referring to his own works, he said that even if he had an expensive installation he did not see how he could work with fewer hands than he had. He therefore considered that he would not be justified in undertaking the expense. The case of light work, of course, was different.

Mr. Arnott said he would like it if Mr. Primrose had said more about the magnetic lifter, because that seemed to him to be a very economical method of handling pig-iron. It was not simply the transport of material from the yard to the foundry that counted. In putting down a new foundry for one class of work, it was easy to lay out an ambitious system, but it was a different matter in a foundry already established.

Mr. A. Campion, F.I.C., pointed out that Mr. Primrose had confined his remarks to appliances suitable for light castings only. That must be borne in mind. Certainly the system he had described did very well for that class of work. The mono-rail no doubt saved a great deal of time and labour. The easier they could make it for the men the better was the work turned out. It was a waste of skilled men's time to employ it in shifting barrows.

THE AUTHOR'S REPLY.

Mr. Primrose briefly replied to the various points raised in the course of the discussion. It was quite an easy matter, he said, if one had a mono-rail running round the yard, to take up material and convey it just as they wanted it. He was quite certain that the system he had mentioned for handling coke was definitely ideal. There was one foundry, not far away, that was putting in the American system, and they would be able to keep their furnaces going with two men. If they carried out their plans successfully, he thought the mono-rail system would have been proved to be right. They could depend on it that the Americans were not spending money needlessly.

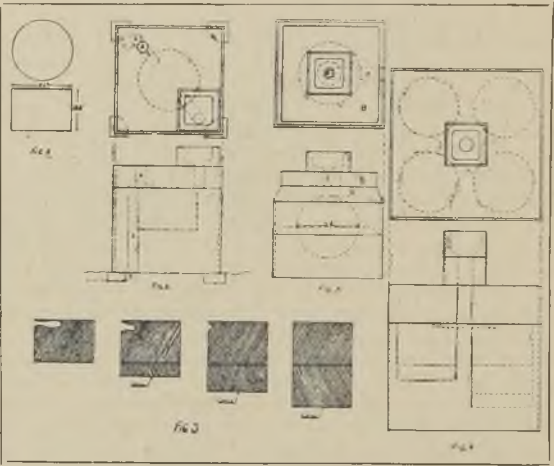
Scottish Branch
(FALKIRK SECTION)

SOME CONSIDERATIONS ON LIQUID SHRINKAGE IN GREY IRON.

By John Longden (Associate Member).

The questions arising out of the phenomenon of liquid shrinkage in cupola melted grey iron are of first importance to foundrymen. Only those in the industry have any comprehension of the extreme difficulty of producing a casting, of complicated design, which shall be sound in every particular. A great deal of this difficulty is directly due to the tendency of cast iron to shrink in volume, whilst passing from the liquid to the solid state. With the difficulties which may arise, consequent on the contraction in volume which continues after solidification is complete, the writer is not presently concerned.

This subject has been investigated by several eminent metallurgists, but it cannot be said that they have yet reached quite definite conclusions upon it. Mallet,[1] in 1874, was of the opinion that cast iron did not expand on solidification. After a number of experiments, he concluded that the alleged fact of expansion on freezing was illusory. In 1882, Roberts-Austen and Wrightson,[2] using the "tektometer," carried out a series of experiments, and concluded that cast iron, in passing from the solid to the liquid, increased in volume by 1.02 per cent. Hatfield,[3] however, is of opinion "that their work cannot be considered quite conclusive." In 1906, Professor Turner, using the "extensometer," proved that grey irons do expand on solidification. Other writers have demonstrated, arithmetically, that liquid iron is heavier, per unit of volume, than is iron which has just solidified; in other words, that grey iron expands on passing from the liquid to the solid. C. Benedicks, D. W. Berlin and G. Phragmen[4] have recently developed an apparatus for the determination of specific gravities of metals of high melting points; and, in respect of a soft iron, have reached results which are said to confirm those obtained by Roberts-Austen and Wrightson. Finally, Smalley,[5] who has carried out an extensive series of experiments in this connection, concludes that "cupola-melted grey cast iron, of normal chemical composition, does not shrink on solidification, if poured with a sufficient degree of superheat, and if cooled faster than a certain critical rate."



Experimental Data.

Does grey iron shrink on solidification? If so, by how much, and in what circumstances? To find an answer to these questions the writer carried out the following experiments. The methods adopted were of a practical character, though it is to be feared they would not be commended by the careful laboratory worker. Further, the writer regrets that he had not available at the time a suitable pyrometer. Nevertheless, the writer is convinced that the broad results prove the conclusions reached.

If the liquid shrinkage of a given volume of metal is to be ascertained by any method which is capable of use in the foundry, it is necessary to eliminate head metal which always feeds the casting below it in some degree. If iron be cast into an open mould, it is difficult to measure its volume, even approximately, before solidification. To overcome this difficulty a cylindrical solid body, as shown in Fig. 1, was moulded in green sand, as shown in Fig. 2. As will be seen from the sketch, as soon as the mould was full the excess metal at

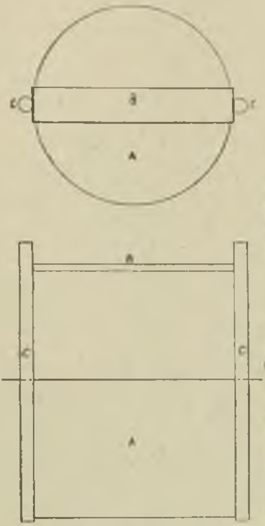


Fig 6

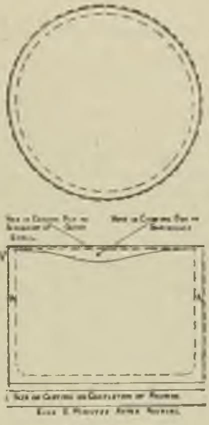


Fig 7

once drained away through the channel A. The hole through the top part at B was placed there to ensure that there should be no possibility of metal syphoning out of the mould, which was therefore left just full of metal, the mould having been made truly level. This was poured with metal having silicon 2.52 per cent. and total carbon 3.84 per cent. Out of the same shank of metal another mould (which had been made in the ordinary way with a 2-in dia. riser in the centre of the top of the mould) was cast and fed up solid with a rod. The two castings, when cool, were carefully cleaned, whilst the riser of the one was ground away exactly level with the face of the casting. The external dimensions of the two castings, as ascertained by calipers, were equal, except in depth, the one cast without head having sunk fairly evenly, as shown in Fig. 11. There is no room for doubt that the volume of the metal in this mould, whilst wholly liquid, was equal to that in the one which was fed, excluding, of course, metal in the runner and riser of the fed casting. The irregularities of the sunken surface of the former prevented anything but a rough estimation by measurement of the volume change.

Volume Difference as Shown by Weight.

A simpler method presented itself which could be depended upon to give relatively greater accuracy, *i.e.*, weighing, which would also take account of internal draws. The weight of the solidly fed casting was found to be 23 lbs. 10 ozs., whilst that of the shrunken casting was 22 lbs. 9 ozs. Taking equal weights of metal of the same composition as representing equal volumes, the difference in volume is 4.49 per cent.

This experiment was repeated with hot metal having silicon 2.42 per cent. and total carbon 3.92 per cent., with very similar results. The fed casting weighed 23 lbs. 11 ozs., whilst the casting without head weighed 22 lbs. 9½ ozs., the difference in volume thus registered being 4.62 per cent. The pipe in the run-off casting is indicated at Fig. 12. In every case in these and the succeeding experiments the sand used was of an open character, with a moisture content of from 6 to 7 per cent., rammed tightly, but not too hard, and well vented. There can be no question of blow holes in the casting.

With regard to these experiments, it may be said there is no assurance, in the circumstances, that the run-off moulds were really full of metal. In reply it may be pointed out that, when the castings were taken out the top sharp outer edge was to be seen all round (see No. 2, Fig. 20), proving that the metal had filled all the space. In each case in casting some 10 lbs. of metal were run through the mould. It may further be objected that the author's method of measuring liquid shrinkage is unsatisfactory, in that it is

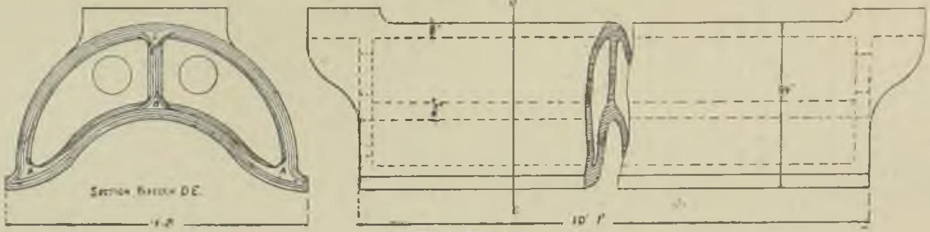


FIG. 8.

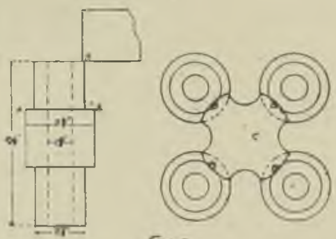


FIG 9

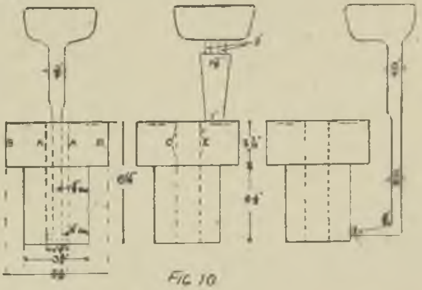


FIG 10

sought to measure it by the weighing of two castings at normal temperature. It seems clear, however, that once the stage of complete solidification has been passed, the two castings follow each other down the cooling curve, the conditions being fairly constant in each case. The slight difference in mass might be expected to promote some little difference in the condition of the carbon, but such difference is negligible. As a check upon the relative accuracy of this method. two moulds were made in the same way—one to run off level and one to be fed up solid. These were cast with commercially pure (98 per cent.) aluminium at 700 deg. C. When cleaned up, the fed casting weighed 8 lbs. 1 oz. and the run-off casting 7 lbs. 9 ozs., showing a difference of 6.2 per cent. Mr. Hikozô Endo[6] has ascertained the liquid shrinkage of several of the lower melting point metals by means of the "thermobalance." In the case of aluminium, he ascertained the volume reduction during solidification as a mean of three estimations to be 6.26 per cent.

Experiments with Spherical Castings.

With a view to ascertaining whether a differently shaped casting would give a different result, a sphere 5¾ in. dia. was moulded in dry sand, as shown in Fig. 3. As will be seen in the sketch, the mould was designed with a flow-off at A, level with the top of the sphere, so that the mould would fill just full and no more. The mould was well dried and cast with hot metal having silicon 2.36 and total carbon 3.92 per cent. The casting was found to have sunk flatly at the top to a depth of ⅝ in., as indicated at Fig. 13. Its weight was 24 lbs. 2½ ozs. Another drysand mould from the same pattern was cast from the same shank of metal, but this was fed solid through a riser on the top. The weight of this casting, when cleaned up, was found to be 24 lbs. 12 ozs. The volume ratio of these castings (as measured by weight) differed markedly from the blocks cast in green sand, the run-off casting being only 2.41 per cent. less in volume than the fed casting. The reason for this difference is important, and will be dealt with later. Four moulds of the cylindrical block were again made in green sand, three to be run-off level and one having a large riser for feeding. The four moulds were poured out of one shank of a denser metal having silicon 1.55 and total carbon 3.41 per cent. in the following way. The metal was caught at the furnace spout, and the first mould made to run off level was cast. The mould made to be fed up solid was then cast and the shank laid down. After a lapse of 2½ minutes from the time when the first was cast the second mould made to run-off level was cast. After a further 2½ minutes the metal in the shank was becoming distinctly dull, and the third run-off mould was cast. When the fed casting was weighed it was found to be 24lbs. 3 ozs., whilst the three run-off castings, in the order of casting, weighed 23 lbs. 2 ozs., 23 lbs. 1 oz. and 23 lbs. 2 ozs. respectively. The pipes in the tops of these castings are shown in Figs. 17, 18 and 19 respectively. A photograph of the two halves of the casting indicated at Fig. 17 is shown at No. 2, Fig. 20. The differences in volume, as against the solid casting, were 4.39, 4.65 and 4.39 per cent. respectively. It is of moment to note that there is no very marked difference among the three castings as regards tendency to shrink, in spite of the fact that they were cast at widely different temperatures. Another mould, made in the same way, was cast in a metal having silicon 1.45 and total carbon 2.85 per cent. This metal was crucible melted and cast rather dull. The casting weighed 23 lbs. 1 oz. and piped at the top, as shown in Fig. 16.

Rapidly Cooled Castings.

With a view to ascertaining whether a quickly cooled casting would show any difference from the preceding results, the following steps were first taken to find the depth of chill which, given sufficient head of metal, would give freedom from shrinkage cavities.

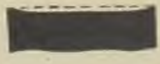
Four moulds of the cylindrical block were made in one moulding box, with heavy cut runners connected with a heavy central down gate, as shown in Fig. 4. Below one casting was put no chill; under the second was put a chill having one-third the depth of the mould: under the third a chill two-thirds the depth of the mould; and, under the fourth, a chill equal to the depth of the mould. When the castings were taken out, the casting with full depth chill was found to be quite solid, the sawn section being shown at No. 3, Fig. 20. The other castings were found to have drawn as shown in Fig. 5.

Thus having found the weight of chill necessary to ensure soundness, if cast in the ordinary way, but with large runners, and a good head of metal, a mould was then made as shown in Fig. 2, with the full depth chill placed below it, and provision being made for all metal to flow off which was not necessary to fill the mould properly. The mould was cast with hot metal having silicon 1.92, and total carbon 3.80 per cent. About 10 lbs. of metal was run through the flow-off. When stripped, the casting was found to have sunk heavily, as shown at Fig. 14; its weight being 22 lbs. 6½ ozs. To try out this again, two moulds were made in the same box. A chill as deep as the pattern was placed underneath each. A separate down-gate was placed to each, but arranged so as to come into the same runner basin; one having provision for 8-in. head of metal, with 1¼-in. down runner and a 3 in. by ½ in. cut runner at the joint. The other was made to drain away all metal above the level of the joint. The result was a solid casting in the first case, whilst the second was sunk to an average depth of $\frac{3}{16}$ in. The metal used was of a similar composition to the last.

Influence of Slow Pouring.

A further experiment was carried out in connection with slow running. A mould was made as in Fig. 2, except that the metal entered the mould through a ¼-in. diameter runner, near the bottom of the casting; the mould to fill only to the joint. The mould was cast with hot metal having silicon 2.19 and T.C. 3.65 per cent. Some 12 lbs. of metal were run through the flow-off. The casting, when stripped, showed a sunken top as shown at Fig. 15, and weighed 22 lbs. 6 ozs. No fed castings were weighed against this and the chilled casting, but it is notable that both are lighter than those in the first experiments, though the metal used was denser.

In respect of all the above experiments, the only analyses taken were of silicon and total carbon, In previous determinations of similar mixtures, however, the other elements have been found to range within the following limits: Phosphorus, 0.60 to 0.70; manganese, 0.42 to 0.60; and sulphur, 0.08 to 0.11 per cent.



Weight of fed casting, 23 lbs. 10 ozs. C.C., 0.21; G.C., 3.63; Si., 2.52.

FIG. 11.

Weight of fed casting, 23 lbs. 11 ozs. C.C., 0.22; G.C., 3.70; Si., 2.46.

FIG. 12.

C.C., 0.29; G.C., 3.63; Si., 2.36.

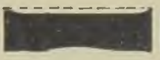
FIG. 13.

Effect of Liquid Shrinkage.

In regard to the results obtained above, is it certain that the whole of the difference in volume, as between the fed castings and the others, is attributable to liquid shrinkage? Professor Turner[7] has shown that grey iron expands immediately after solidification. This is shown to be due to the breaking down of iron carbide into the bulkier condition of free iron and graphite. In all probability no carbon is freed (in an iron not supersaturated) before the main solidification is complete (locally) before which primary crystallisation is complete. As it is in crystallisation that the change of volume is most seriously effected, the mischief is then already done. Granting, however, that the separation of graphite expands the metal, how far can it be shown to neutralise the already accomplished shrinkage? At this stage

Heavy chill beneath casting. C.C., 0.35; G.C., 3.45; Si., 1.92.

FIG. 14.



Pencil Runner. C.C., 0.26; G.C., 3.34; Si., 2.19.

FIG. 15.

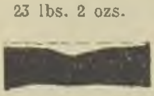
C.C., 0.40; G.C., 2.45; Si., 1.46.

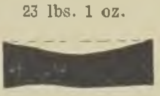
FIG. 16.

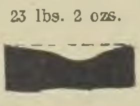
may be considered the "box effect" favoured by the late Mr. Buchanan,[8] and, to some extent, endorsed by Professor Turner.[9] If a cube be cast, a thin film of solidified metal at once forms on the walls of the mould. As the metal cools, this film grows thicker, building up from the walls inwards. Assuming insufficient resistance from the mould, the solidified walls will expand, each in the direction of its length, as well as in other directions; so that the cube is, whilst solidification is proceeding, actually bigger than the original mould, and thus, unless new metal enters, a cavity is accounted for. To try out this idea, within the limits of the means of the writer, a mould of the cylindrical block was made, in green sand, as shown in Fig. 2. In addition, two steel rods, ⅜-in. dia., were rammed up at two opposite sides of the pattern, as shown at C, Fig. 6. The rods stood up through the top part of the mould, holes 1 in. in diameter being left for that purpose, the holes being covered at the joint by pieces of tin which had been drilled for the rods to pass through. Above the top of the box a bar, B, was placed, the length of which was exactly the distance between the rods CC. The mould was cast with hot metal having silicon 1.59 and total carbon 3.65 per cent. Two minutes after casting it was ascertained, by means of feelers inserted between the rods CC and the bar B, that the casting shell had expanded 0.034 in., and at the end of 2½ minutes from the time of casting the expansion had increased to 0.054 in. No further expansion was discernible.

At the moment when the block had expanded across its diameter 0.054 in., the circumference would correspondingly be increased by 0.17 in. The cubical contents of the block would thereby be increased by 1.817 cub. in. If, as seems very probable, the linear expansion of the sides took place in a vertical direction also at the same rate, the increase in depth of the casting would be 0.038 in., making a further increase in the capacity of the block of 0.92 cub. in. The total increase of volume at the moment when the maximum expansion was reached would be, therefore, 2.737 cub. in., or 0.714 lbs. If this result be subtracted from the difference between the casting referred to in Fig. 17 (which was cast in a metal of similar composition) and the fed casting, there is left a residual shrinkage percentage of 1.44 per cent., which would remain if the whole of the expansion had been directed inwards to the heart of the casting.

This was tried out again, but with a drysand mould of the cylindrical block. Hot metal having silicon 2.45 and total carbon 3.90 per cent. was poured into it; and an expansion of 0.021 in. was registered at the end of 3 minutes, after which no further expansion took place. If this expansion and a vertical expansion of the same linear ratio be taken as in the last case, it would increase the capacity of the block, at the moment of maximum expansion, by 0.707 cub. in. or 0.163 lb. Following this, two moulds were made in drysand from the same pattern, one to run-off level with the top of the mould, as in Fig. 2, the other to be fed solid. Metal having silicon 2.51 and total carbon 3.89 per cent. was poured, hot, into them. When cleaned and weighed, the fed casting weighed 23 lbs. 1 oz., whilst the run-off casting weighed 22 lbs. 8½ ozs.—a difference of 2.3 per cent., which agrees very well with that reached in connection with the spheres cast in drysand. If from this difference be taken the value of the increased volume of the castings at the moment of maximum expansion—in terms of weight, 2.29 ozs.—the difference is reduced to 1.595 per cent. The latter is net shrinkage which would remain if the whole of the expansion had been directed inwards. An attempt to show pictorially the factors which go to produce the pipes in the run-off castings is shown at Fig. 7. Shell expansion would cause an immediate void, which would







Weight of fed casting: 24 lbs. 3 ozs.

C.C., 0.33; G.C., 3.08; Si., 1.55.

Fig. 17. Fig. 18. Fig. 19.

be followed by a further void due to the progressive failure of the expansion to compensate fully for the loss of volume due to liquid shrinkage.

Origin of Pipes.

In further consideration of this part of the question, it may be said that, if cast iron did not shrink in volume on leaving the liquid state, the outer shell would solidify first and duly expand. Successive layers of the metal would solidify and expand in turn until the whole was solid. If the expansion of each layer took place in the same ratio as the preceding one, the result must be a solid casting without any shrinkage cavities; but one which, soon after casting, had become temporarily larger than the mould. In Figs. 21 to 27 are shown microphotographs* taken from the areas blacked out at A, B and C, No. 2 of Fig. 20. Figs. 21, 22 and 23 respectively show, from the side to the centre, the relative disposition of primary graphite. Whilst the centre section shows less primary graphite than the outside section, and more secondary graphite, there is evidence that the post-solidification expansion had continued, though perhaps at a slightly diminishing rate, right to the centre of the casting. In

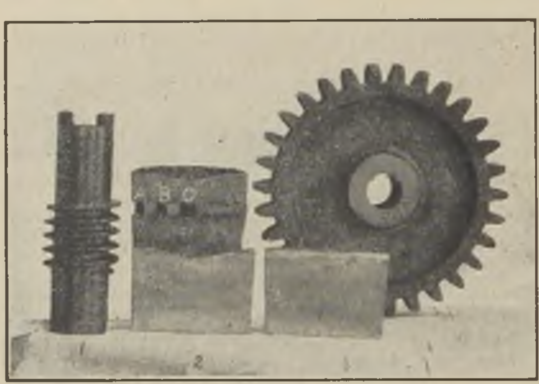


Fig. 20.

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* All the micros have been reduced 50 per cent. in reproduction.

spite of this, however, a large pipe is finally left in the casting. It would appear, therefore, that each layer of metal cooled and expanded, but such expansion was progressively insufficient to make up the loss of volume by shrinkage on crystallisation. It seems very likely that the pipes in the green-sand-cast blocks really represent the degree of shrinkage on crystallisation. A green-sand mould offers so little resistance to the post-solidification expansion that each shell would expand to its limit. This would be just as true of the solidly fed castings as of the ones which were run-off level with the top of the mould. It may further be said, without extravagance, that the ratio of expansion per unit of volume would be closely alike in both castings. In the case of the fed casting, the initial void due to shell expansion would at once be made good by metal fed down the riser. The progressive shrinking would also be made up. Consequently, the fed casting simply represents what the unfed casting would be but for liquid shrinkage. The true liquid shrinkage (preceding expansion) of these grey irons, therefore, is fairly represented by the differences

Fig. 21.—Unetched × 75 dias.—Edge.

between their respective weights, which differences are shown above to be from 4.39 to 4.65 per cent. Figs. 24 and 25, and Figs. 25 and 26, taken from areas A and C respectively (Fig. 20, No. 2), show that the irons used are quite of a normal character. A point of interest is the shrinkage cavity shown in the top right-hand corner of Fig. 23. The number of these cavities to be found in the centre of the casting indicate that the whole of the shrinkage is not in the pipe.

In all sand-made castings, therefore, the voids left are the combined resultants of two factors—shell expansion and net liquid shrinkage. In the green-sand moulds dealt with above, if the castings are to come out solid, round about 4.5 per cent. of new metal must be put into it whilst solidification is proceeding; and, in the drysand mould, round about 2.35 per cent. This result does not appear to be appreciably affected by temperature of metal at pouring, rate of cooling, speed of pouring, or composition—within the limits drawn by the above experiments.

How Expansion Factor Operates.

From what has been said, it is clearly brought out that grey iron of the composition dealt with, when cast into a mould, can only result in a sound casting if a sufficient supply of new metal is got into it whilst solidification is proceeding. Whilst, owing to the differently shaped sections of many castings, the expansion factor may work often wholly in the direction of aiding solidity, in other cases the factor may work to the detriment of solidity; but, in every case, not less than 1.5 per cent. of new metal must pass into the mould, whilst solidification is going on. This is equally true of parts of a mould which are chilled. The true function of a chill is therefore implicit in that name. The word "densener" may have a more pleasing sound, but the fact is that the function of a chill is so to hasten the solidification of the part concerned that new metal can flow to that part whilst a liquid channel of metal is open to it; otherwise the chill is ineffective, or it is effective in the degree in which that function has been carried out. This must also be true of the all-metal mould. The solidity obtained thereby is the resultant (1) of post-solidification expansion being directed inwards, and (2) of the fact that the casting cools rapidly, the net shrinkage being made up just as rapidly from the runner.

Shrinkage Factor Often Masked.

In workshop practice, however, the shrinkage factor is often hidden; indeed, it is in many ways compensated for, otherwise the production of sound castings of an important character in this metal would be very difficult. Nevertheless, it leaves its witness, as an examination of any old castings which have been broken up will show. When cast iron is poured into a mould, the metal flows from the basin down the runner gate, filling first the bottom portions of the mould, then gradually filling up to the top and passing through the risers. The metal which comes through a riser is always much cooler than that remaining in the runner head. Hence a riser seldom naturally feeds a casting. The runner, however, is always the hottest part of the casting, and serves to feed the solidifying casting for so long as any part of its (the runner's) cross section remains liquid to

FIG. 22.—UNETCHED × 75 DIAS.—NEXT TO EDGE.

the casting proper. Further, in any casting the region near the runner remains liquid longest (assuming equal metal sections throughout the casting). The whole of the metal in the mould having passed through that part of the mould nearest the runner, the walls of the mould in that region are considerably heated by the time the mould is full. The parts farthest from the runner solidify first, making up their loss of volume by shrinkage from the hotter portions nearer and nearer the runner, the latter, with its head of metal, serving as a reservoir for that purpose. In a casting of thin section this sequence takes place very rapidly. If, however, a fairly large casting having been poured, the runner head be closely watched for a minute or so after pouring has ceased, it will be seen that the level of metal in the head is falling. This may be observed more readily if a series of moulders' sprigs be pushed, prior to casting, into the side of the runner basin. Some one of them will then serve as a datum line from which to measure the fall of metal in the head. It should be remembered, however, that, in some cases, especially in green-sand work,

FIG. 23.—UNETCHED × 75 DIAS.—CENTRE.

solidification has taken place in some degree in parts of the mould before pouring has ceased, the shrinkage loss being at once made up. A compensating factor for liquid shrinkage is found in many important castings in the expansion of cores, which tend to swell immediately they are enclosed in the hot metal and pressing on the yielding metal. This is so pronounced in some cases that metal is squeezed up through the riser or runner. This, of course, can be prevented by pouring water on the head immediately pouring has ceased.

There are many important kinds of castings, however, which do not lend themselves to a complete natural feeding from the runner. Even though the designer has so far considered the foundry as to provide for equal cross-sections throughout the casting (which seldom happens; indeed, can seldom happen, for machining allowances increase the thickness of some sections as cast), the necessary joining together of wall with wall, each re-entrant angle calling for fillets, tend to leave pools of liquid iron cut off from any means of feeding. The remedies which lie to the hand of the foundryman are the judicious use of chills, and, where possible, the feeding rod or head. If there is a continuous channel from the heavy portion to the runner, which remains open to the last, freezing nearer and nearer to the runner, then it should feed solid naturally. If a frozen wall intervenes, then the remaining liquor must lose round about 1.5 per cent. of its volume in solidifying. This may mean an irregular cavity in the section, or it may show itself in a very open, porous structure, which leaks under light pressure.

Steam Chest and Liquid Shrinkage.

Consider the casting, a steam chest, shown in Fig. 8. The engineering trade needs many types of casting much more difficult than this; but it will afford room for serious consideration of the problem referred to above. From the whole of the surface of the bottom of the casting, as shown in the sketch, 3-16 in. is machined off and the face highly polished. The castings are tested by the water test at 250 lbs. per sq. in., followed by a steam test at 130 lbs. The places at A and B are where trouble sometimes shows itself. The skin at C is never broken, and no trouble is ever experienced. These are the spots, however, where the experienced foundryman would look for danger. When such a casting has been poured, solidification proceeds from all faces inwards to the centre of each section concerned, at a rate commensurate with the speed with which heat is abstracted from each such face. The isothermal lines, however, are not parallel to the faces concerned at every point, but are as shown in the cross-section shown in Fig. 8. Where heat is being conducted from two faces at a large angle, as at B and C, solidification has proceeded considerably on those faces before the metal at the fillet begins to solidify. Where the angle is acute, as at C, that tendency is much more pronounced. Consequently, at a certain stage in the cooling of this casting the areas represented by the unlined spaces at A, B and C are still liquid when the remainder of the casting has solidified. If at this stage there is a continuous channel still liquid to the hot runner, or any alternative head of metal, they should feed solid naturally. If, however, they become isolated by a frozen section intervening, then, whatever material the mould may be made of, the remaining liquor must lose round about 1.5 per cent. of its volume in solidifying. This may mean an irregular shaped cavity, or it may show itself in a very open, porous structure. This last view will be further considered in connection with the ideas which have become associated with the name of M. Ronceray. Before leaving this part of the subject, reference might be made to the view, which appears to be widely held by Continental foundrymen, and in less degree by some of our own foundrymen, which tends to discount the importance of liquid shrinkage in cases like the one detailed above, finding the explanation in the failure to vent the cores properly, cavities and porosity being assumed to be due to gas from the cores. It has always seemed to the writer that the advocates of this view should inform us what has become of the metal which presumably occupied the space afterwards occupied by the gas. Take, for instance, the corner of the core at A, Fig. 8. If there were any tardiness in getting the vent away from that part of the core, it would show itself at an early stage, as soon as cast. The bubbles would at once pass to a higher part of the mould, and, if they could not pass out of the casting, would later be found there. As each bubble left the point the space would immediately be re-occupied by fluid metal. This can be imagined as continuing until the metal above became too pasty to allow of the passage of more gas. At some stage of this process, however, the escaping gas at the point A would have to discharge itself into an area already fully occupied by metal, which, though liquid itself, was surrounded by frozen walls. What, then, becomes of the metal which was in the space which is said to have been occupied by gas? It seems to the writer that liquid shrinkage affords a truer explanation of the weaknesses found at such places. Whilst faulty venting of cores is the cause of a good deal of trouble in castings, it can be saddled with too much responsibility.

FIG. 24.—ETCHED × 75 DIAS.—EDGE.

No discussion of the problem of liquid shrinkage would be complete without consideration of the important contribution made to its solution which has been voiced by M. Ronceray. The principles which he has laid down are, in the writer's opinion, capable of very useful application, and the industry is his debtor. He has, however, said[10] that he would expect no casting to shrink on solidification if run with filter gates of a maximum cross-section of 3 ins. or less. Now, if molten iron which is cast into a 5¾ ins. dia. sphere, cast in drysand, shows a void of 2.4 per cent. of its volume, there seems no reason why a smaller section should not shrink in a similar ratio. The writer's view of the process of solidification has been given above. A few experiments with slow pouring will be detailed.

Fig. 25.—Etched × 700 dias.—Edge.

Feeding can be Eliminated in Small Castings.

Fig. 9 gives details of a worm gear blank, machine moulded and jointed at A. A photograph of the finished article is shown at No. 1, Fig. 20. These are cast four in a box. Many ways of running these castings were tried, but difficulty was experienced in getting them free from spongy places in the worm and inside the bore. To feed a day's work of these castings is more than a nuisance. There are not many men who will take the trouble to feed a lot of small castings conscientiously. Finally, the writer put on a disc runner, as shown at C, Fig. 9, each mould being filled with metal through a slit not more than $\frac{1}{8}$ in. at its widest, tapering away at each end to nothing over a distance of $\frac{3}{4}$ in., as shown at B. Many hundreds have been cast in that way without a single rejection from the machine shop. The principle involved is that advocated by M. Ronceray.

The pinion, with cast teeth, shown at No. 4, Fig. 20, was equally successful. These castings had hitherto been cast by means of a $\frac{3}{4}$-in. runner, placed on the boss (which is rather heavy), through which each casting was fed. In spite of this, however, many of them were found spongy on boring. A $\frac{3}{8}$-in. dia. runner was tried on the rim (the white spot on the rim of No. 4, Fig. 20) and the feeders were dispensed with. There was also no riser. There was no further trouble with this casting, and the laborious work of feeding was not necessary.

A Casting Requiring Feeding.

In the case of the gear blank, shown at Fig. 10, the results were unsatisfactory. If cast in the ordinary way, it is imperative that it should be fed. A spongy place very often is found at A, after boring, or B, when the teeth are cut. Slow pouring was tried. A small runner through the core, as shown, was tried, but a depression of varying depth was found in the top face, as shown in the sketch. A $\frac{5}{16}$-in. pencil runner on the top was tried, with the same result. A filter gate containing two $\frac{1}{4}$-in. dia. runners was tried, with a similar result. In addition, the metal had shrunk away from the core at C. A pencil runner was placed at the bottom of the casting, as shown in the sketch. The result was similar. In most of these cases, however (and they were tried several times each) the depression was fairly well distributed round the top, which depressions, not being deeper than a $\frac{3}{16}$-in. machining allowance, allowed the castings to clean up. They were found to be quite solid.

Reference was made earlier to the casting of the cylindrical block by slow pouring, run off level at the joint. It was shown to shrink not less than in other cases. A further experiment with the block was tried. A mould was made with no riser and a heavy down runner leading to the casting by a $\frac{1}{4}$-in. dia. runner. Head metal was provided to a height of 13 in. above the top of the mould. It was cast with hot metal. When the casting was taken out the middle of the top was depressed to a depth of $\frac{1}{8}$ in. An inch-diameter hole drilled through the centre revealed a large cavity.

FIG. 26.—ETCHED × 75 DIAS.—CENTRE.

Distribution of Liquid Shrinkage.

It appears to the writer that the difference between a slowly poured casting and one poured in the ordinary way is not that the total liquid shrinkage is diminished, but that it is distributed in a different way. In a casting poured in the ordinary way, the total shrinkage may show itself in a cavity at some "hot spot," the last place to solidify. Slow pouring means quiet pouring. When a casting is poured rapidly, it is probable that currents are set up which circulate throughout certain regions of the liquid in the mould, and that the momentum is not lost for a considerable time. This may accentuate uneven crystallisation—in point of time, *i.e.*, it may be that in certain parts of the casting, being without eddies, primary crystallisation may begin before that in the hotter, agitated portion. Thus local crystallisation would proceed, all its requirements of mother liquor being met—at the expense of the remainder of the casting if new metal did not enter the mould. On the other hand, the casting run with filter gates would fill very slowly. There would be very little agitation of the metal. There would be no riser, the pouring would be the sooner complete, and the metal at rest almost as soon as cast. What then happens? Consider the following, by Professor Tschernoff[11] on the crystallisation of salts: "When studying under the microscope with high magnification the formation of salt crystals as they separate from their solutions, we note that the growth of crystals from their *nuclei* manifests itself in a rapid, nearly simultaneous appearance of axes, branches, and even planes, starting in definite directions in accordance with the crystallographic axes of the growing crystals. From the principal axes will branch off axes of the first order; from these, axes of the second order, and so on. This takes place in so rapid succession that it is impossible to trace the formation of every individual branch. The rapidly forming branches gradually thicken and elongate, and as a result meet neighbouring branches and grow together."

That cast iron, when solidifying, behaves very similarly is probable. Every foundryman knows that, when a casting is being fed with a rod, there comes a moment when it feels to the hand as if the rod were snapping off innumerable microscopical carrots. At this stage the metal feeds away very rapidly into the casting, this being, in fact, the effective feeding stage. If, then, it be imagined that something of a similar character takes place in solidifying iron, the following may be the sequence of events in the case of a slowly run casting. The mould fills with relative quietness. Cooling takes place from metal to mould walls, and from the centre of the metal to the outside. Before crystallisation can begin, the metal must be undercooled. In this case (if the mass is not too great), before crystallisation seriously commences, the whole of the metal in the mould is probably below main freezing point. Consequently, in a quiet medium, the whole of the metal, at a given moment, may be intersected in every direction with the axes, branches and planes of elementary crystals. The formation of these elementary crystals will cause a demand for mother liquor. The skeleton structure only having been formed, gravitation may induce a feeding downwards, thus explaining a shallow depression on the top of the casting. Crystallisation is proceeding, however, very rapidly, the branches quickly thicken, elongate, meet neighbouring branches, and grow together. Any deficiency of mother liquor is now equally distributed, the process taking place so rapidly that shrinkage takes the form of intercrystalline spaces. These spaces may not be seen with the naked eye on a planed or polished surface, but may be found by the aid of the microscope. Thus, in the writer's opinion, is the relative freedom from shrinkage cavities

FIG. 27.—ETCHED × 700 DIAS.—CENTRE.

obtained by slow pouring—that is, of course, in addition to any advantage obtained from the partial solidification which may have taken place in some part of the casting before pouring is finished. Admittedly the foregoing is hypothetical. If true, however, it would afford some explanation of the relative success of slow pouring. The writer is aware of no other explanation, certainly none has been put forward, even by M. Ronceray.

The experiments detailed above were limited to what may be fairly described as average foundry irons. No high-phosphorus irons were tried, nor were any very low-silicon irons. From Professor Turner's work it is probable that the phosphoric irons would show a different result, *i.e.*, the shrinkage may be fully compensated for, in suitable circumstances, by post-solidification expansion. On the other hand, with much lower silicon irons the post-solidification expansion would probably be less, thus making for a greater residual shrinkage.

The writer is indebted to the manager of the Kilbowie Laboratories, Mr. R. K. Tullis, for the analyses and microphotographs, and to Messrs. D. & J. Tullis, Kilbowie Ironworks, for permission to carry out the experiments detailed above.

Conclusions Deduced.

With respect to the grey irons which were tried, the writer reaches the following conclusions:—

(1) Grey iron shrinks round about 4.5 per cent. of its liquid volume on crystallising.

(2) If the expansion which immediately follows crystallisation be directed wholly inwards there is a residual loss of volume, due to liquid shrinkage, of round about 1.5 per cent.

(3) Quick cooling (as by the use of chills) does not reduce the rate of liquid shrinkage, but makes for greater solidity only if solidification is so speeded up thereby as to enable new metal to reach the part concerned.

(4) Slow pouring does not reduce the rate of liquid shrinkage, but may alter its distribution throughout the casting.

(5) The aggregate loss of volume, due to liquid shrinkage, does not appear to be appreciably affected by composition or temperature of pouring.

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AN ANALYSIS OF DEFECTIVE CASTINGS.

By E. Longden (Associate Member).

Founding is an art, and one cannot do otherwise than think that it will remain so for many, many years to come, and although much waste can still be saved, it will be impossible to eliminate scrap until this personal element is eliminated.

A story is told of a lawyer who was defending a moulder in an action for the recovery of wages stopped for making a waster that: " Making castings was like growing potatoes; no one could tell what they would be like, good, bad, or indifferent, until they were dug up."

There is much truth in such an explanation of the founder's lot. Watch the actions of the moulder when his casting is taken from the sand. He will scrape and tap his casting in various places, looking actually for that which he does not wish to find. If the casting is apparently sound he is relieved, but his anxiety is not ended, and perhaps during the dinner hour he may visit the machine shop to see his casting at some stage of the machining operations; if a little dirt is disclosed on an important surface he fearfully inquires from the machinist if there is not still a little more to machine off which would clean the surface. If the answer is in the affirmative, he returns to the foundry with lightened heart.

The subject dealt with is so vast that the author has concentrated his remarks on grey cast iron, but the majority of faults explained in this Paper would apply to all metals which are cast.

Cavities and Porosity due to Gases.

Without doubt, the greatest single cause of casting losses can be attributed to those embarrassing defects which are usually described as blow holes, liquid shrinkage cavities, and porosity, and which are thought in the case of grey iron to be due to gases generated in the mould and cores which may or may not combine or interact with gases occluded by the metal when cooling. Such defects are the more distressing because they are discovered, mainly, after machining and testing operations, and are especially dangerous when found in work of a high-class nature, such as internal combustion and steam engines, machine tools, pumps, turbine and hydraulic machinery, etc.

Foundrymen would be astonished if they knew how near sometimes they are to a scrap casting. For instance, a hydraulic cylinder which was broken up after many years' service showed a deep, irregular blow hole about ⅜ in. round, almost cutting through the section of 3 in., leaving only ⅛ in. of sound iron, yet it had stood the wear and pressure until rejected for some other reason.

Gas cavities and porosity occurs in many ways, the chief causes being:—Insufficiently-dried cores and moulds when dry-sand and loam moulding is attempted; excessively hard-rammed cores and moulds; in some instances lack of ramming locally, because a pocket of loosely-rammed sand provides an easy exit for the gases generated in the harder surrounding sand, so that the gas easily flows forward into the mould cavity and metal; abuse of the swab locally, or too much moisture in the sand generally, especially when green-sand moulding; lack of the natural venting properties of moulding sand; omitting artificial venting; improper use of the vent wire, because, if probed deeply, it will be found that quite an appreciable percentage of blow holes are due to the over-sharp vent wire which is so often thrust through the sand and penetrates the pattern, the fine holes so formed are easily passed over by the moulder, and when the metal enters the mould the generating gases blow through into the mould cavity and, later, the metal; incorrect sand mixtures for the particular type of casting; faulty sand mixing; faulty and wrong mixtures of mould dressing; allowing metal to penetrate subsidiary and main vents in core or mould; choking of vents by sand due to unskilful manipulation; blow holes from inserted solid metal which has not received correct treatment, such as denseners, chills, nails, studs or chaplets; also these pieces of metal, in spite of much care, attract and condense steam created in a green sand mould in which has been placed a warm core, or from an imperfectly dried mould closed warm, and then allowed to stand so that it cools before receiving the metal; blow holes from wet loam stamps, which are placed on cores to make up the common errors in size between core and mould print; absence of openings or risers for exhausting mould gases quickly, particularly in confined sections of the mould, and especially if the nature of casting compels rapid pouring; insufficient fluid head pressure; escape of metal from mould, with the consequent arrest or ebb and flow of the molten iron; incorrect gating, so that metal enters mould wildly, or too slowly, perhaps the metal enters and impinges on mould or cores eddying and churning, so that air and other gases are mechanically mixed with the metal, or it may be that the gate is so concentrated on one portion that sand becomes overheated and the gases escape from the mould face into the metal rather than through the back sand, which has become unduly overburdened with gas generated at very high pressure—it may be that metal has such a tortuous passage, due perhaps to wrong location or insufficient git, that it becomes lifeless and unable to expel collected gases, for it might be said that the very act of pouring tends to create blow holes because of agitation; omitting to feed metal through riser gates to replace escaping gases and badly located feeders; dull iron, because there is always much more difficulty in obtaining castings free from blow holes when the moulds are poured with sluggish iron, for, whatever might be the cause, the gas cannot find its way out if the metal is viscous—good hot iron hides much faulty venting, etc.; wrong mixture of metal for the particular type of casting; and last, but not least, the difficult, and very often absurd, design of the casting, which makes it practically impossible to conduct gases rapidly enough away from the mould or core.

Cavity and Porosity due to Loose Sand, Slag or Sullage.

One or more of the following reasons might be the cause of cavity and porosity under such a heading:—Scabbing of cores and moulds, which will be described later, is a prolific cause of dirty castings, the sand and blacking so disturbed floats about on the metal, and is most likely found above the locality of the disturbance, but sometimes far removed from the seat of the trouble, which will depend on the position of the runner gates and shape of mould and cores; loose sand left in mould, perhaps hidden from view under cores or projecting portions of the mould, and can be introduced by scraping of cores on prints, or from careless handling of cores detaching pieces of sand; crushing of joints of mould and cores, especially in dry-sand and loam; sand may fall down the runner or riser gates when making up the bush for the reservoir of metal after the mould has been closed (to prevent such a possibility when closing important work, the pouring and riser basins are completed on the top side of moulding box before closing); careless rod-feeding, so that the sides of the feeding gate are scraped and sand pushed down into the casting. This happens particularly when the metal has become sluggish; sullage floating on the feeding head metal can also be carried into the casting by the rod; erosion of mould in various places introduces sand, such as soft ramming around gates, breaking away of the keen edges often formed on the mouth of the main down runner, which happens especially when placing stoppers over the openings, and if the bottom portion of the in-gate which receives the first blow from the falling metal was examined more frequently, some of the mysterious dirty patches found on castings would be explained, or if a casting is run by top drop-gates, erosion of the bottom side of the mould may take place due to the blow from the falling metal. Sometimes the sides of the mould or cores are scraped by the falling metal, especially if there are shoulders of sand or the moulding boxes are not placed quite perpendicular, so that metal can fall clear to the bottom of the mould without impinging. Pieces of mould may break away and wash before metal; arrangement of gates, so that eddies are created near entrance; sullage and slag may be sucked down with metal if there is insufficient and incorrectly-formed reservoir-capacity in the pouring basin to feed the down runners, or main gates may be so situated in the pouring basin that a whirlpool is formed. Again, it may be due to careless pouring, allowing head of metal to sink too low, and to faulty skimming; using blacking excessively, especially on green-sand, much of which washes before the flowing metal. This happens also with dry-sand, loam and cores with insufficient binder in the face-dressing, or subjecting moulds to too high a temperature when drying, so that binder has been burnt out or weakened, due to expansion of the sand grains and passage of steam. After the mould has been closed a gagger may be touched or moulding box jarred, and the adhering sand on the inside of the mould dislodged.

It has been stated that some of the strange, dirty-looking patches discovered near in-gate entrance may be due to air being drawn down runner, which causes oxidation of the graphite. It is probably due to excessive local heat about runner entrance, especially if metal impinges immediately on a core, the spots so overheated allow a freer exit for the surrounding mould gases. In any case, the in-runner should not be placed near an important or machined surface, if it can be avoided, because dirt or open-grained structure is possible in that locality.

Scabbing of Moulds and Cores.

The term scab is used to describe a rough incrustation which forms on castings when gases are generated rapidly locally or are unable to escape speedily enough through the pores of the sand and vents, or rapid expansion of face of sand locally, thus a portion of the sand face is pushed forward into the metal, creating extra thicknesses at these points and sand cavities at others.

Scabbing can be caused by many of the reasons described above, and may be due to:—Absence of or incorrect venting; too much moisture in sand, especially when green-sand moulding; insufficient drying of cores and moulds when dry-sand and loam moulding is practised; hard and also soft ramming of sand, particularly when local; incorrect sand and mould-dressing mixtures; excessive tool sleeking of mould and cores; location or bad design of runner and riser gates; a portion of the mould or core, due to its shape, may expand and become detached; nearness of mould and core irons to surface of sand may cause a piece to become loosened, either because the body of sand is so thin and weak that it scales off, or the core iron expands and pushes the sand before it into the metal; hook holes provided in cores may not receive correct attention, such as drying, venting, or sprigging to the already dried core; pasting sand on an already smoothed surface of the mould or core; suction created when withdrawing pattern from sand, may cause a part of the mould to become loosened, and if it misses the eye of the moulder and he does not cause the affected spot to adhere to the main body of sand, it may be detached when the metal flows around it; an excess of binder in mould and core washes will cause the face of sand to contract and buckle after drying; making up of joints of assembled sections of cores with new material instead of old or sand more nearly corresponding to nature of core which has been subjected to the prolonged drying temperature; blacking cores whilst hot and allowing them to cool before pouring metal; inserting hot cores in green sand moulds so that moisture is formed on certain parts of the core or mould; cores absorb moisture if allowed to stand in a green sand mould too long, and may scab; oil-sand cores may be so weak because of the lack of binder or drying at too high a temperature that blacking, especially if core is hot, when washed may be rapidly absorbed and adhere in thick layers, to be disturbed later when the metal touches it; explosion of gases in vents may cause either mould or core to scab or even to shatter; if, when making a loam core, the last layer of loam applied is thin, it is not unknown to find a scrap casting, because when the metal has poured around the bottom side of the core the sand expands, the tendency being to push upwards where there is the least resistance, and this thin layer of loam buckles and scabs away when the metal closes around it; buckle scabs may be caused by a weak core bending perhaps because of insufficient support by chaplets or studs, etc.; vents too near the surface of the mould allow gases to blow through into metal and detach some of the sand; with certain medium and heavy castings, especially in green sand, metal may be admitted at too high a temperature; in some cases omitting to face-sprig the mould and core opposite the runner entrance and about the shoulders of sand over which metal must pour to fill a lower part of the mould; allowing metal to penetrate vents blocking the exit of gases.

Moulders have been known who have stood and stamped on large slender cores with a view to carrying the core solidly down into the mould print and experiencing at once any weakness in the support prints rather than later, when more cores were built upon it. After the casting has been taken from the sand, much surprise has been expressed when scab sand has been disclosed. When the casting has been broken up the reason became very evident. When stamping on the core print the moulder had caused the core iron to move and strike the sand above it some distance in the mould.

Contusion of Mould and Core Joints.

When extracting a pattern from mould, especially one with little draft, joints tend to lift, and after the mould is finished joints may stand quite proud, so that when boxes are brought together crushing takes place. In dry-sand and loam, thick blacking on the joints or when the mould has been subjected to a rather high temperature, swelling of the sand may take place, and if the joint clearances have not been cut, as is usual with dried moulds, joints are contused. A crush on a dry sand mould is usually more serious than is the case with green sand, because the dried sand, although strong, is not plastic like green sand and crumbles. Thus it is common in dry-sand practice to pare joints and core prints of mould whilst in a green state. Poorly-fitting box-locating pins may guide the top-side of the mould too keenly on one side of a core print or an irregularly-formed joint. This may happen if the top box is placed unsteadily. Box-joints, especially if unmachined, may be so irregular that, unless packing is wedged into the open joints in various places before clamping or bolting together, a very serious crush may be the result. A scrap casting from this type of crush can be guarded against by a trial closing of the moulding boxes and clamping together before coring. It is good practice with heavy bedded-in work, such as bedplates, etc., to try on the top boxes after the mould has been finished to the point of blacking and whilst the mould is still green. With an absence of, or insufficient reinforcement, to the bottom or top sides of prints, the weight of core may sink in the bottom print or burst the top print when the metal-pressure is exerted on the core. With heavy bedded-in work serious crushes are sometimes experienced, due to lack of foresight in placing bearers leading from below the bottom side of the mould to the joint face to receive the weight of covering box. Sometimes too much weight or bolting may be applied. Cores may be canted in a mould, thereby fouling a print formed on the top side of the mould. Boxes are sometimes placed together the reverse way to the right one.

Escape of Metal from Mould.

Considerable waste can be recorded under this head, and the causes can be ascribed to:—Metal leaking through incorrectly-formed sand joints; runner gates too near the sides of the moulding box, especially if the flask joints are not machined; the joints of the box may be held apart by cores, which are too large for mould prints or by failing to remove sand which falls on the iron joint of the box; nearness of the lower side of the mould to the bottom side of the box, so that if not well-weighted down, in addition to clamping or bolting at the joints, and the sand bed well formed, the metal will force its way out with little hope of stopping the flow; soft ramming of bottom side of mould will show up its weakness when the full head pressure is reached and the metal escapes; omitting to clamp the box together sufficiently or not at all, or placing too little weight on the boxes. Metal may force its way through surface of core due to nearness of a hay or straw band to the sand surface or in an ordinary sand core through soft-rammed places; proximity of vents to surface of sand, either in ordinary sand mould or core, may cause scab as described above; metal can then escape through the vent thus exposed. The print of a core may be too small for mould print, perhaps because the core box has become worn on the joints by usage, or the coremaker unduly rubs the joint of core before assembling, or the print of the pattern may have become enlarged because the two halves do not sit together, the metal escaping through the spaces thus formed. An escape to the vents is sometimes made when cores are imperfectly jointed and sealed; moulding box may be strained due to weakness or abnormal head pressure, causing an opening of the mould joints or fissures in sand through which metal issues. A portion of the top side of mould may be pushed upwards by metal, because of a lack of bars or soft ramming. Again, an explosion of gas in a mould when it is stated to be blowing may so strain the mould and cores that metal finds its way into vents and also through joints of mould. Displacement of cores will allow metal to enter the vents.

Heavy castings, from perhaps a couple of tons to, say, fifty tons, and which are made and constructed practically below the moulding floor line, must be specially cared for, if metal is to be held securely. Brick- and metal-lined pits are essential for safety with certain weights and shapes of castings, especially if the type does not lend itself to moulding with the usual sturdy prodded building rings. The bottoms of these pits, in addition to metal plates on the bottom side, have strong cast- or wrought-iron stretchers underlying the plates, which are made to receive strong vertical bars, used to bolt down the top boxes after the mould has been assembled. If, as is the case in some foundries, no specially-constructed pits exist, a known good section of the floor is chosen and the rough hole excavated by labourers. The moulder then examines the bottom and sides for weakness. It may be that he can strengthen a soft place by ramming, but often he is compelled to place loose plates in front of these danger spots, because the sand may be too dry and the extent of the soft place unknown. However, in spite of the ingenuity of the moulder, even such foresight is sometimes beaten, and metal escapes, spoiling an extremely expensive casting.

Displacement of Cores by Metal.

Much ingenuity can be exhibited when securing cores in moulds so that as little solid metal support be introduced into the casting sections as is consistent with safety.

Cores may have ample mould-print or seatings to avoid using chaplets, studs or nails, but the moulder fails to reinforce these sand supports by inserting material which is stronger and more resisting than sand, so that core either sinks by virtue of its own weight or is crushed upwards when the fluid pressure which is exerted by the molten rising metal. In some cases, chaplets or studs are placed on the prints of the pattern when ramming the mould, securing them either under a bar or by clamping or weighing, as is the case with those which penetrate the casting section. Chaplet, stud or nail may be forgotten, or may be too weak or insufficient of them used to fulfil the duty expected. Studs or chaplets may sink into the core or mould because the sand surface is too weak to withstand the weight or core or pressure on top side when the metal rises in the mould. Chaplets are sometimes wedged too lightly or too heavily. Studs may be displaced by movement of cores by the flow of the metal, especially those which are simply wedged vertically between cores or core and mould; they should in certain cases be nailed to the core or mould. Weakness of core irons may cause the core to bend, also to disturb other cores. Hooks in cores, if placed at an angle, may be too weak and allow the core to lift by straightening the hook somewhat.

During the author's apprenticeship period at a large engineering firm, which was then being run on American lines, provided many amusing incidents. He well remembers the horror on the face of a moulder when he discovered three days after having poured a large casting, that he had wedged down the stem of a straight-limbed gagger which protruded above the top of the moulding-box face alongside the stem of a chaplet. It might be pointed out in passing that it was an American system to use straight-limbed gaggers, which often stood well above the top of the box.

Leaking Around Studs, Chaplets and Nails.

It is erroneously thought by many that the chaplet or stud fuses; this only happens very rarely. As a matter of fact, this article would not be fulfilling its duty if it did melt, because one can imagine a core floating, or in some instances sinking in the metal.

Faults in this section may be due to pouring with dull iron so that metal does not cling or knit closely enough to these inserted pieces of solid metal; omitting to allow extra metal around chaplet stems, a good button or pad can often be arranged around the stem on the inside of the casting and out of view of critical eyes. The running of a casting may be so slow or gates may be so located that these pieces of cold metal have little chance of becoming heated before the metal flows about them; a deposit of moisture may form on the chaplet or stud by placing warm cores and closing the mould too early. When core is displaced the metal section is thinned, and consequently less metal around the stud or chaplet. A stud may be too strong for a given section of metal. Defective tinning or rust on chaplets, etc., is a frequent cause of leaking.

Moulders have been noticed placing the nail stud or chaplet, and then deciding to damp the mould, and incidentally the chaplet, etc., and in other cases when dry-sand moulding fixing nails or chaplets before wet blacking the mould. Of course, the blacking adheres to the nail, and forms a parting from the metal.

Misplacement of Cores.

Chaplets or studs may be inserted which do not correspond with the desired thicknesses; the breaking down of sand prints and subsequent incorrect repair, which might be full or short, is a further cause. Insufficient print, or absence of a protruding print, may be the cause of wrong location of cores. Others are:—The pattern or core box may become so much worn that position of cores alter; rubbing core prints before placing cores; when placing loam cores, such as for liners and cylinders, cores are sometimes placed without first ascertaining the thicknesses. It is very desirable to check by the aid of clay stamps under and above the cores; absence of or indistinct guide or setting pieces on mould and core prints may be the means of locating cores wrongly. Often, if the setting or locating piece is not bold, the moulder may tool it over, especially if for some reason the mould has been dragged and broken at this point. On one occasion a dull moulder cut off a bold guide on his sand print, so that he placed cores the reverse way about in four out of six castings.

Short Run Castings.

Shortage of metal due to miscalculation is almost an everyday occurrence in foundries. Metal may escape from mould, and is run short if a surplus of metal is not available; this is an everyday mishap. Misplacement or lack of runner gates may not allow metal completely to fill the mould; this may happen also if metal is dull, or a blow-off riser is not provided above thin or pocket-like sections.

Lap or Crossed Joints.

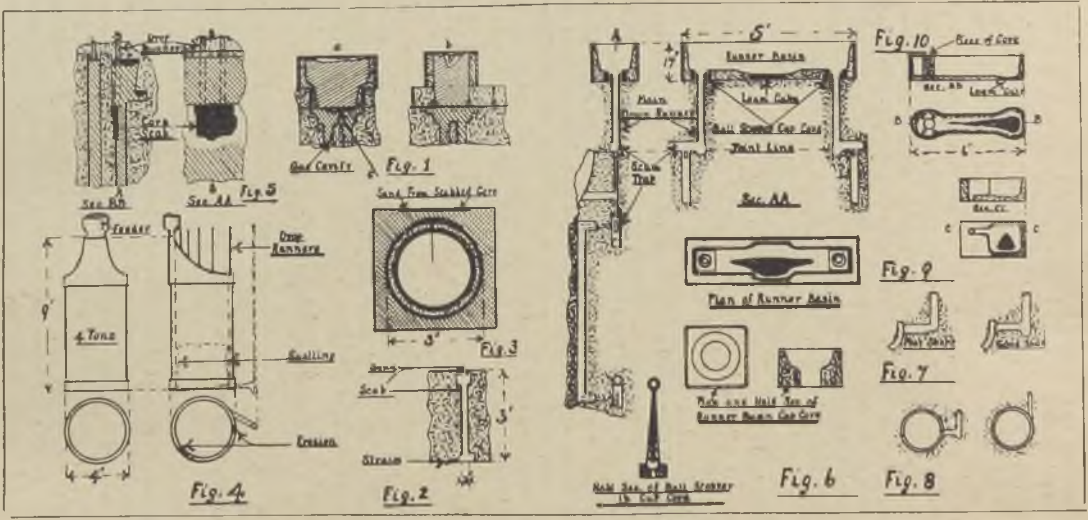
Pattern dowels may become loose by ordinary wear and tear or unfair usage, such as rapping the dowel-pin to loosen the pattern. Moulders sometimes drop a rapping bar in a dowel hole to loosen the pattern because either no loosening plate was provided or it had become too free to fulfil its proper function. Insufficient or worn pins and pin-holes are a prolific cause of waste under this head. With bedded-in work, locating stakes may be incorrectly placed or loosened in various ways. In loam work, and sometimes when using moulding boxes, loam marks and flats are cut astride the joints before dismembering the mould and cores, when made together, for finishing, as when making intricate turbine and centrifugal castings, etc. Occasionally, after drying, these marks cannot be induced to correspond, due perhaps to careless handling when lifting with the chain slings, so that mould is strained, or the same trouble can arise if the tackle is too weak. Marks may be disturbed by moulder brushing them with his clothing or tools whilst they are green. The drying temperature of one part of mould may be more intense than another as the grains of sand on cooling do not quite return to their original position, and trouble is experienced in matching joints when assembling. When withdrawing a pattern, the mould may be disturbed about the joints, and the moulder fails to finish to the correct position. In snap-flask work, moulds may be disturbed when releasing the flask after closing or when placing the strain jacket around the sand. Often when a moulder is lowering the top box he nudges the cores, especially if the pins be short or loose. Cores may be placed incorrectly or insecurely and moved when metal touches it, giving internal crossed joints. Weak core-boxes may, when sand is being rammed in, bulge, and allow a section of core to override another. Patterns are sometimes wrongly located on pattern plates. With plaster and white metal match plates, especially the latter, wear and tear and bruising may soon cause lap joints.

Cold Shut and Seams.

This fault occurs mostly in thin castings, especially if of considerable area, and can be caused by one or more of the following reasons :—Dull metal; shortage of runner gates or their bad location; arrest in the flow of metal due to either mould or core disturbance; carelessness in admitting the metal to the pouring basin; escape of metal from mould; the mould or core may blow; hard-rammed or sand with too much moisture; incorrect mixture of sand; a densener or chill may be too heavy for a given section of casting, or moisture may have formed on it; blacking and loose sand may run before the metal and form a parting; design of casting may present a very tortuous passage for the metal, so that it becomes oxidised on the surface and consequently sluggish and refuses to amalgamate with other streams of metal meeting from one or more directions; lack of fluidity in metal due to composition.

Abnormal Distortion and Fracture.

Where camber is required, insufficient may be allowed, or in certain cases it may be quite the reverse to the right way. Cores may resist contraction, and the casting breaks or turns out much deformed, especially when made in loam; cores, if not placed centrally in pipes or box-shaped castings, will produce uneven contraction and a bent casting. Failure to relieve runner and riser gates when close to the metal of box bars or loam plates gives trouble. A casting may be exposed too early after pouring. The cooling of heavy sections is sometimes neglected. Fin


Drop Runners
Core Scab
Sec. BB
Sec. AA
Fig. 5
a
b
Gas Cavity
Fig. 1
Sand from Stabbed Core
3'
Fig. 3
Scab
Strain
3'
Fig. 2
Feeder
Drop Runners
9'
4 Tons
Swelling
4'
Erosion
Fig. 4
A
17"
5'
Runner Basin
Main Down Runner
Loam Cake
Ball Stopper Cap Core
Joint Line
Scum Trap
Sec. AA
Plan of Runner Basin
Plan and Half Sec. of Runner Basin Cap Core
Half Sec. of Ball Stopper in Cap Core
Fig. 6
Fig. 10
Face of Core
Sec. BB
Loam Cake
B
6"
Sec. CC
C
Fig. 9
Fig. 7
Fig. 8

on the mould joint or internally on core joints may give rise to cracks due to the rapid contraction of the thin section which pulls away from the heavier metal to which it is attached long before the latter has quite set; usually these cracks are only shallow. Heavy denseners, unless continued all over a given surface, may also cause shallow cracks. There are also castings which crack after an attempt to burn metal into a defective place. A bent casting is occasionally erroneously ascribed to distortion, when it is really due to a weak pattern bending. Metal, poured-dull, may cause excessive distortion or even fracture, especially along the line of a cold-shut or seam. Abnormal distortion is easily noted in long, plate-like castings when the camber has been determined with a desirable casting temperature which may be fairly high; pour this same casting with dull iron and camber is all wrong. Certain castings are so designed that it is almost impossible to produce them unbroken without an extraordinary amount of care and labour. Cases are on record where even a combination of camber, hastening cooling and metal manipulation—both of composition and temperature—which failed to give complete satisfaction.

Faulty Repair of Mould and Cores.

When withdrawing a pattern from the sand portions of the mould are very often broken or disturbed. Extra metal is added to the casting if the repairing of sand is short; if the repair is too full or proud, the casting loses weight, and it sometimes happens that machining allowances are robbed or lost altogether and portions of the mould cut through thin sections. This happens occasionally when a section of a mould is stopped off or altered to meet various changes in design. Faulty repair also may mean pieces of mould or core being moved by the wash of the metal. Blow holes and scabbing are often due to faulty repair and finishing by introducing an excess of water; the pasting of sand over already-smoothed places and the lack of venting. When a difficult repair is needed the pattern is sometimes returned to the mould in so doing, especially if the pattern is old, much damage is done which more than counterbalances the help given by returning the pattern to the mould.

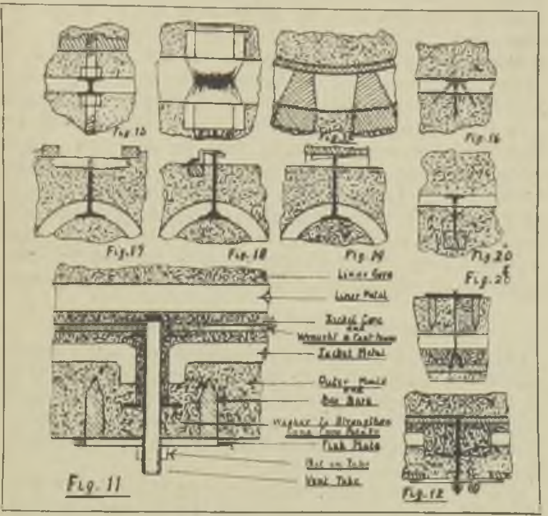
Failure in General Construction of Mould.

The strength and construction of a mould are sometimes faulty, and one or more of the following troubles may arise:—Pieces may drop from top side of mould due to insufficient gaggers, or the latter may be so placed that they add a burden, instead of helping to sustain the sand. Sand may be detached from projections and cods of material in which there is indifferent reinforcement; it may be that insufficient rods of metal have been introduced to bolster the sand or too many rods have been placed which causes sand to break up and shatter. Sand between the running gate and the mould cavity may burst and be pushed into mould —badly-formed runners or the ineffective reinforcement of the sand being the cause and the trouble happens mostly in deep moulds. Core irons may be too weak, especially in lengthy castings, and if the use of chaplets or studs is prohibited, the core bends, and if not a complete waster, a thinning and thickening of sections results, and perhaps unexpected distortion. It is not unusual for a core to fracture completely when metal exerts pressure, because the coremaker has forgotten to insert one or more of the strengthening irons.

A case is on record where a heavy casting which, being made in an improvised sand pit, was lost because the metal found its way across the distance of 12 ft. into another pit.

Mistakes in Setting Loose Pieces of Patterns and Loam Boards.

Sometimes, in spite of ample guides, the moulder and coremaker omit to position loose pieces of the pattern according to instructions. Pieces are also wrongly located by:—Ramming out of place, after removing screws or pegs; insufficient guide on the pattern and core box; wearing away of the guides or if the mould has been lacerated by a poor pattern draw, perhaps due to the moulder forgetting to free the loose pieces, he may, if the mould is repairable, replace the loose piece, but not quite to its correct position. A very important part of the loam moulder's work lies in setting sweep boards and loose pieces, forming branches, flanges, lugs, bosses, etc. Occasionally the strickle board is not set correctly, which either gives a casting too thick or too thin. Loose pieces are also set wrongly when marks on boards become obscured, and perhaps because the moulder does not possess the symmetrical eye. Wherever possible the author strongly advocates the patternmaker overlooking the setting of loose pieces in loam moulds.



Indifferent Looking Castings.

Castings are rejected when they do not present a good finish and regular shape and can be attributed to:—Swelling on the mould and cores, perhaps because of the soft ramming of the sand or in case of loam cores abuse of hay and straw-wrapping or burning of the latter during drying; in very heavy castings formed in deep moulds, it is almost impossible to prevent swelling at particular parts of hand-ramming alone, so that the moulder reinforces the sand by laying pieces of wrought iron or pig to within 2 in. of the mould face, this precaution is not always taken, and a swollen casting results; marks showing up due to the unskilful use of moulders' tools on the sand, and many of the defects such as scabbing, lap-joints, burning on of sand, etc., as explained in previous sections.

Breaking of Castings.

Thin, and occasionally thick, castings are cracked by the dresser when he hammers the outside of the casting to disturb or eject the core. The dresser breaks castings also by delivering heavy blows at the wrong angle or when using a blunt tool. In some cases, when clearing a core, he may drive a chisel bar too heavily between a core iron and casting bursting the latter. The dresser, although not responsible, in the first place, may break in runners and risers, which may be due to:—Dirt about the gates; sponginess, which is quite common; poorly-formed and wrong location of gates; after pouring a casting, detaching the runner and riser-heads either too early or too late, or the runner and riser may be strained, due to resisted contraction in the mould. These are moulding errors.

Miscellaneous and Rare Causes of Defects.

The improper use of the feeding rod gives a substantial waste. A core is sometimes omitted from a mould. Bleeding of the heavy sections of castings may happen if the mould is released too early. Open sand plates may not be uniform in section if the sand bed is not level.

Perhaps some foundrymen are able to give an account of defective castings from rare causes; the author could cite many. A waste casting appeared to have scabbed; a closer examination showed that a seed had germinated sometime after mould had been closed pushing before it a portion of the sand face. It is not so unusual to find insects crawling out of the face of the mould after the pattern has been withdrawn. There was recounted a case of a moulder wedging down a straight-limber gagger instead of the chaplet stem alongside it. When raking out the core from a large jacketed-pipe, the dresser drew the attention of the foreman to two holes which he thought were not quite central. It was soon discovered that the holes referred to were not required. The moulder, when testing the thicknesses had forgotten to take out two pieces of clay. The casting was so urgently required that it was decided to plug the holes with studs, and quite a sound job resulted. After parting the sink head from the top of a large hydraulic cylinder a large cavity was disclosed. After a little inquiry and thought the foundry foreman remembered that, desiring to use the casting pit for another job, the following morning, he had caused the moulding box containing the casting, which had been poured only three hours, to be lifted from the pit and placed horizontally on the floor. Apparently the metal in the top portion of the casting and sink head had not finished freezing, and the act of laying down in moulding box had allowed some of the still molten metal to pour back from the casting into the cavity which had been formed in the head. It should be pointed out that metal was burnt into the defective place and the casting saved. The excellence of the burn is proved by the constant use of this particular casting over a period of years.

Unsuitable Metal.

The percentage of waste which can be attributed to metal. especially in grey iron, is not great, most of the conditions having been stated under preceding sections. It only remains to emphasise that castings are rejected in addition to the reasons mentioned, because metal may be too hard or soft, or is not homogeneous, due to bad coke and melting practice and to incorrect casting temperatures. Grey iron, although a complex mixture, is comparatively easily dealt with and suitable analyses are available for any foundryman who is able to use the knowledge.

If one was to arrange for all metals a percentage of waste which could be separated out and apportioned and stated as foundry technique or metal the author would arrange them in the following order :—

	Foundry Technique. Per cent.	Metal. Per cent.
Cast Iron	95	5
Malleable Iron	80	20
Steel	70	30
Aluminium	85	15
Brass	95	5
Gun Metals	75	25
Bronzes	80	20

Percentage of Waste.

To state a reasonable percentage of waste for various classes of castings poured would be indeed difficult and could only be comparative. There are many factors to consider, such as:—Quality and availability of labour which affects certain localities and shops more than others; systems, as determined by the economics of the particular business; production by time rates or payment by results; accessibility to moulding materials and their quality, also metals and fuels, etc.

A 6 per cent. waste bill in one locality or shop might be a more noteworthy achievement than 3 per cent. in another. In the former case, in addition to points previously mentioned, they may be operating a system of payment by results, or labour is not so skilled and low-rated; whilst in the latter case time-rated, and highly skilled. The availability of highly-trained moulders is of the first importance. Good conditions of employment are not inconsistent with cheap and, at the same time, high-quality production.

Machinery will help partly to fill the gap made by the dearth of moulders, but foundrymen will still be compelled to rely on the human element for the bulk of the work done.

Britain still possesses the finest type of moulder in the world, but unfortunately, due to state of trade and other causes, the number of good moulders has steadily diminished.

Examples of Defects.

Fig. 1 gives an example of porosity due to gas, and also, as explained under the section dealing with abnormal distortion and fracture, the effect of placing a heavy feeder head to remedy the fault which, whilst helping to eliminate the gas porosity, introduced a defect quite as serious. It will be noted that the feeding head is quite close to the box bars. The casting, being much thinner than the feeder, contracted much sooner than the huge feeder which was prevented from following the movement of the casting and became slightly suspended between the bars. Many castings are lost in a similar way. Dressers are often blamed for breaking-in the gates when the moulding is at fault, as explained above.

Fig. 4 is a sketch of a liner, showing how erosion of the bottom side of a mould occurs when drop-gating from a height of about 10½ ft. This, of course, is due either to soft ramming, burnt mould, wrong mixture of sand or loam, or omitting to face-sprig these danger spots, which are struck as with a hammer blow. Sometimes it is possible to allow a small amount of metal to enter mould by way of a bottom gate, as shown by dotted lines in the sketch. This metal — first poured — forms a cushion to receive the bulk of the metal delivered by the series of top drop-gates. Such a way of gating is advisable with heavy liners, as the one shown, but for ordinary and medium sized liners no fear need be felt at running the whole of the metal through top drop-gates. This example also illustrates how a core can swell when hay or straw wrapping is burnt when drying, or the material mentioned is too near surface of core, as dealt with previously. The erosion of mould has also been explained. Fig. 2 illustrates points made when dealing with scabbing and shows how the face of a mould may expand and push a shoulder of sand into mould or metal, if the sand at this part is not sprigged. It also shows how a mould strains. Fig. 5 explains how scabbing can occur, as in the case of a large jacketted gas-engine cylinder, weighing three tons and caused by the metal, which was delivered through top drop-gates, impinging on the shoulder of sand. Fig. 3 is also mentioned in the section on scabbing and illustrates how a loam core can scab if last layer of loam is too thin and the underlying core has not been roughened. The metal when pouring around the core causes the outer skin of core to expand and buckle, as previously described.

In the section bearing the caption scabbing of moulds and cores is given an account of how cavity and porosity are caused by sand, etc. The sketches, Figs. 6 to 10, show a number of ways by which castings can be cleanly poured. Fig. 6 depicts a system for gating and pouring, horizontally, important castings such as steam cylinders. This method proved highly successful, hundreds being produced without waste. Let us follow the movement of the metal. After placing ball plugs in the cup-cores, the runner-basin, which holds about one-third of the total metal to be poured, is filled; the ball stoppers are lifted; the metal pours down two 3-in. dia. main runners and drops on to the dished-out place on the bottom joint of the mould; the scum gate quickly fills; this is helped by cores which have been placed across the intermediate flat down-gates leading from the joint, which are much less in area than the main runners; the metal then passes quietly into mould through the in-gate, which is slightly larger than the intermediate runner.

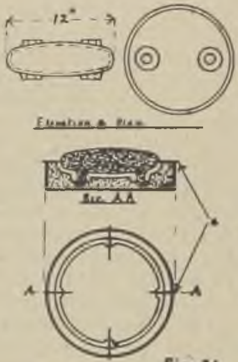


Fig. 21

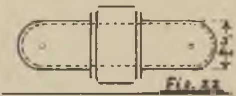


Fig. 22

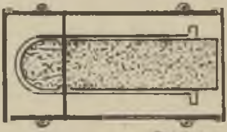


Fig. 23

Fig. 24

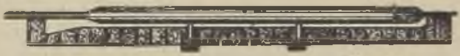


Fig. 25

Fig. 10 shows formation of pouring basin for such as flywheels, etc.; Fig. 9, a basin for pouring cleanly small important work without the aid of stoppers or plugs. Fig. 7, shows on the left a very poorly-formed runner gate which is altogether too common with indifferent moulders. The bottom of the down runner is subjected to the erosive action of the falling metal until the mould is filled. Sometimes this bottom portion scabs immediately metal falls on it and sand washes into the mould. Later, wonder is expressed as to why sand was found in the casting. The running-gate is quickly disposed of and so is the evidence. The right-hand sketch is a safer shape. Fig. 8 depicts on the left an indifferent way of gating pipes and box-like castings, and on the right, a better way if a flange is not convenient.

Figs. 11 to 20 illustrate the various methods of securing cores to avoid the many defects described when dealing with core troubles. Fig. 13 shows how the single or double stud can be supported by bearers. Fig. 14 is a cast-iron stud used in certain types of heavy castings with sections ranging from 3 to 6 ins. and are used, especially if compelled, to place them near the wash of the incoming metal. Fig. 15 depicts another cast-iron stud made to support a round core in a heavy furnace column, which, due to its length, was made in two pieces, the section of metal being 2¾ in. to 4 in. The examples 14 and 15 show that the studs are again supported by iron bearers. In Fig. 16 is shown how the resistance of a nail can be increased by suitably placing the ordinary moulders' sprigs. Fig. 20a shows a block of wood bedded below the face of the sand into which is driven the nail. Figs. 17, 18 and 19 show common methods of securing chaplets. In the case of Fig. 17 the chaplet is secured by excavating a small amount of sand from around the top of chaplet and under bars of box in which is poured molten iron just prior to the pouring of the casting and allowed to set.

In rare cases a core cannot be secured in the top part of mould by the ordinary studs, etc., until the mould is turned over for the purpose of closing, so that wire and sometimes a bolt is projected through the section of metal, as shown in Fig. 20b. Fig. 12 shows at the dotted lines, how a bolt is sometimes placed to hold a core down. In such a case one need not be surprised if the core lifts by the act of the bolt straightening itself somewhat when fluid pressure is applied. With certain types of castings the method outlined in Fig. 11 proves very satisfactory. The sketch shows how the jacket cores in a large twin gas-engine cylinder were secured and at the same time providing a very safe vent. In certain classes of castings, the use of studs, chaplets or nails, are not desirable. Figs. 21 to 25 illustrate how to avoid and minimise the use of chaplets, etc. Fig. 21 is a thin box-like casting subjected to steam pressure. For some time much trouble had been experienced with defective castings due chiefly to leaking around chaplets and studs which were placed under and above the core. Arrangements were made so that the cores could be made in oil-sand and to allow 6-in. sprigs newly cleaned and ground on the emery stone and placed in the cores, so that they stretched through the section of metal and sat astride the sand and metal joints. The method was highly successful because the cores were instantly located when placed in the bottom side of the mould and secured when the top part closed on the sprigs sitting on the joint. Fig. 23 is a similar case where a bar of wrought iron is stretched right across the core. Fig. 22 shows two castings made from one pattern by the use of the balanced core. In special pipes cores can be prevented from bending by using lever bars as indicated in Fig. 24. When making hydraulic rams of considerable length, say up to 35 ft., trouble is very often encountered by inability to

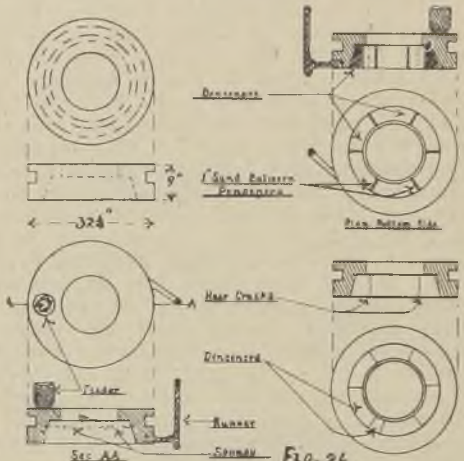


Fig. 26

keep core central. Due to its length core bends so much that it sits on the bottom of mould when coring up in the horizontal position, and when the box is lifted up vertically, the core fails to find the centre of the mould as intended. The author made rams twenty years ago and never failed to keep the core central by adopting the method depicted in Fig. 25, which is quite simple. Temporary wooden chaplets are inserted in and protrude through the bottom side of mould, lodging on a wrought-iron carrier attached to bottom of moulding box. In the core iron bearers are built to correspond with the wooden chaplets. The core is adjusted, the box closed and the mould lifted to the vertical position. Wooden chaplets are then taken out and the holes they leave plugged with a piece of core and secured by means of the carrier again. It will be noted that the core is bolted down at the bottom end, thereby allowing the core barrel to expand freely through top end of box.

Fig. 26 illustrates, again, gas porosity as described early in the Paper, but this sketch is shown chiefly to explain how shallow cracks are formed when using denseners over a large area. The cracks were due to splitting up the denseners, so that 1 in. of sand divided them. The trouble was overcome by continuing the denseners, which were made so that they could be easily knocked out of the casting while still hot. The whole of the mould, including the denseners, remained in the stove until ready for pouring.

It is advisable when commencing the production of a new type of casting, if it is comparatively small, to break up the first or even the second and third for examination.

When a system of moulding produces a minimum of waste it is inadvisable to alter until it has been proved that a different method is superior, or when cost can be reduced by placing for moulding by machine. Very often there is less waste from the moulding machine than from the jobbing floor.

Scottish Branch.

FOUNDRY PLANNING FOR ECONOMICAL PRODUCTION.

By Evan J. Ross (Associate Member).

Why Planning is Necessary.

In many foundries, for general engineering castings, there is a special class of work in the production of castings, for standard designs of machinery. It may not be for hundreds or thousands of castings at a time, but for an intermittent supply in batches of much smaller quantities, say, from 3 to 12, and at times, just one, as required, yet a standard product. When such castings are produced in the ordinary way, there are many operations constantly recurring, which a little foresight could obviate.

When the ordinary way of moulding is cited the constant use of loose pieces, hand-filleting of moulds, thicknessing, stamping, carding, sprigging, etc., is meant. These operations, when studied with a view to rapid and economical production, in standard work, show themselves in the light of unnecessary evils. Under this the case of the patternmaker making the pattern to suit himself without considering the foundry in any way, may be cited.

For purely repetition work, where no expense is spared in the manufacture of metal patterns and coreboxes, almost all these objectionable foundry operations can be eliminated, but for work which cannot stand the cost of such expensive gear, these operations can be considerably minimised by planning. Unfortunately, foundries are at the mercy of the designing staff and patternshop, very often without redress in any way, and more so, if the foundry is not a part of a general engineering establishment.

Origin of Difficulties.

Generally, in the design of a standard product, every consideration is given to attain efficiency in the working of the machine; reduction of weight to a minimum, compatible with strength; rapid production in the machine shops, and accessibility. More often than not, the draughtsman through a lack of knowledge, unintentionally embodies pattern-making and foundry troubles and difficulties.

There are very few draughtmen who have the privilege of studying these various questions at first hand, yet they are generally quite conversant with at least the first four, that is, efficiency, strength, machining, and accessibility. This knowledge is assimilated by the drawing office staff, through being in constant contact with the personnel in the various parts of the engineering shops, or by direct study.

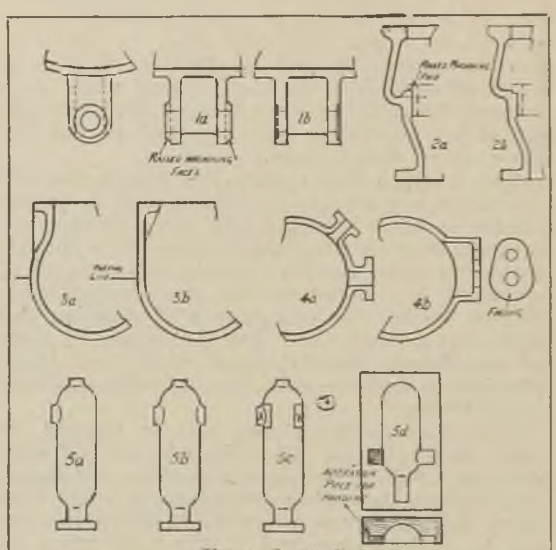
The designer knows from test results the efficiency of any complete machine, and is always hankering after a higher efficiency. Designs are carefully studied, particularly competitive designs, should these be available. Again, the strength of materials is well known to the draughtsman, because he has the opportunity of studying this particular subject, and has the result of years of experiment, well tabulated, always at hand. Provision is made to assist the production engineer in machining.

The inaccessibility of any part is brought to notice through the difficulties encountered when erecting. Difficulties in patternmaking and founding, little understood by draughtsmen, apart from metal difficulties, are seldom difficulties which cannot be entirely overcome in the patternshop or foundry, as far as turning out the casting is concerned. A pattern can be made to almost any design, and the moulder can devise ways and means of making the complete mould.

Patternmakers may see unnecessary difficulties due to design, which, if altered, would simplify their work, *and it invariably happens that the simpler the patterns and coreboxes are, especially for an intricate casting, the easier will it be for the foundrymen.*

Because a pattern can be made, little is heard of the difficulties in the patternshop; then, in the foundry, difficulties are generally taken as inevitable, and there to be overcome. *The pattern is made, and the castings are wanted quickly.*

Occasionally, draughtsmen see a casting scrapped through draw or some other defect in some particular part, which trouble might be obviated by a little alteration in design, but it is seldom that the actual cause of the trouble is pointed out, which, if done, would help to educate the draughtsmen for future designs.



Figs. 1 to 5.

Emulate Machine Shops.

Foundrymen are constantly being reminded of the progress which has been made in machine shops, under the supervision of the production engineer and his staff. Castings are now being machined at anything from *half to one-fifth* the time taken a few years ago for similar castings.

The production engineer, not only calls for castings in greater quantities within a given time, depending on the output of his machines, but for castings with a minimum of machining, and a much greater degree of regularity of contour than was previously considered necessary, or thought possible. Such circumstances make it imperative for foundrymen to try and meet the increasing demands for castings.

There are various privileges that the production engineer has been granted which might well be emulated, or taken advantage of by the foundry side of an engineering establishment. Certainly, every encouragement has been given, and no expense spared, to attain rapid production in the machine shops. Designs have been altered to suit machining methods. Very expensive jigs and tools are designed and made. The production engineer always works on the principle, *that a jig is only made once, then why not make it perfect? The same argument holds good for patternshop work,*

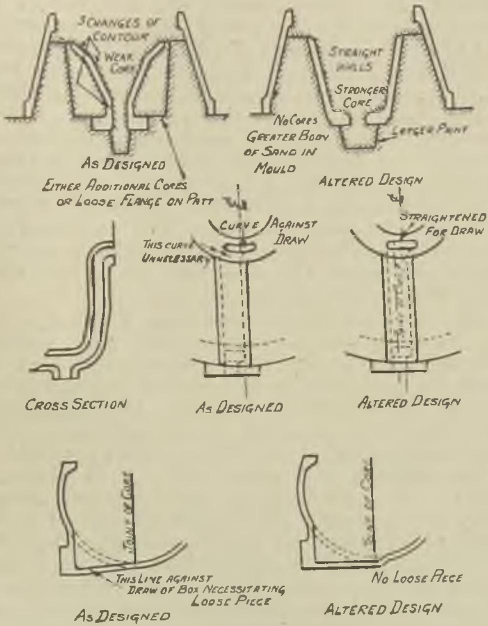


FIG. 6.

even more so, as the value of the jig really depends on how true and how near the casting is to the detail drawing.

Every operation in machining is carefully thought out and planned. No doubt, rapid production in the machine shops has been greatly assisted by improvements in the design of machines, and, by the use of improved materials. *One of the main reasons for machine shop progress is that the production engineer takes advantage of all improvements, in machinery and materials.* Can the foundryman say that he does so? Unfortunately, in many cases, economic conditions do not permit of installing the most up to date appliances in the foundry, but foundries can be helped considerably, with a very little additional expense in design and patternmaking. The various types of moulding machines now on the market may quite well be compared with the most up to date shop machines, as time saving devices.

Jigs are designed for machining, similarly, jigs may be designed for corebuilding and setting, ensuring accuracy in the general thickness of metal and alignment in the internal parts of intricate, or very important castings. The main principle underlying planning, for any scheme, is that all operations are predetermined, to be carried out in the simplest and surest form. If planning methods are economical in the machine shops, might not a similar effect from planning for the foundry, be hoped for more especially when the use of machines is involved. Under ordinary conditions there are many troubles and difficulties in the manufacture of a mould for a casting, and even in the casting itself, which can be seen and counteracted, prior to any time being spent on the pattern. If definite troubles can be provided for, the resulting casting will be more economically produced and nearer the ideal.

Effective Economies.

The engineer or foundryman who has realised the advantages and possibilities of moulding and coremaking machines, finds it possible to have castings produced fast enough, and with a degree of accuracy, well nigh meeting the production engineer's demands.

Undoubtedly, what strikes one as a *most extravagant use of time*, is the time taken to hand man-ram a half mould, in a box, say, 6 ft. × 6 ft. × 2 ft., when the same mould may be rammed, in a very few moments, say, on a jolt machine. Next, in withdrawing the pattern by hand or crane there is firstly, the time spent in rapping, secondly, the attaching of withdrawing gear, and thirdly, the time and exceptional care required to withdraw the pattern, with as little damage to the mould as possible. With a pattern-drawing machine the vibrating and withdrawing of the pattern is accomplished in the matter of a few moments. If the pattern is well arranged and manufactured, the possibilities of damaging a mould are very remote, thus eliminating the time spent in repairing moulds, a factor which almost invariably occurs when withdrawing a pattern by hand or crane. In this operation, the machine not only results in an economy in time, but has a much further reaching saving, in the matter of the life of a pattern. The bill to meet the damage done to patterns by hand rapping, particularly when a heavy hammer is used, is an expensive item, when converted to money, for, say, a period of a year, whereas, *wood patterns which are used on machines, will last for many years, and be as good, if not better,* than on the day on which these left the pattern-shop as new.

The use of loose pieces in moulding, with, in many cases, resulting inaccuracies, is to be much deprecated, when in many instances an alteration in design, or a simple core, saves time and gives greater satisfaction. In the matter of making cores, *it is very often much more expeditious to make a core in two, or three parts, not only for making, but for handling in the green state*, particularly if the finished core is of a very irregular contour, or has internal intricacies.

When coring an intricate mould in the ordinary foundry method it often happens that the closer has to think all the time as to how, and when, the cores must be placed in the mould. *There is no doubt that such an operation as coring a mould may be planned, ensuring that any core goes into its correct place in the correct way and in its proper order, and, once placed in the mould, need not be withdrawn.*

Foundry Planning.

The following is a short description of how a planning scheme has been successfully carried out for the speedy and economical production of castings used in general engineering, these castings varying in weight from a few lbs. up to two tons.

Some of the illustrations which are shown and described are of moulds for iron castings, made in accordance with such a scheme. The moulds, made on jolt, roll-over, pattern-drawing machines, and the cores—of silica sand—turned out on to flat plates, whenever possible, either by hand or by machine when too large or too heavy to be manœuvred by hand.

Planning Procedure.

When a detail of any standard piece of machinery—in the form of a casting—is designed, a copy is immediately issued to the foundry planning department, for the consideration and elimination of the patternmaking and foundry difficulties which may be incorporated. The procedure under such circumstances is as follows:—(1) Consideration of the various ways of making the mould, and in conjunction with this, how the casting will be cast. (2) Consideration of the most suitable type of mould, whether green sand, dry sand, or silica sand. When considering the type of mould it must always be remembered that if a dry-sand mould is used, there is firstly the expense of drying, and secondly, the loss of the use of the box while in the drying stove. This is a very serious matter when on production. (3) Consideration of where and how the pattern will be parted if a split pattern is necessary. When these three points have been discussed and settled, a plan, and if necessary, sections, of the mould are drawn out. This drawing, generally designated a "Method of Moulding" drawing, permits one readily to visualise the various patternmaking and foundry difficulties in the design. (4) Difficulties encountered due to design in relation to the withdrawing of the pattern from the mould; also intricacies in the corebox manufacture and core making. (5) Probable difficulties due to design, such as draw, contraction, etc. (6) Ensure proper venting, and (7) gear required.

If any alterations to reduce patternmaking costs or facilitate moulding are considered necessary, these are marked on the detail drawing or shown on a special drawing, and returned to the designing office, where, if possible, these alterations are incorporated in the final design.

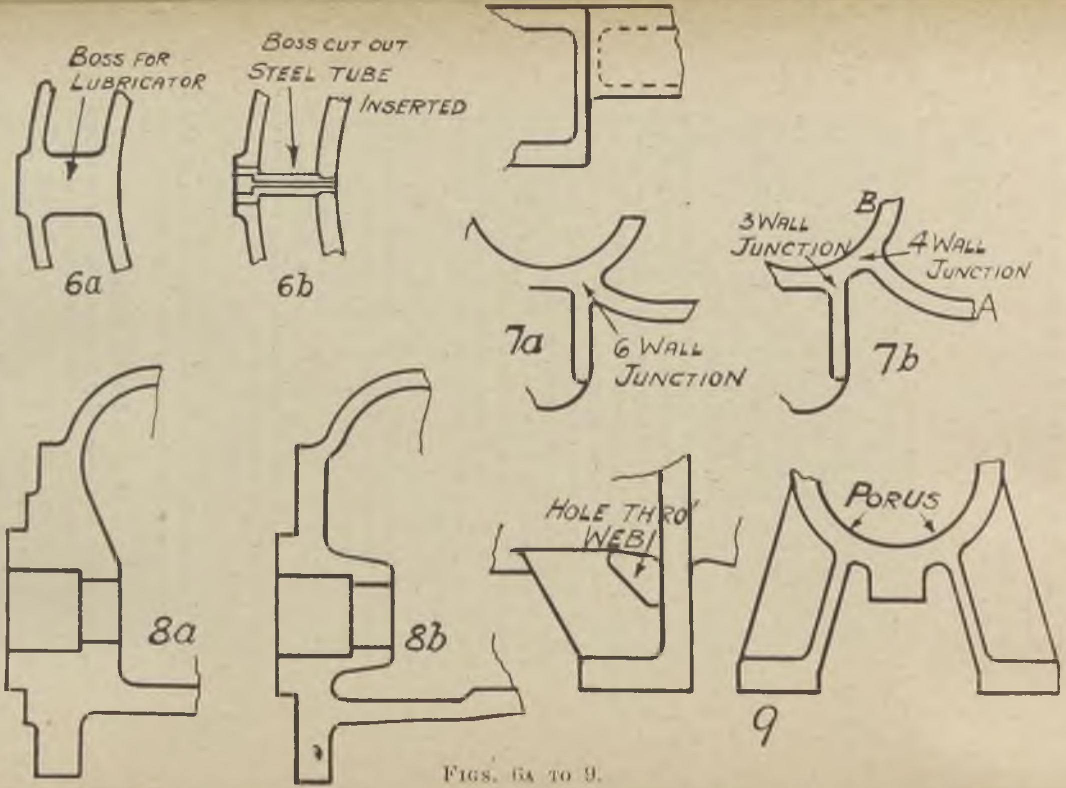
When the final design is issued a complete "Method of Moulding" drawing is made embodying the following:—(1) Patterns required. (2) Size and shape of all core prints. (3) Joints of cores indicated, where a complete core is made in parts. (4) Arrange for the minimum number of coreboxes most suitable for the expeditious production and handling in the foundry. (5) Any exceptionally difficult core-box is detailed and the arrangement of any interchangeable, loose or removable pieces clearly defined. (6) Core-locking and registration devices are arranged. (7) Ensure that all cores are rigidly held in position, and if chaplets are necessary, the number and position of same are fixed. *Every chaplet in a mould, especially a stud chaplet, is a plentiful source of danger to the production of a perfect casting, therefore too much stress cannot be laid on the fact that these must be eliminated wherever possible, particularly in moulds for important castings;* and (8) decide on how mould will be cored, carefully watching core clearances.

With large cores, when special core irons are considered desirable, these are designed and made of steel in place of the usual cast-iron grids. This type of core iron does not get broken as the cast iron does when the cores are being knocked out. Provision is made in the core-box for carrying such core irons, making their insertion the simple and expeditious operation of laying the iron in the registration pockets and on the supports. Provision is also made for handling large cores.

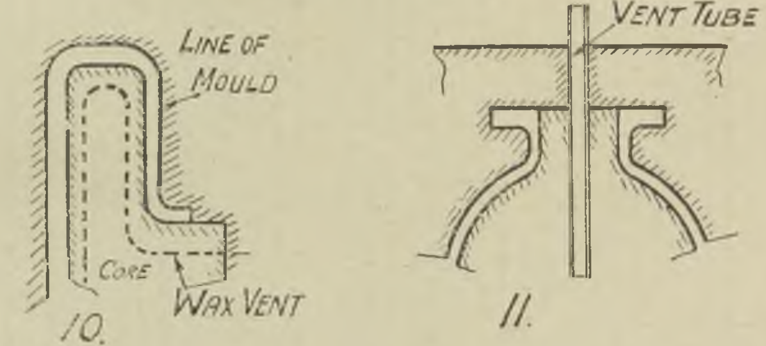
To explain more fully the various points of the foregoing procedure a few illustrations are necessary.

Ways of Making Mould.

In many instances this is governed by the shape of the casting, and in others by the duty which the casting will be called upon to perform. The mould may be made for coring and closing horizontally, and arranged for either horizontal or


Boss for Lubricator
6a
Boss cut out
Steel tube
Inserted
6b
6 Wall
Junction
7a
B
3 Wall
Junction
4 Wall
Junction
A
7b
8a
8b
Hole thro'
Web
Porus
9

Figs. 6a to 9.



Figs. 10 and 11.

vertical pouring; or again, it may be made for coring when in a vertical position. This, together with "type of mould" and "parting of pattern," will be more fully discoursed upon when illustrations of moulds are detailed.

Another phase, "Troubles encountered with regard to draw of Pattern from Mould and intricacies in Core-making," calls for the following remarks:—

Fig. 1 *et seq* show a few cases—which are fairly general—of difficulties in moulding and core-making, due to the design, and how these difficulties may be overcome without disturbing the general design of any casting.

Fig. 1a shows a support having machining faces which necessitate either loose pieces with their ofttimes irregular effects or cores, but may be made flush, as 1b, which gives an easy draw with a better-looking finish. These faces are then machined by a spot facing.

Fig. 2a is of a similar trouble inside a valve chest. This also entails the use of a loose piece, sometimes a very delicate piece, especially in a thin section low-pressure Routledge valve, or an extra core, either of which can be obviated by having the chest designed as at 2b. This is a serious difficulty in globe or straight-through valves.

Fig. 3b shows how a rather difficult piece of foundry work, 2a, is overcome by altering design. The flat wall, 3b, is brought straight up to the outside of the flange, the inside of the flange being taken out with the main core. *This is a particular case where the duty which the casting is called upon to perform must be taken into account, as the section* 3b *is not by any means as strong as* 3a.

Fig. 4a is a very common arrangement of branches on any cylindrical casting, and the moulding and coring of the angled branch are operations which take a considerable time. Such branches are very often only for pipe connections. By pointing out the difficulties both in moulding and coring an alteration as shown at 4b in all probability may be arranged. Whilst this is rather an extreme case, the advantages gained in the foundry by this alteration are very obvious, and it is also of great benefit to the machine shops, as there is only one setting required when machining the faces.

Fig. 5a shows an air vessel having a boss for an air cock. No matter what finish is called for on a job, an extra boss, as shown at 5b, will not spoil the look of the job nor waste an excessive amount of material, yet it cuts out the making of a half-pattern, *i.e.*, when the pattern is mounted on a plate, also eliminating the necessity of changing the half-patterns when moulding. It is also a most suitable way of making provision for jobs which are handled.

Fig. 5c is an alternative arrangement requiring only one half-pattern and yet having only one boss on the casting. The interchangeable pieces x and y are changed over when one half of the mould is made, which change only necessitates the manipulation of a few screw nails. *This method can be adopted on innumerable occasions for branches, brackets, facings, etc., on patterns or in core-boxes, as* Fig. 5d.

These simple illustrations show various points which are very often overlooked and might with advantage be embedded in the design of fairly large castings.

Alterations to simplify moulding and coremaking are also a benefit in pattern making, as each one decidedly reduces the cost of pattern making.

Fig. 6 shows various alterations which have been carried out in one casting to reduce patternmaking costs and simplify moulding. Freehand sketches similar to the "altered designs" were submitted to designer and incorporated in the final design. The first alteration reduces patternmaking costs by having a straight wall in place of three changes of contour, and also cuts out the additional cores, which involved core-boxes and coremaking or working with a loose flange in the foundry. The benefit of a much stronger mould and core is also obtained.

The second alteration cuts out a curve in a very slender drain core. The core is illustrated by cross section and "as designed" entailed the manufacture and working with an awkward corebox. The altered design is a much more straightforward job; also the core is stronger when the possibilities of bending are considered, due to weakening of core by heat from metal. The third alteration to an oil box drain sump is self-explanatory. When the advantages gained by such alterations in design are once pointed out to the drawing office staff they quite naturally carry them out in all work, and it becomes a matter of course, yet has very far-reaching effects, even in jobs which are not standard.

Fig. 6a shows two cylindrical walls of metal with a boss for a lubricator between. This boss, very thick in comparison with the adjoining walls, would in all probability have shown a considerable draw when drilled, necessitating bushing with steel. Fig. 6b shows the boss cut out and a steel tube inserted. In the manufacture of the core-box this boss is certainly an additional expense, and again, if inclined from the vertical, *i.e.*, as the box draws from the core, it is a very awkward part in the core making. Overcoming these latter two difficulties in themselves quite warrant the alternative method being employed.

Fig. 7a is an example of six walls of metal meeting at one point, and this is undoubtedly a fairly certain source of draw. It is not only the joining of the walls of metal, but it is the formation of an *aggravated T section*. To reduce the volume of metal at the junction the vertical walls were separated, as shown at Fig. 7b, where wall A is made to join wall B radially.

Quite a common form of junction of walls of metal is shown at Fig. 8a, also an abnormally thick portion. With the casting designed as at Fig. 8b these sources of draw are perhaps not entirely overcome, but the chances of draw are greatly reduced. Where the circular wall meets the vertical wall tangentially (Fig. 8a) there is an excessive thickness, which is cut out by the alteration as in Fig. 8b. The under side is also reduced in metal.

Another method of preventing draw not very often resorted to, particularly in cast iron, is in taking the corner out of a web, as shown in Fig. 9. This is seldom if ever shown on a detail drawing, and if used in the correct way does not weaken the web. Castings when machined prior to having this corner taken out showed a considerable draw and were rejected at test. This is often carried out even before a trial casting has been made.

One reason for abnormal changes of section in castings is that the draughtsman quite overlooks the additional metal required for machining. To take the example of a cylinder barrel, say finished at 1 in. thick, having ports and attachments, such as supporting brackets, the connecting walls will generally be found to be about $\frac{5}{8}$ in. thick. The variation in metal thickness does not look exceptional as drawn, until $\frac{1}{4}$ in. machining is added, when the difference in metal thickness is increased to 100 per cent., *i.e.*, $\frac{5}{8}$ in. metal forming a T section with $1\frac{1}{4}$ in. metal.

These illustrations are given to show the type of trouble which is generally embodied in designs and to which the draughtsman gives either little or no thought. *When it is desirable to alter a design it is imperative that an alternative be submitted.* In doing so a lead is given, and once given, it will often be found that the designer can improve upon it.

Venting.

The precautions necessary for easy venting are not so numerous when cores are made of silica sand in place of ordinary sand. Due to its free venting qualities, it is very seldom that an additional core vent hole is found necessary. Wax vents are practically eliminated, and are only used to ensure that a vent reverses, Fig. 10, or, in the case of a very fine core, that the vent may be kept open where the section of sand is very small and irregular and the quality must be varied a little and strengthened by additional bond.

By cutting channels in the centres of the cores before pasting the halves together, a very free vent is obtained. It is often found advantageous to insert a tube into a core centre, as Fig. 11, giving an easy exit for the gas from a large volume of core sand, thereby reducing the chances of a blown casting.

Gear Required.

On completion of the Method of Moulding Drawing there is tabulated the following:—Patterns necessary, whether one-half pattern or cope and drag patterns. When two half patterns are necessary respective halves are marked cope or drag. In some cases this is done with raised letters imprinting same in mould, so that no mistake will be made when closing. When only one-half pattern is used this is typed " cope " and " drag," thus preventing the chance of only making a half casting.

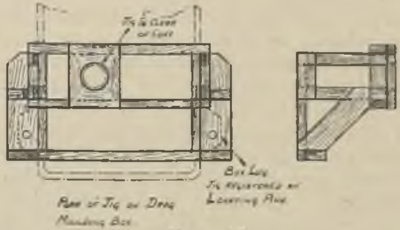


FIG. 12.

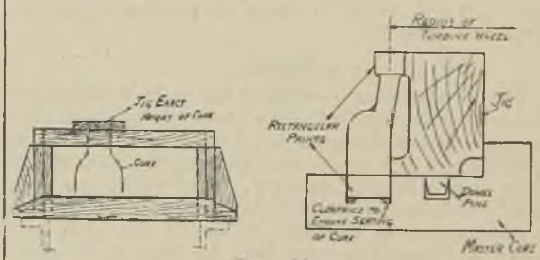


FIG. 13.

All core-boxes are scheduled and given an identification letter, which is imprinted on the core by a raised letter in the box. For a complete box the letter is, say, A, but if the core is made up of various parts, each part has the addition of a numeral, such as A1, A2, and so on.

A copy of the planning drawing is now forwarded to the pattern shop, and is used in conjunction with the detail drawing. This ensures that the manufacture of the patterns and core-boxes is most expeditiously carried out, as the patternmaker has only to think on the actual construction of patterns and core-boxes.

Should a jig for core-building or alignment of a core in the mould be considered necessary this is also arranged and detailed. Such jigs, made of wood, are constructed by the patternmaker from a jig detail drawing. Figs. 12 and 13 will show exactly the types of jigs referred to. Fig. 12 illustrates an arrangement of jig for the alignment of a core before putting cope mould in position. The thinner the metal of a casting, the more serious are the effects of the slightest inclination of a core from the vertical. Such a type of jig may be practically a false cope mould, registered truly by the locating pins and governing the exact position of various cores. This jig cuts out the necessity of trying green sand copes for even thicknesses. Fig. 13 is an illustration of a jig for positioning the cores of a turbine nozzle segment. The jig is registered in the master core by dowel pins, and the nozzle cores are positioned, truly vertically and radially, also the correct height is assured.

On delivery of patterns, core-boxes, and any special gear required at the foundry, there is forwarded to the superintendent all information necessary for organising the production, which includes:—(1) The pattern plate on which the pattern is to be mounted. (2) The moulding box most suitable for the mould, and for which the pattern plate is arranged. (3) The number of cores, or parts of cores, required for one casting. When a core is made in parts, information is given on the parts which require pasting together, each part being easily picked out by the identification letter and numeral. If it is necessary to file a fillet on any core this information is also given, so that the core is finished and ready for the mould on leaving the core room, and (4) the order in which the mould must be cored. This includes the hanging of cores in the cope, a practice which is avoided if at all possible.

If any casting has to withstand an exceptionally severe test pressure, say, from 500 to 2,000 lbs. per sq. in., this information is also forwarded to the foundry superintendent.

Pattern Shop Practice.

There are a few general instructions which the pattern shop must work to. The patterns and coreboxes must have a better finish than for hand moulding, particularly as to joining of timber, general finish and painting. All fillets, when possible, are put on the patterns and in the coreboxes, either cut out of the solid wood, which is expensive, but is undoubtedly the better way, or made up of a plastic material. For a standard pattern, from which, say, batches of from 12 to 24 may be made, the fillets should certainly be cut out, but where the batches are smaller, and perhaps not so often called for, the fillets may be made up. This is a point which can only be decided when design and quantity of castings are considered together. Patterns need not always be of heavier construction for use on machines, but the internal construction should be arranged to permit of patterns being well secured to plates. In jolting and vibrating they certainly have to withstand a very severe strain, but this is evenly distributed, and not so destructive as in the case of hand moulding, when a hammer is used on internal bridges and ends.

.*It is essential* for speed in coring that all core prints fit exactly in the drag mould, therefore patternmakers must work with a much greater degree of accuracy than is usually the case where stamping, carding, shaving of moulds and sprigging is constant *practice.*

For ordinary foundry practice patternmakers generally make prints on patterns larger in diameter than actual core print, necessitating the closer adjusting the core. This means stamping and sprigging, thus taking time which is additional on the production of the casting. Accurately fitting cores prevent metal from passing over the ends of cores and stopping venting.

Again, patterns very often show a lack of consideration of the foundry, by the length of prints on patterns for very large cores. These are often made too short to give sufficient surface to transmit the upward pressure to the mould.

On account of the lighter designs now put forward, and of a reduction on machining allowances, cores must be truly registered and held in position. Pattern-making costs are, on the whole, higher, but the more intricate a pattern, or to take the other extreme, the simpler a pattern, the nearer is the cost of planned patterns to that of patterns for ordinary methods. There is a saving in the cost of repairs to patterns if used on machines, and this must not be overlooked when initial costs are considered. The quality and construction of patterns can be graded for machine work, depending on the number off just as patterns are graded for ordinary methods.

The next few figures illustrate a few closing, core-locking and registration devices to facilitate speedy coring and closing of moulds. Fig. 14 shows a circular end print for a mould when cast horizontally. Complete circular prints are only made use of when the core is fairly short, in comparison with the diameter. When two half-patterns are necessary the core fits exactly in the drag mould, but the cope mould is made clear on sides and end to avoid a crush. The cope mould bears on the core print for about one-third of the circumference. This is allowed for in the construction of the pattern, and is worked to in all cases wherever possible. When a circular core is of considerable length, and the upward pressure due to the displacement of metal becomes very great, it is always better to transmit same to mould by a flat surface. Fig. 15 is of a round core with a flat on the print. Clearances in cope mould as shown are arranged for on pattern.

If a core has projections, or must be set very true, it becomes necessary to make print as Fig. 16. The taper on this print is made such that, when lowering the core into mould, the print will touch the mould before any projecting part fouls other cores or side of mould. A print of this type is very good practice when an adjoining core is hidden or hung in the cope, as it ensures accurate matching. The length of such prints is usually about one-third of the breadth for large cores, but in the case of a small core, say, 1 in. dia., the length would be 1½ times the diameter, and the diameter of print would also be enlarged, as shown by Fig. 19 print B. This enlargement ensures a better seating, also, when small cores have small prints, there is a tendency for the sand to fritter or crumble away.

Fig. 17 shows how scraping of mould or filing of core is eliminated when coring vertically or closing over a core. The print fits at the casting, but is clear at the end of the print. When a horizontal core has a blind end, Fig. 18, it is advisable to make sure that the core cannot be inserted too far. This is prevented by the bridge of sand at A. In some castings, chaplets are not permissible, and when such is the case the core print is made heavy enough to counterbalance the overhang, and prevent the core from tilting, thus avoiding sprigging and perhaps a crush when closing.

To prevent the necessity of thicknessing, and ensure proper alignment of internal horizontal cores which butt, Fig. 19, a keyway and key are arranged for, in core-boxes of adjoining cores. With such a registration device it is necessary to have clearance at the external print in the drag mould, to allow of lowering the core to correct the level before sliding the key into keyways.

Fig. 20 is an illustration of how two cores, one vertical and the other horizontal, are truly registered in all directions to one another. Fig. 21 illustrates how a port core for a steam cylinder casting is registered into main barrel core. This is for a mould closed horizontally. The port core is of a fairly narrow section, but the print is given extra width, ensuring better registration, and also a more secure anchorage for the core iron. Each of these devices, and many others are used in various forms and in various ways, as the type of core or mould demands.

Contraction.

When a standard product warrants the additional expense of metal patterns and core-boxes these are designed as an ordinary engineering job, and finished with tool room precision. In figuring up the pattern details for it, contraction in the castings is allowed for, but not the usual pattern-shop rule contraction for iron, 1/10 or 3/32 per ft. all over. The contour of the casting and direction of contraction is considered. In an ordinary cylindrical casting the lineal contraction may be $\frac{1}{8}$ per ft., but in the diameter only 1/16 per ft. In some instances it is better to neglect contraction, such as in a casting having three circular sections connected to one another. Each circular portion contracts towards its own centre, but the contraction between the centres is negligible. These centres would be made to standard rule, and the allowance in each circular section would be 1/16 per ft.

The various points in the foregoing general description of the smaller details in planning, along with points Nos. 1, 2 and 3 can now be more fully dealt with.

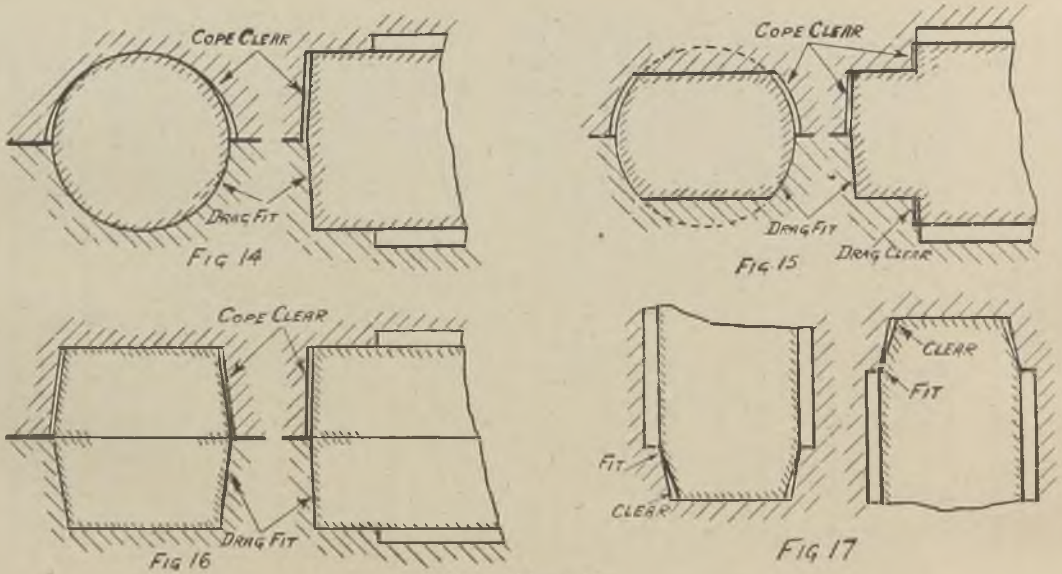
Fig. 22 shows an arrangement of a mould for cast iron casting. The duty of this casting is comparatively light. The casting weighs 11.5 cwts. Each half moulding box is 7 ft. × 4 ft. × 2 ft. deep.

As to the " Ways of making the mould " there are obviously two ways in which this may be moulded. One is with the open door down, and the other as shown. The door face is a machined face, and generally, machined faces are arranged either down or vertical, thus ensuring a perfectly clean joint on machining. The disadvantage of having this face up is the possibility of dirt floating to top of the mould and showing in the machining. To meet such a contingency the machining allowance may be increased by 1/16, $\frac{1}{8}$ or 3/16 in., depending on the size and shape of casting. The more complicated the inside of a mould, the greater is the possibility of dirt accumulating and rising to any machined faces, therefore, any additional machining thought necessary is marked on " Method of Moulding " drawing for patternmaker. In a mould such as this, having a simple contour and only one internal core, 1/16 in. addition machining on door face is quite sufficient, *i.e.*, $\frac{1}{4}$ in. machining in all.

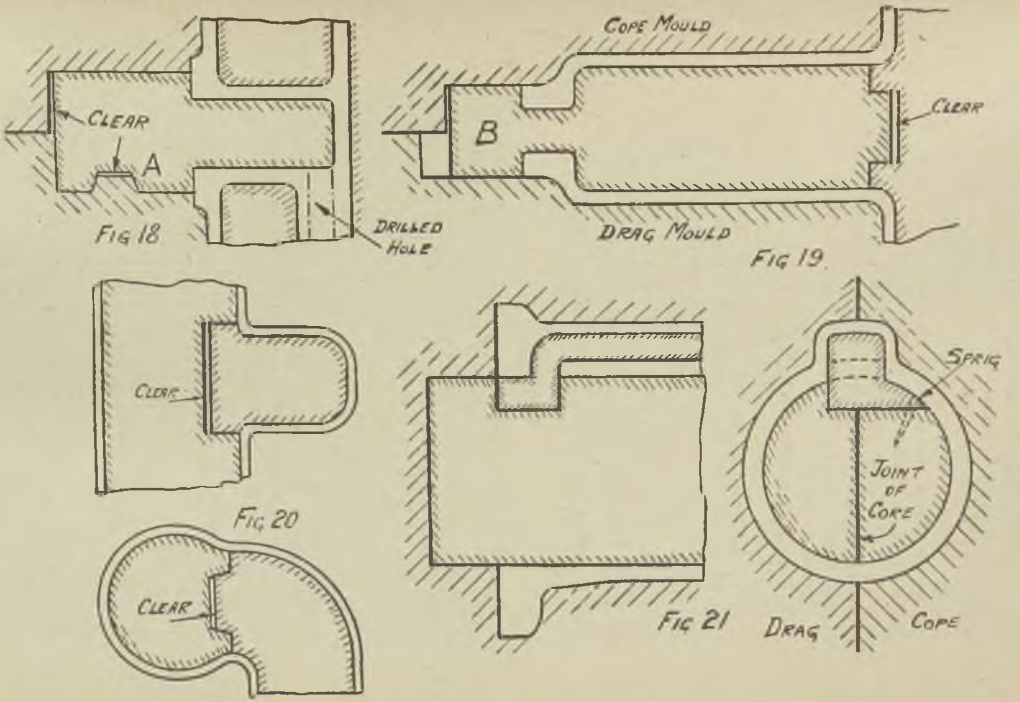
Undoubtedly the greatest problem with this mould is the floating of the core. If the door were cast-down, this would necessitate anchoring the core from the core iron, to the underside of the drag box bars, an operation which takes considerable time, and for which provision must be made when making the core. By making the mould as shown advantage is taken of the core in bearing direct on the cope mould thus eliminating the necessity of anchoring.

In considering the type of mould most suitable, *i.e.*, either green sand, or dry sand, the simplicity of contour and absence of numerous cores lend themselves to the advantage of a green sand mould, but this, however, has disadvantages, due to the size of mould, shape of casting, and imperfections of machines which outweigh any advantages.

It is evident that there is only one way of parting this pattern no matter whether the mould is cast with the door up or down, and that is longitudinally as shown. An alteration in design as


COPE CLEAR
DRAG FIT
FIG 14
COPE CLEAR
DRAG FIT
DRAG CLEAR
FIG 15
COPE CLEAR
DRAG FIT
FIG 16
FIT
CLEAR
CLEAR
FIT
FIG 17

FIGS. 14 TO 17.


CLEAR
A
Fig 18
DRILLED HOLE
COPE MOULD
CLEAR
B
DRAG MOULD
Fig 19
CLEAR
Fig 20
CLEAR
Fig 21
SPRIG
JOINT OF CORE
DRAG
COPE

Figs. 18 to 21.

illustrated by Fig. 3 was carried out on this casting. In this particular casting there are no points which are liable to cause draw, as the metal thicknesses are very even all over. Venting is satisfied by having the open door up the core when the gases have a direct flow up through the cope mould. The gear required for this casting necessitates the use of two half-patterns and two half-coreboxes. Actually special core irons were designed.

The end print B (Fig. 22) is made rectangular in this case, to ensure that when the complete core is in position, the inside of vertical wall of door will be parallel to the outside of the wall made by the cope mould, thus giving an even metal section. The cope half end-print B is made rectangular to obtain a large flat surface to transmit its full share of the upward force due to the displacement of metal. The core is made in two parts—A1 and A2, these parts being turned out from coreboxes on to flat plates on joint face where indicated.

Coring.

In coring A1 is inserted in drag mould, then A2 is placed on top, being lined up by edges of halves matching. Clearance is allowed for on ends and sides of cope pattern prints, thus eliminating the necessity of cutting clearances in mould or may be crushing. The mould is now closed and runner and riser boxes arranged for pouring. For such a casting as this the pattern shop only get the general outlines of the cope and drag, and also some general particulars of the prints, additional machining, or any other special features thought necessary. No elaborate drawings, however, are necessary.

Fig. 23 is a section of mould for a steam turbine nozzle segment casting. The number of nozzles in a segment may vary from four to twelve. This casting, the most important in the manufacture of a turbine, demands the greatest care and precision. The registration and alignment of nozzle cores in master core is illustrated by Fig. 13. The casting is made completely in the drag mould, thus cutting out any minute discrepancies which are possibly due to inaccuracies of moulding box pins. The contour of the master core is parallel with the edge of the flange of the segment, except for registering keys as illustrated. These three keys fit exactly in mould, but the mould is otherwise clear of master core round the edge. This gives the most accurate location, *i.e.*, a three-point location. The mould at the outlet of the nozzle is also ample clear to avoid scraping when placing the master core in position, the nozzle cores being entirely hidden.

Such castings formerly made in dry sand moulds are now made in green sand moulds, as all the features which are liable to result in inaccuracies are controlled. The principle of this arrangement may be applied to turbine nozzle segments cast in nickel steel or other sheet metal blades.

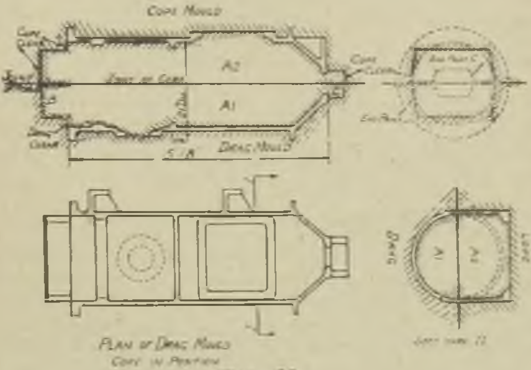


FIG. 22.

Fig. 24 is an arrangement of mould for a cylinder casting, the internal diameter of which is 16½ in. The walls are ½ in. thick, and the weight 5 cwts. This mould is built of cores G, H, H, J, and these cores are made entirely of silica sand. No moulding boxes are used in making this casting. This type of mould is very suitable for castings where accuracy and weight are two very important factors, also when more than a two-part job the expense of making mid part boxes is dispensed with, which is a consideration when there are not many castings to make.

The casting was designed as shown, but altered to reduce pattern-making costs and facilitate moulding. By making the water chamber symmetrical about the centre line Y Y only one part pattern is required for making cores H, H, *i.e.*, three part patterns in all G, H, J, and it also cuts out the manufacture of a half corebox for core C. The boss, as indicated, is duplicated, thus preventing handling when making cores H and C; also eliminating the possibility of error when building.

The external cores, all equal in depth, are made in a "Universal" corebox, *i.e.*, a corebox which is designed to take any pattern within its range of diameter and depth. Maximum depth of pattern permissible is depth of box, but to accommodate shallower patterns a false bottom is inserted. The changing of a part pattern is only the matter of a few moments, and does not necessitate disturbing the box or fastenings while on the machine table.

Manufacture of Complete Mould.

All cores are turned out on to flat-plates at joints of cores, as is indicated by heavy lines.

External Cores.—Part pattern J is fixed in the universal corebox and one core made; the part pattern H fixed in the universal corebox and two cores made, and finally part pattern G fixed in universal corebox and one core made.

Internal Cores.—Two half-cores are made from corebox A, the halves are pasted together, a loose downgate, and the runners are in the box; two half cores are made from corebox B, the halves pasted together, the loose downgate being in box; core B is made $\frac{1}{16}$ in. short to allow for the settling of the external cores when drying; two half cores are made from corebox C. They are not pasted, and must be put into the mould separately; four half-cores from corebox D, and the halves pasted together; eight half-cores are rammed up from corebox E, the corebox making two halves in one operation, *i.e.*, the right- and left-hand halves which are pasted together and then pasted in position in cores C; two cores are made from box F and pasted to core B.

Building.—Steel channels are laid in position on the floor, and core A is placed upon them and levelled. Then core J is placed over A, the latter being registered by the extended prints on the short pipe bend at the foot of core A. Core H can then be placed on J and registered by the alignment recesses as shown in the plan.

One half-core C is now inserted, and registered by prints into core H. Then complete cores D are placed in position and registered by prints into cores H and A. The centre print of core D is the only one which fits at the sides, thus permitting any slight discrepancy in the exactitude of core adjusting itself. The prints of core D, registering in core A, are clear in the inside as shown.

The second half of core C is now placed in position, lining it up by the matching of the edges on the lower half of C. The top-core H is placed in position, and then core G is positioned. The complete core B is now inserted, having cores F attached. The top channels are positioned across the mould, and four 1in. dia. bolts are tightened up, thus binding the mould together. Loose sand is inserted under the mould to prevent any sagging of the cores due to the weight of metal. The runner and riser boxes are now placed in position, and the mould is ready for pouring. These castings are run as shown—a method which has been found very satisfactory for castings of this type.

Fig. 25 is an illustration of a partly machined Diesel engine cylinder, and Fig. 26 is a typical example of a "method of moulding" drawing for such a casting. This latter illustration, to make it readily understood, is much more fully detailed than an actual drawing would be. This casting, described in its simplest form, is composed of an internal cylinder joined to the external casing, which is partly rectangular in form, by ribs and also by walls of the scavenge and exhaust ports. Due to the size and importance of this casting, it is considered advisable to make this a dry sand mould. The casting is run with the mould in a horizontal position. The pattern is parted along joint of the mould. There are one or two points in the design of this cylinder which necessitated special provision for simplicity of manufacture and closing of mould. Four oval facings were made to draw direct from the sand, as illustrated by section III, III, otherwise these facings would have been loose on the pattern, thereby running more risk of an imperfect draw.

As it is, there are still three facings, two circular and one oval (see section through pattern), which are too large to permit of straightening to draw. These are checked into the pattern, as shown, allowing the pattern to draw clean away, after which the facings are picked out of mould. The sand on the underside of these facings must be hand tucked. Section II, II shows where the cope and drag moulds are given clearance for closing from the extreme points of cores C1 and C2. This is the point which governs the taper of the end prints, as shown by the end view of the pattern. The rectangular print also ensures cores C1 and C2 matching with C3, which are blind for coring and closing. The internal length of core C3 is governed by the internal radius of the casting, as illustrated by longitudinal section through VI, VI. To hold securely the various very irregular shaped cores, forming the water jacket, and to ensure the speedy coring of the mould, the internal keys and external prints are arranged as the illustrations indicate. *Chaplets in this mould are entirely dispensed with, as the cores cannot move in any direction; also thicknessing is quite*

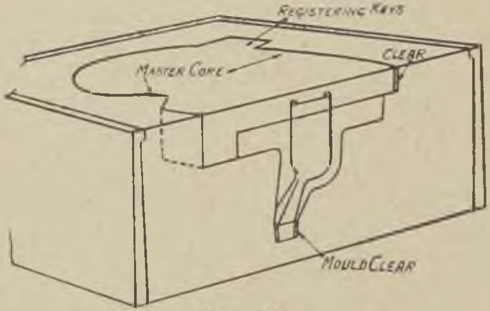


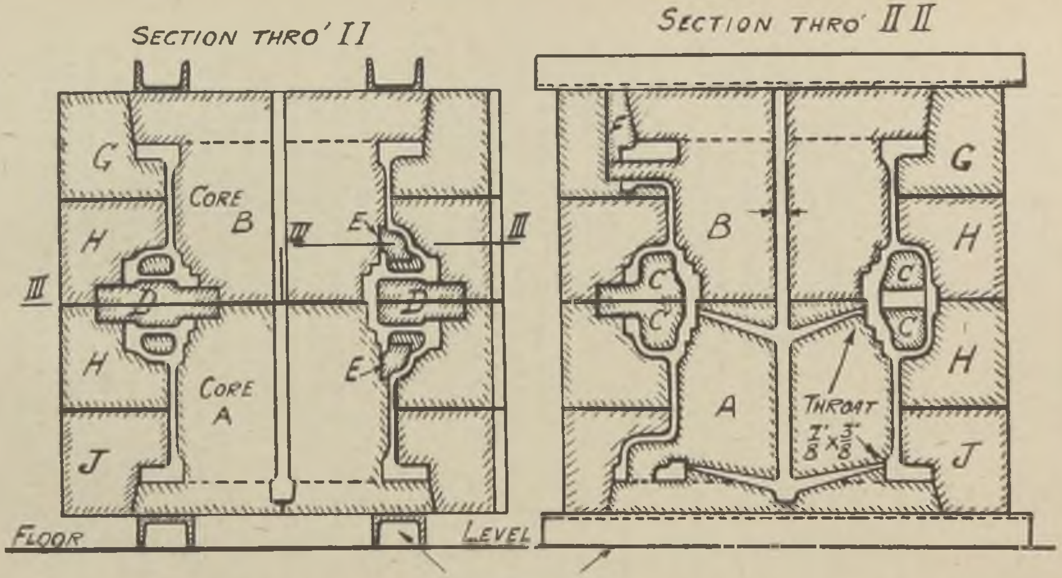
FIG. 23.

unnecessary. The gear necessary and the order of coring mould is fully detailed on the illustration. The various core boxes for this job were illustrated by drawings showing arrangements of removable and loose pieces, which drawings were issued to the pattern shop. The dimension lines on the drawing are dimensions which are fixed for the patternmakers. The overall length and maximum breadth of pattern over prints are controlled. Length of all prints are fixed. The dimensions on left-hand end of the plan controls the position of the pattern in the moulding box to suit the ribs. The depth of the core F is made to suit the maximum depth of the pattern permissible in the moulding box. The clearance in the cope mould is provided on the cope pattern, on end, and the sides of all prints, but the mould is made to bear on top of core prints.

As cores F are fixed in position in the drag and cope moulds and $\frac{1}{8}$-in. clearance is allowed between the cores F and the main core A to prevent scraping when closing, the main core is positioned longitudinally by the projecting prints at the right-hand end where marked " FIT," and is positioned transversely by the end prints. The manufacture of cores for this mould is as follows:—Half cores, A1 and A2, which are turned out on to flat plates on the joint-line faces are made from one corebox, having prints interchangeable for handing, also having vertical pins making the bolt holes.

Core B, which is practically circular, is turned out on a sand bed, the open side of the corebox being the internal face of core, which face is strickled, the alignment of strickle being governed by a central runner fixed on the box, ensuring a true surface. The open sides of coreboxes C1 and C2 are in this case the external faces which are strickled and cores turned out on sand beds.

Cores C3 are turned out on the larger flat face: core D, made in two parts, D1 and D2, both of which are turned out on flat faces of joint as shown in the plan and are pasted together; core E is turned out on the left-hand side, looking on plan of mould: core F, of which there are two parts, one being in the drag and one in the cope, is turned out on the end flat face.



STEEL CHANNELS.

FIG. 24

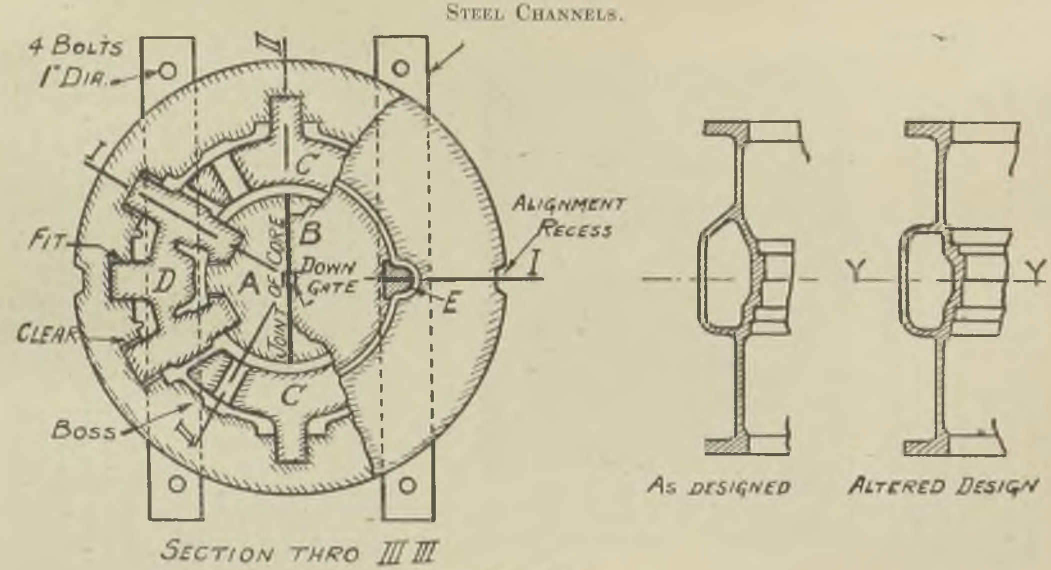

Steel Channels.
4 Bolts
1" Dia.
II
I
C
B
Fit
D
A
Joint of Core
Down Gate
Alignment Recess
I
E
Clear
C
Boss
II
Section thro III III
Y
Y
As designed
Altered Design

Fig. 24.

When the various cores are hung on the main core A in the order given on the illustration, the eye bolts are screwed on the two end bolts which hold the halves of core together. Slings are slipped through the eyebolts and over the ends of the moulding-box lifting-beam. The assembled cores, when suspended, are levelled and then lowered into the drag mould. The cope mould is now lowered on, guided by accurately fitting locating pins. The runner and riser boxes are arranged thus, making the mould ready for pouring.

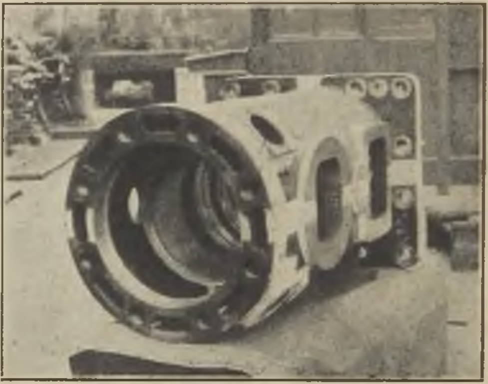


FIG. 25.—PARTLY MACHINED DIESEL ENGINE CYLINDER.

Fig. 27 illustrates two arrangements of a mould for a cylindrical casting. This casting has an opening at each end, set eccentrically to the centre line of the main body. A casting of this design, say 4 or 5 ft. dia. and 4 or 5 ft. long, in a moulding box or pit would require to be run as moulded. In the top view the joint of mould and parting of patterns, if parted, lie on line A.B. This is the simplest way to make this mould, but from a *consideration of foundry facts it is not by any means the correct way.* When the metal is run into the mould, the core on floating has a rotational direction as indicated by the arrow Y, the centre of rotation being the centre of the opening, *i.e.*, the point of intersection of centre lines A.B. and C.D. To hold the core in position by chaplets or other means is a most unsatisfactory arrangement, the upward force not being direct but having a tendency to displace the fixtures. The thicker the metal the greater is this tendency. In coring there is also the difficulty to be overcome of the heavy side of the core drooping. In the bottom illustration, the joint of the mould lies along line E.F. With the centre of the opening and centre of the main body of the casting in a vertical line, the upward force is direct as is indicated by arrow Z—a force which can be readily controlled at end of the core by prints or bar. This arrangement certainly takes more time to make the mould, due to the difference of levels between centre of the opening and centre of the main body, but the core is much more easily handled and more quickly positioned. An even thickness of metal may reasonably be expected.

Advantages of the System Outlined.

There are a few outstanding advantages which foundry work carried out in the manner described has over the ordinary methods:—

(1) From the "Method of Moulding" drawing, a very accurate estimate of the pattern-making costs is obtained, as each pattern and corebox can be visualised and the necessary timber and time of construction readily calculated; (2) the time required to make moulds and cores, the time of closing, and the amount of sand used can be accurately estimated; (3) very many castings, both simple and intricate, which were formerly made in drysand moulds, can be made in greensand moulds; (4) dressing costs are reduced to a minimum, due to the accuracy with which moulds come from the machines and accurately fitting cores; (5) the time of production shows a considerable reduction when compared with the time for similar castings produced in the ordinary way, which induces quicker deliveries. This is a point which becomes more evident every day and may be stated thus: The more intricate the casting, the greater is the difference in time of production between ordinary foundry methods and planned methods; (6) the weight of the castings turned out is the correct

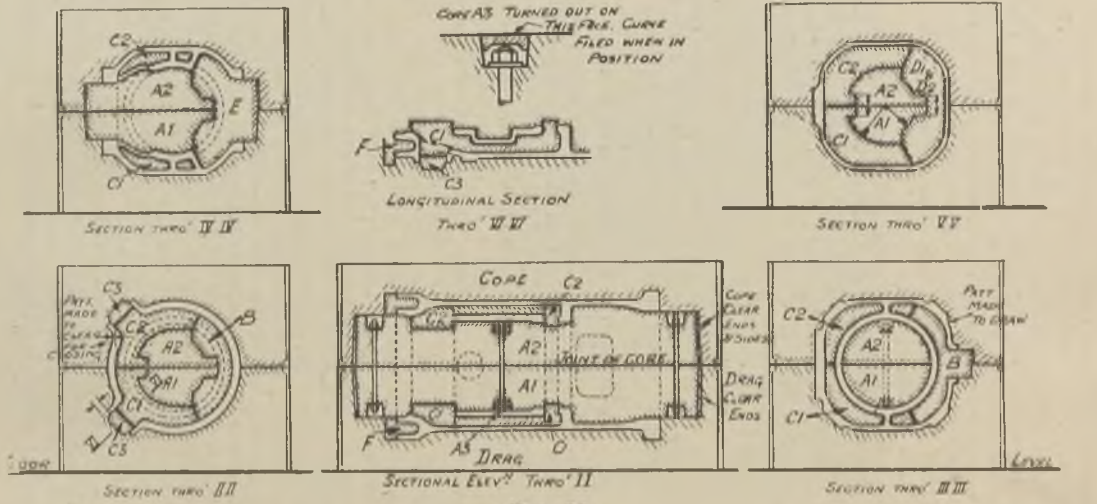
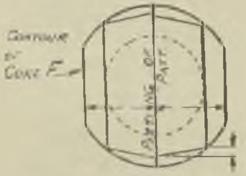
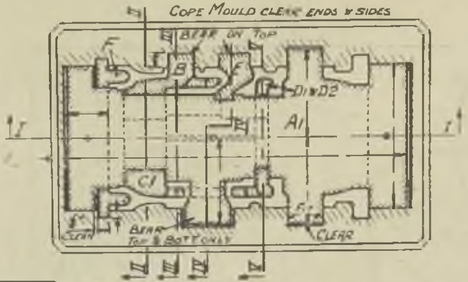

Core A3 Turned out on This Face. Curve Filed when in Position
C2
A2
E
A1
C1
Section thro' IV IV
F
C1
C3
Longitudinal Section Thro' VI VI
C2
D1
D2
A2
A1
C1
Section thro' V V
C3
Patt. made to clear for closing
C2
B
A2
A1
C1
C3
Floor
Section thro' II II
Cope
C2
Cope Clear Ends & Sides
A2
Joint of Core
A1
Drag Clear Ends
F
A3
Drag
O
Sectional Elev.n Thro' I I
C2
Patt. made to draw
A2
A1
B
C1
Level
Section thro' III III

Fig. 26.



End view of Patt



Plan of Drag Mould
Cores in Section

Section Thro' Patt
Shewing Loose Pieces

GEAR NECESSARY
2 Half Patts "Cope" or "Drag" raised letters
1 Corebox Cores A1 & A2
1 " " A3
1 " Core B
2 Coreboxes Cores C1 & C2
1 Corebox " C3
2 Coreboxes " D1 & D2
1 Corebox Core E
1 " " F

METHOD OF MOULDING

DIESEL ENGINE CYLINDER

DETAIL DRG Nº 123
PATT Nº 86

PATT PLATE Nº 7 MLD BOX Nº 9

Nº of Cores		Order of Coring	
Core	Nº off	Order	Core
A1	1	1st	Cores F in Drag & Cope
A2	1	2nd	" C3 " " " "
A3	2	3rd	Main Core with CBDE
B	1		A1 & A2 Bolted together
C1	1		Cores A3 inserted &
C2	1		Filed.
C3	2		C1 & C2 Hung on
D1	1		Core E " "
D2	1		" B " "
E	1		D1 & D2 Pasted & hung
F	2		on Main Core

FIG. 26.

weight and not from 5 to 15 per cent. too heavy, as with ordinary foundry methods. Engineers are always complaining about the excess of weight by which castings exceed the calculated weight. If quotations for castings are based on calculated weights and these weights are exceeded, there is a direct loss equal to the excess of metal in the casting—metal which the engineer does not want;

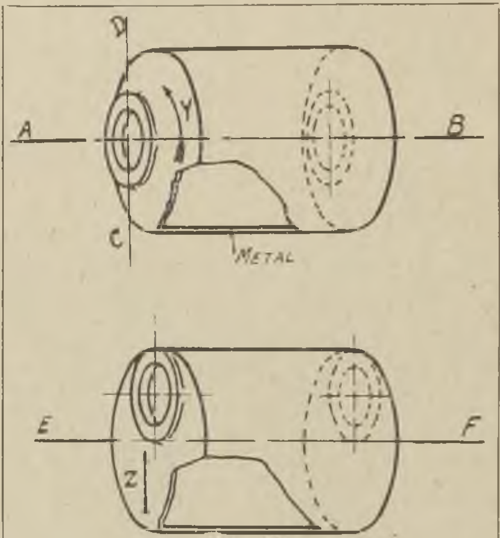


FIG. 27.

(7) economy is not all entirely on the foundry side, as many ports and passages formerly necessitating machining are cast with an accuracy which eliminates machining operations, thus permitting of rapid production in the machine shops; and (8) the regularity of contour and very true alignment of the castings allow jigging for machining. If the castings are machined without jigs or, if marked off on the surface table, there is a considerable reduction in the time of setting.

Conclusion.

If foundrymen wish to have the various troubles and difficulties due to design overcome, they must bring every one of them to the notice of the designing staff either by direct explanation or sketches showing alternative methods, the latter being undoubtedly the better way. This entails that foundrymen must be able to read drawings and make sketches.

The designing staff will always give full consideration to any alteration towards cheapening production or making a good job better. That is their business, and they are always anxious and willing to learn, their training making this a kind of second nature. *For a considerable time now there has been a persistent call for co-operation between the drawing office, the pattern shop, and the foundry, and this scheme, as outlined, is at least one way of accomplishing this end.*

One of the essential features for the successful carrying out of this work is a fairly extensive general engineering training; that is, a general knowledge of the technical side of design and a knowledge of the duties for which castings are designed. A knowledge of machining methods is also a great asset.

In concluding, the author desires sincerely to thank the directors of the Argus Foundry, Limited. for kindly granting him the privilege of describing their methods, also to thank Messrs. G. & J. Weir for allowing him to use drawings of their products as illustrations—kindnesses granted in the interest of general foundry progress.

DISCUSSION.

Mr. Longden said Mr. Ross's Paper certainly contained a great deal of information which represented first-class foundry practice. With regard to Fig. 9, however, Mr. Ross said that taking the corner out of a web was not very often done in cast iron. To his own knowledge, Mr. Longden said that was done twenty years ago by cylinder makers near Manchester. They placed these cores in the cylinders they made at that time. Nevertheless it was very valuable, and well worthy of study. Fig. 17 showed the core engaging the mould at the bottom line of the casting. It occurred to him that if that was green sand work, it was a very bad method indeed, for the simple reason that probably or occasionally the core would get out of the centre. There was one other illustration to which he would like to draw attention. In connection with Fig. 22 Mr. Longden asked how the weight of the core was carried. He presumed that it was a dry sand mould, and he thought that the little print at the outer end of the casting had to take up a great deal of the weight of the core, and that there was very little bearing for the core at the end. The tendency would therefore be for it to sag in the centre. He would much prefer to make that the other way up. He would like to ask Mr. Ross how the planning department of the foundry was organised. Were all these contrivances worked by very expert moulders or by the foundry foremen, or, alternatively, had it a staff of draughtsmen to itself? If it were not done by the foreman he had to get the work laid down and the patterns planned by a department over which he had no control. It seemed to him that there was not much room for a new department for that sort of work, but still it was very advantageous to have the thinking out of the work done before the job was started. It was really the application of commonsense to foundry practice, and it seemed to be work that could not be done outside the foundry manager's office.

Mr. Ross, in reply, said he did not think that the system was anything abnormal, but he did say that they knew what would be done in the foundry once the work was planned. They knew also very closely the cost and time to make cores and moulds. It had been said that Fig. 9 represented a practice that had been carried out for 20 years. He had done so himself for a considerable time, and he had also done so in the design of steel castings. He thought he was safe in saying that few draughtsmen realised the value of taking out the corners of a section of that kind. With regard to Fig. 17, he might say that prints of this type were used in green sand moulds; they found that they fitted very well, as good as sand would allow. The clearance at the bottom allowed for any little grip of the mould, and they worked them every day like that. Referring to Fig. 22, he had pointed out that there was a little neck of sand at the right hand end of the core. There was an opening nearer to the left hand end which helped to support the core, also a chaplet immediately under the door opening, this casting being only a light duty casting. The manner in which planning was carried out he had stated in the Paper he read. The foundry superintendent was consulted, and the foreman might be consulted if required. Generally speaking the duty and quality of the casting was first considered. The foundry foreman had to work with the patterns as arranged when planned and all arrangements were made for machine moulding. In that way matters worked smoothly, and they had few complaints.

Mr. Charteris said what he desired to know was what was done to bring out the capabilities of the highly skilled tradesman. Was the planning staff able to limit the amount of work expected from the man who was industrious, enthusiastic and highly skilled?

The Chairman explained that the planning department had nothing to do with labour or apprenticeship questions, but was concerned only with the actual development of methods.

Mr. Marshall, referring to Fig. 19, said he supposed that was an example of foundry planning work. There were there two cores, and the one on the right hand side of the figure had another core inserted into it. He was inclined to think that the pressure of the metal would press the core back out of its place.

Mr. Ross pointed out that there was a clearance at B in drag mould. The clearance might be $\frac{5}{8}$, $\frac{3}{4}$ or 1 in., depending on the length of key at other end. The core was laid in and the key could then be slipped into the keyway. The clearance in the drag mould could be filled in with greensand. The cope mould had a clearance of about $\frac{1}{16}$ in. and there was no fear that the core would come back. The force was upwards and had a tendency to lift the core. He used that method very often and there was no tendency for a core to come back.

Mr. Laurie said they were all indebted to Mr. Ross for his Paper. The one thing that seemed clear was that there was an intelligence department in Messrs. G. and J. Weir's. The Paper showed them what they were up against when they received patterns from the general engineer, who seldom considered the difficulties which had been referred to. Many jobs came into the foundry which were not just what the foundryman would like, and he had to form himself into a ways and means department in order to make that particular casting. There it was, and he was allowed no latitude but to make it as the pattern had come to him. It was a pity that there was not someone at the elbow of the designer to present the foundryman's point of view. Mr. Ross had an excellent grip of the foundry trade, and he knew what the foundry manager tried to embody in his work. But in time, he had no doubt, the foundryman would get hold of that end of the stick which was his due. In speaking of the bad design of a pattern, he said, they had to keep in mind the fact that the pattern-shop belonged to the engineering side of the business. One thing he might add was that where they got proper designs they could usually get the costs a good deal cheaper.

Mr. Primrose said they had listened to an excellent Paper, and his only hope, as he listened to Mr. Ross, was that the Paper would get into the hands of the engineers. Mr Ross had the advantage of having a foundry and an engineering works combined. But in most foundries they were never allowed to touch a pattern, and in many cases they did not know what the castings were for. An interesting case had come under his own observation. His firm's traveller in the West of England wrote saying he could get an order for a large quantity of conveyor drums which were wanted at a certain price. He said that the company wanting these drums had tried several foundries and they had found porosity in the metal. If his firm wanted the work they could get it at a certain figure. In his view, with the pattern in question, Mr. Primrose could get nothing but porosity. So he wrote to the company suggesting that the pattern might be altered, but he got a curt note in reply saying that that could not be done. He took the work and altered the pattern, and just that morning he had received a letter from the company saying they were the finest castings they had ever had.

The Chairman in closing the discussion said that the planning scheme as outlined in Mr. Ross's Paper was obviously designed for a number of different classes of castings. It had clearly certain limitations when viewed from that standpoint. Mr. Ross did not put it forward as a "cure all" nor in any generalised sense, but merely as a way of handling certain problems. He (Mr. Affleck) could say, as one who had been associated with Mr. Ross in this class of work, that planning had solved these problems, and that it was a success from the important point of view of £ s. d. He could assure Mr. Charters that the Planning Department was under the control of the foundry manager, who also controlled the pattern shop. Every attention is paid to the point of view of the practical man, and this was really the secret of Mr. Ross's success, as all along he had kept in close touch with the man handling the work in the foundry. The effect of this was very much greater than one would think. On the engineering side, the castings were utilised in a scheme organised more or less for mass production. Jigs were made for machining work, and accordingly the castings were required to be true to form so that they would drop easily into the jigs on the machines. A detailed study of costs previous to the institution of foundry planning showed that in some cases foundry costs represented about 60 to 70 per cent. of the total cost. This was partly due to excessive weights and to the production of castings in excess of drawing thicknesses. The system of foundry planning not only led to a distinct improvement in form of castings, but also to remarkable reductions in weight. If one could get $\frac{1}{8}$ of an inch or even $\frac{1}{32}$ of an inch of metal off the surface of a casting all over, the weight was materially affected and also the cost. Mr. Ross has also shown very clearly the important effect of foundry planning on the design department of the engineering side. With regard to patterns, he added, pattern makers were not in the habit of being instructed as to the exact method in which a pattern was to be made. The usual method was to hand the pattern maker the job and let him make the pattern according to his own ideas, but in work of the class dealt with by Mr. Ross it was obviously not advisable to give the pattern maker full powers of this sort. One must consult with the moulder, with the engineer and with the designer, and the pattern must be made to suit the requirements of all as far as possible. Mr. Ross had most ably and most completely described a planning system as applied to a definite class of work, but it was clear that a similar system with modifications could be applied to other classes of work.

A vote of thanks was accorded to Mr. Ross for his Paper.

Newcastle Branch.

THE USE OF CHILLS IN MARINE ENGINE CASTINGS.

By J. W. Frier (Associate Member).

Of the problems confronting the engineer and the foundryman at the present day the manufacture of sound cylinders and cylindrical castings is possibly the most pressing.

Faulty cylinders are responsible for the heaviest losses in both the foundry and the machine shop, and many foundries have been financially embarrassed in attempting manufacture at the present time. The number capable of producing sound cylindrical castings is very limited.

Since starting to write this Paper, the author has endeavoured to find some information and opinions in the printed Proceedings of the Institute, but has only been able to find two Papers dealing with chills or denseners. The late Mr. E. H. Broughall, M.I.M.E., in a Paper given at Birmingham, said: " It is to be regretted that foundrymen have given this most important subject such scant attention, the majority satisfying themselves by using denseners on the most simple castings. It is a subject which has huge possibilities and opens up a way whereby far better products from the foundry can be obtained."

Further on, he says, "As regards the use of ordinary denseners, it is, of course, understood that the necessity for denseners is caused through the uneven rate of cooling of thick and thin parts adjacent to each other. Moreover, a thin part adjacent to a thick part will, under ordinary circumstances, draw metal from the thick part owing to the quicker cooling of the thin part, leaving a spongy place at the junction of the two parts. This, in my opinion, is the cause of many castings failing under water test."

It is not every foreman moulder who has the opportunity of seeing the pig-iron come in by

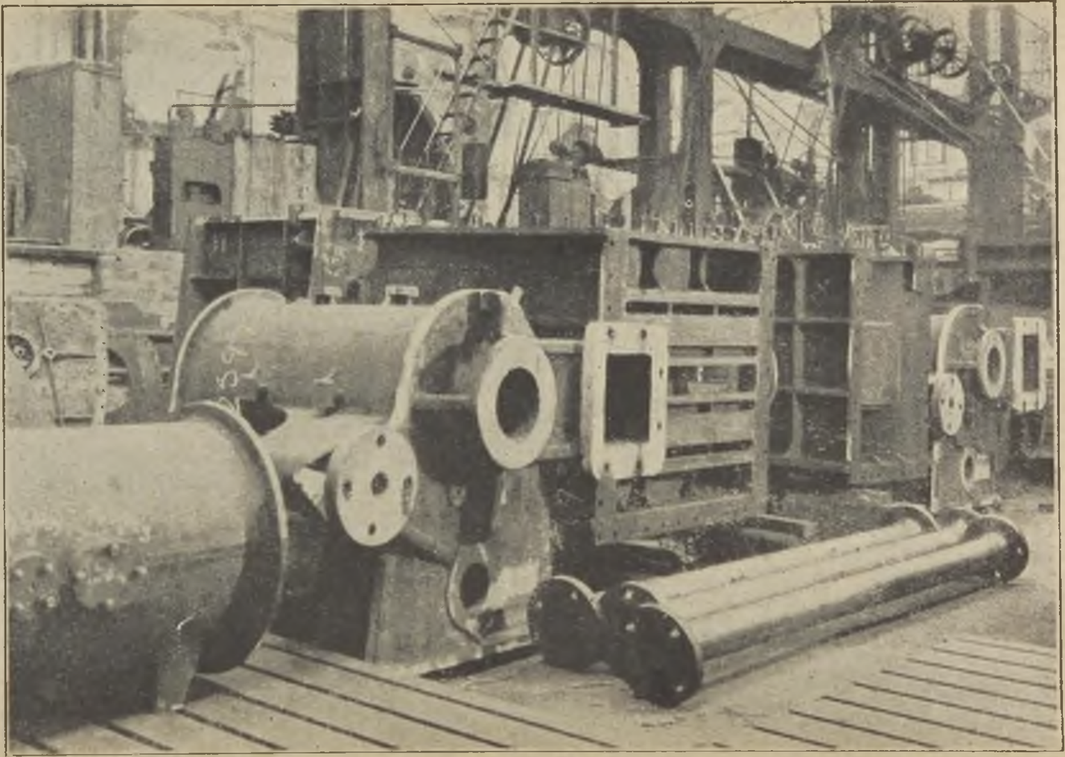


FIG. 1.—MARINE CYLINDERS AT VARIOUS STAGES OF MACHINING.

rail and, after the castings leave his hands, to follow them through the various departments, until he sees them put into the ship, a finished engine.

In passing through the shop he looks for the castings which give the most trouble and anxiety, namely, cylinders. If, when the casting is put on the marking-off table in the machine shop, it is all right, he does not hear anything. He waits, therefore, until the machine man has had his turn at it and that is where trouble may be expected.

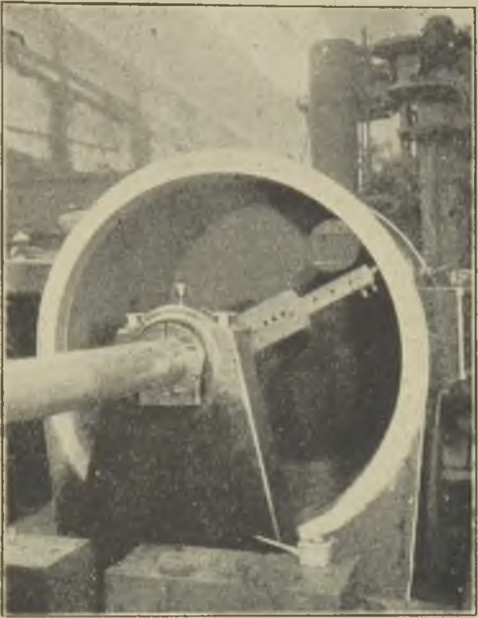


FIG. 2.—MARINE ENGINE CYLINDER IN THE BORING MACHINE.

Fig. 1 shows a number of cylinders at various stages of machining, and Fig. 2 an L.P. cylinder, 72-in bore, on the boring machine.

When one first examines the bore of a cylinder it may be thought to be perfect, but, on closer inspection, it may be found that the metal is more open-grained in some parts than in others. A search for the cause is liable to centre round the outside of the cylinder, the feet, brackets, and indicator bosses, and the question arises "Are these the cause of the trouble? If so, what can be done to overcome it?" In the erecting shop, the casting is drilled, fitted, closed up and tested under water pressure, and again one may look for trouble and perhaps find it in the shape of "weeping."

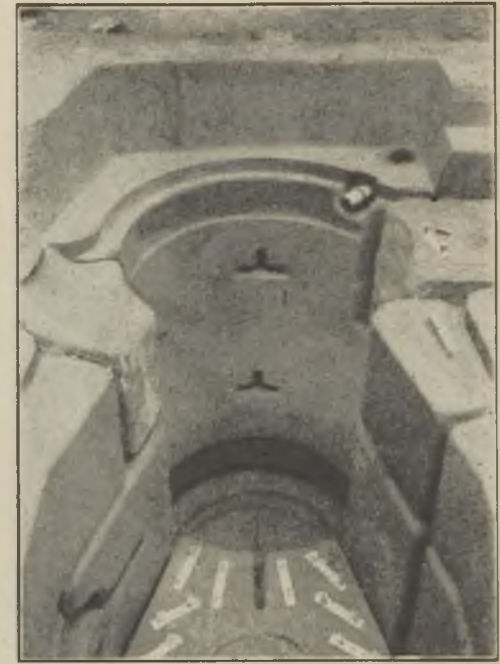


FIG. 3.—MOULD FOR H.P. CYLINDER SHOWING POSITION OF STEEL TUBE AND CHILLS.

Many foundrymen, when visiting the North Eastern Marine Engineering Company's foundry in 1922, saw an H.P. cylinder-mould, finished in

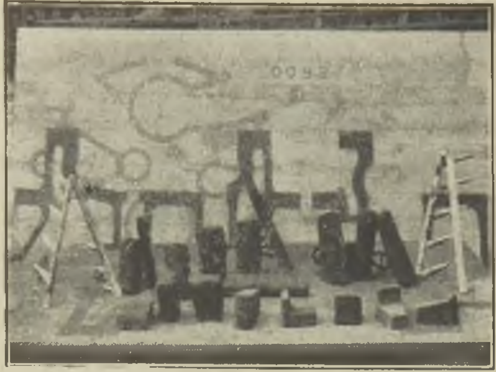


FIG. 4.—GROUP OF CHILLS FOR CYLINDER CORES AND THE MOULD.

FIG. 5.—SET OF CORES FOR A H.P. CYLINDER, WITH CHILLS IN POSITION IN THE CENTRE CORE.

the pit, with a steel tube in the indicator boss, instead of a core. Some asked why it was there —many passed it by. The men concerned have stated that it saved both time and trouble, and, consequently, money, by casting it in that part of the cylinder; so much so that the author has orders to use them wherever possible. The bore of the tube, being the size of the required hole, does not need to be drilled into the thick sections

Fig. 6.—M.P. Cylinder Mould showing the Square Foot Core in Position.

joining the body of the cylinder—where trouble is met. After seeing some hundreds of marine cylinders pass through the shops, the author has found most of the trouble met with is where the body joins the crown and the column feet join the body. All this may be prevented by making the castings crown-down, but, as this is a question for the engineer, with regard to cost and time, this method is only carried out under special arrangement. Other methods of dealing with these troubles is the subject of the Paper.

These are some of the troubles, that every foundryman is up against, which the author has tried in some small way, and, he thinks, with some success, to overcome. It was during a visit to a foundry in Birmingham some years ago that he noticed pieces of plates on the faces of some small cylinder cores, and, not wanting to show his ignorance, he kept his eyes open to follow them. The men were seen closing a mould and the author noticed that these plates were set in

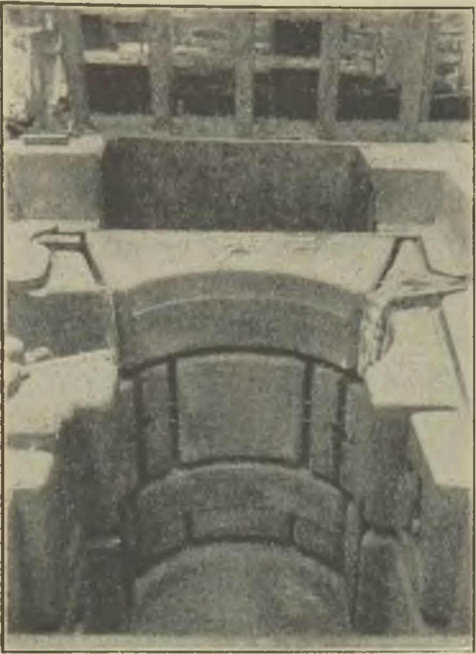


Fig. 7.—M.P. Cylinder Mould showing the Blank Chest with Chill Marked in White.

the cores to meet any cross-sections and thicker parts connecting the barrel of the cylinder with the other parts of the casting. Again, in going through the machine shop, similar castings were seen in the finished state, and with a perfect bore. The castings were for high-speed engines. They had had trouble with open patches in the bore and that was how they overcame it.

FIG. 8.—M.P. CYLINDER MOULD, WITH THE FOOT CORE IN POSITION.

The problem was, however, the employment of similar methods but the high-speed engine castings were much smaller than marine engines and all cores were rammed up in core boxes. Apparently it presented a difficult proposition to apply it to cores built up with bricks and loam and a sweeping board and, therefore, it was decided to tackle the job from the outside of the casting.

The first attempt was an H.P. cylinder, and the author informed the two men making it what he wanted to do, and aroused their interest in the experiment. The first chills used were pieces of broken grates; something like the fillet required where the cylinder foot joins the body. These were placed in position with each ramming of sand, and, when the mould was being finished, they were shaped off. As it was necessary to wait some time to see the effect of this, the foundry continued with the other cylinders and waited for results.

Fig. 9.—M.P. Cylinder Mould viewed from Reverse Position to Figs. 6 and 7.

Attention was then given to the cores to see where a chill would be of some use, and, as the seat of the liner is the heaviest part, it was thought advisable to try chills in the cores to meet those on the outside. These core chills are made so that they can be built up with the core.

In Fig. 3 is seen the mould of an H.P. cylinder, showing the position of chills and steel tube, mentioned earlier in the Paper, while Fig. 4 shows a group of chills for cylinder cores and the mould.

It was then decided to have some patterns made for the chills required for the other cylinder moulds. These should be of a fairly standard size, if possible, and always kept in stock, so that the moulders can just stamp a few in the bed along with their grates. Fig. 5 is a view of a set of cores for an H.P. cylinder with chills in position in the centre core.

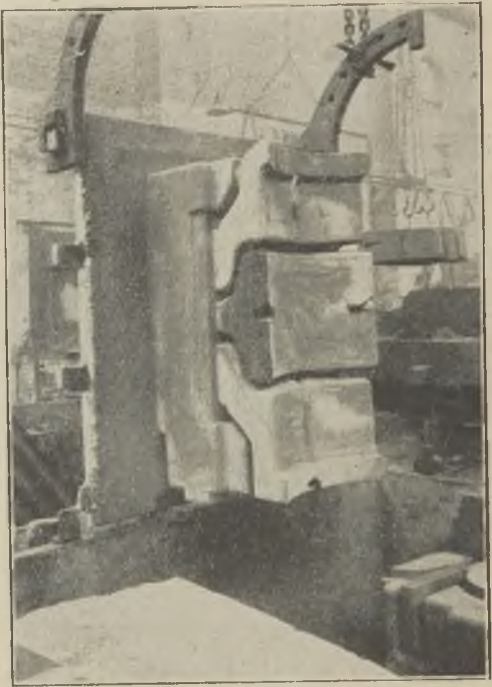


Fig. 10.—Steam Chest Core being Lowered into the Mould.

The M.P. and L.P. cylinders may be treated in a similar manner on the outside of the casting, but with a different chill for the centre core.

Figs. 6 to 9 are photographs of M.P. cylinder moulds, in which can be seen the steel tubes.

z 2

Fig. 6 shows the square foot core in position; Fig. 7, the blank chest with chill marked in white; and Figs. 8 and 9 are of the other side of the cylinder, showing round foot cores in place.

After a time a marked improvement was found on the outside of the feet joining the cylinder, but, as the inside of the feet was not what it should have been, some straight bars were cast and these were wired on to the grates for the foot cores and left bare except for a coat of blacking. These answered the purpose very well, and now the fettlers seldom, if ever, have to put a hammer on to such parts.

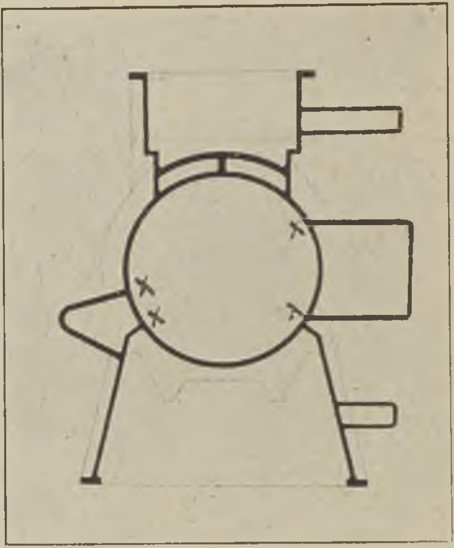


FIG. 12.—SECTION OF M.P. CYLINDER SHOWING POSITION OF CHILLS AT X.

In Figs. 10 and 11 are seen, respectively, the steam chest core being lowered into the mould and a complete set of cores for M.P. cylinder with chills in position in centre core and in feet cores.

Fig. 12 is a section of an M.P. cylinder taken immediately under the crown, the points marked

"X" being those where the chills are used to counteract the effect of the thickness of metal at the junctions, and Fig. 13 shows the top part of an M.P. cylinder mould.

Of course, it is not claimed that, even with these methods, perfect castings are made, but they are undoubtedly better than they ever were before. With the use of chills or denseners many failures and difficulties met with in the foundry can be overcome.

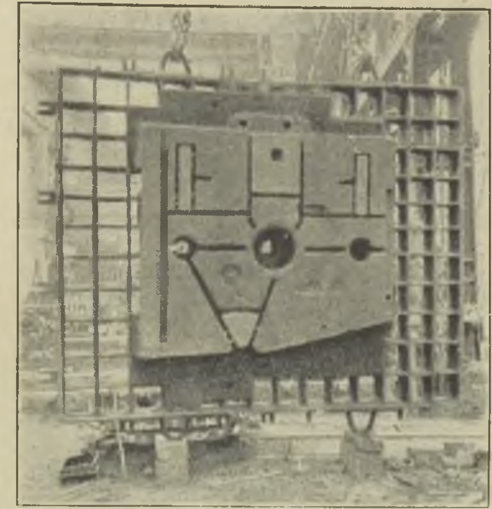


Fig. 13.—Cope for M.P. Cylinder Mould.

Another casting on which to use chills is a very important part of an oil engine, namely, the exhaust valve. These castings, when in the cylinder head, are subject to the full temperature of the exhaust gas, whilst having cooling water circulating through at the same time. There is a chance of the water coming through the thin wall of metal into the spindle chamber. This, of course, is bad and must be prevented, and, after cutting up a casting, it was found that the thinner parts were pulling the metal away at the heavy flange, making it too open to resist the water pressure.

It was decided, therefore, to try what effect chills would have upon that part. A plaster of paris pattern was first made out of the half-core box, with allowance for half-an-inch of sand between the two chills, but it was found that, to get them out, they would have to be cut into sections. In the complete core there are six pieces of chills. These are placed in the core box and rammed up with the core, leaving a small portion of sand between each chill. When dry, a single wire is fastened round them for safety.

FIG. 14 SHOWS THE PATTERN, CORES AND CHILLS FOR AN EXHAUST VALVE.

Fig. 14 shows the pattern, cores and chills for an exhaust valve, and Fig. 15 a mould with core in position, which illustrates the considerable differences in thickness of the various parts of the casting.

It was also found that the nip on the top and bottom of the chills made it very difficult to get them out, so a groove was cut in the pattern to allow them to be broken out. The chills quite overcame the trouble on that particular part, but it was found in another part, namely, on top of the flange, so it was decided to chill that as well.

The first chills on that part were made 1 in. thick, but the castings were too hard to machine. It had to be machined behind the chilled metal and broken off. The chills were then reduced down to $\frac{5}{8}$ in., and this had the desired effect. They were quite machineable and perfect under water pressure. The foundry now makes large numbers without any trouble, and the cost of the chills is nothing compared with that of a replace casting.

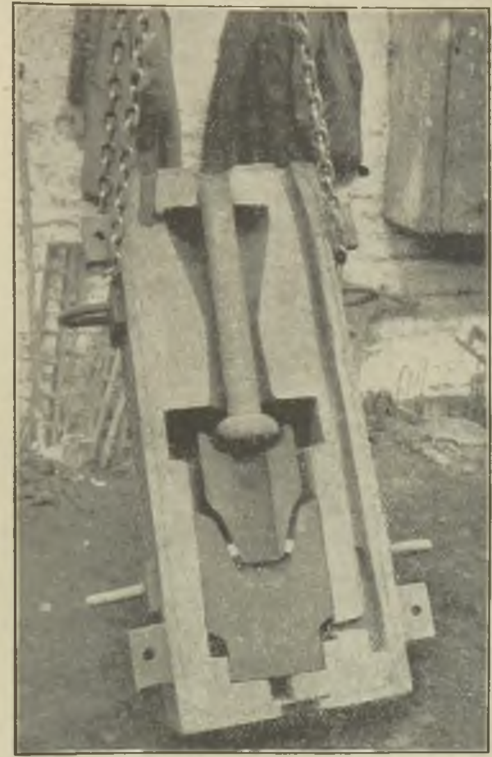


FIG. 15.—MOULD, WITH CORE IN POSITION, ILLUSTRATING THE LARGE VARIATION IN METAL THICKNESSES.

Only the practical side of this subject and that within the author's own experiences has been dealt with. From what has been done, the author is convinced that if foundrymen had the chance of seeing their castings undergoing the tests required of them, many failures could be saved with little, if any, extra cost.

In conclusion, the author desires to thank the North-Eastern Marine Engineering Company for allowing him to give this Paper, and also Mr. H. J. Young, F.I.C., for his assistance in preparing the illustrations and slides.

DISCUSSION.

Mr. Herbst opened the discussion, saying that they had listened to Mr. Frier's Paper with great profit. He was of the opinion that chills would not have been required in the first place had the engineer not been at fault. The engineer often gave the foundryman a drawing in which the sections were not symmetrical, and in that case chills *had* to be used. At his firm they had found that chills were not effective in places where there were joints.

With regard to the head on a casting, his experience was that a head of about 3 in. was equally as good as one of, say, 1 ft.

Mr. Edward Smith thought that, as a rule, metals could be mixed in such a way that chills were unnecessary. There was no doubt, however, that chills would be an advantage, probably, where there were large fillets.

The lecturer had shown a photograph of the core of an H.P. cylinder where there were three or four chills round the top, and he wondered what effect those chills would have upon the machining qualities of the metal. In the majority of cases if, when the casting was sent into the fitting shop, there was any difficulty with the tool jumping a little, the foundry heard about it.

In reply, Mr. Frier said that there were no chills on the parts of the cylinder which had to be machined. The effect of a chill depended upon its thickness, *i.e.*, the thicker the chill the deeper its effect. The metal round about the chill was sometimes about 5 in. thick, whilst the chill at that part was only, say, $\frac{3}{4}$ in., so that the effect upon machining would hardly be felt and the chill would merely close up the grain of the iron at that point. The chill was not carried right down to the bottom, as there is a recess for the liner.

Mr. Edward Smith asked if the effect of the chills upon the iron was to cause whiteness.

Mr. Frier explained that in the particular case in question the casting was made of special close-grained iron, and the effect of chilling was greater than in the case of an ordinary open-grained iron.

Casting Cylinders Crown-down.

Mr. James Smith remarked that he had listened very carefully to the Paper, and he could not help feeling somewhat surprised to find that Mr. Frier was using chills. Years ago, of course, they had never thought of using them in certain classes of castings, and one would naturally think that the science which had come to the fore in the last few years would be sufficient remedy. The lecturer had mentioned that they might cast the cylinders crown down, but that it would be an expensive procedure. In his (Mr. Smith's) opinion, to cast a cylinder crown down was undoubtedly the correct method, and he was not so sure that it was the most costly one in the long run, because if, when a cylinder arrived in the fitting shop, there was trouble, it sometimes cost more to put right than it would have cost to mould it crown down.

During the past 15½ years his firm had made castings for about 250 engines, and each H.P. cylinder had been cast crown down, with a head according to the size of the casting, say from 15 in. to 2 ft. 6 in., and he could say, without fear of contradiction, that they had never had a failure with one of those cylinders. In his opinion, the proper way to make a cylinder, even when using chills, was to cast it crown down and to put a sufficient head on it to feed the casting. If there was a leakage in the cylinder it was either at the feet, the indicator boss or the crown. It was pressure that was wanted, and it was pressure that the cylinder received when cast crown down. He felt confident that, rather than have to run risks, it was much simpler for the foundry, and more accurate, to make the castings by that method, and it was the only way to overcome the trouble.

Mr. Frier agreed with Mr. Smith that the perfect way to make a cylinder was to cast it crown down. Since he had been with his present firm they had made castings for about 2,000 engines, and although they themselves made all the cylinders crown up, it did not alter the fact that the other method was the more perfect one. Of course, he was not able to speak upon the extra work and expense entailed. In their present method they used chills, and he thought it was quite evident, from what other speakers had said, that they met the same trouble where there were junctions of metal.

The cost of making chills was practically *nil*, as they did not have to alter the design of the cylinder, and they had certainly proved the benefit of them.

Mr. James Smith pointed out that, when he had referred to expense, he had not meant the cost of the chills, but that, when the casting arrived in the fitting shop, a tremendous amount of expense was often incurred in patching it up. Would it not pay to cast the cylinder crown down. and so get a sound casting in the first place?

Mr. E. Wood, B.Sc., said that they had already considered the question of casting cylinders crown down, but that it meant scrapping their patterns, which was a considerable item. That was probably the only thing which prevented them from making the castings by that method.

Choice of Chills.

Mr. H. F. Clements drew attention to the fact that the lecturer had not mentioned what depth of chill he used on the particular parts of the cylinders. He, personally, would imagine that the deeper the chill the greater would be the amount of heat extracted from that particular part. He inquired how Mr. Frier decided upon the depth of the chill, and whether it was simply by experience or by some more definite method. He asked if the lecturer had experienced any ill-effects from strain, due to using too large a chill on one part of the casting, and thus getting an adverse effect to that desired, causing the casting to crack during machining. For instance, if there was a heavy chill on the core and a heavy chill on the mould, the rest of the mould would cool more slowly and the metal would be drawn from that section. When the whole of the casting had cooled down there would be a strain there, although there was probably nothing to see.

In reply, the **Lecturer** stated that the effect of the chill depended upon its thickness. It was hardly possible to see the effect of the chill upon the metal unless it was cut into sections. He did not see how there could be any strain, as the chill was quite free; also the amount of heat in the mould would prevent a strain taking place, as before very long the chill would be at the same temperature as the casting. One might get a bad effect, however, by using a chill too many times, in which case a certain amount of gas arose from the chill, due to its having been heated too many times. For the outside of the casting a chill can be used a good many times, but for a part which has to be machined a chill should not be used more than three or four times. When the chill commences to crack it should be scrapped.

Scientific Aspect of Chills.

Mr. H. J. Young, F.I.C., said that many people did not seem to quite understand what they were doing when they were chilling metal, and seemed to look upon it as a kind of practical thing about which the chemist knew nothing. Also they seemed to think that if a foundry had a chemist they should not be using chills. He did not think that there was anything unscientific in a chill. Whichever way the cylinder was cast, if there were different thicknesses of metal, how was the foundryman to get them alike? There were only two ways of doing it, and one was by using denseners. If chills were not used where there were different sections of metal, the iron would vary considerably when solidified. He supposed founders would say that the chemist should make his iron hard enough to get over the difficulty, but even if the iron was very hard there would still be variations in strength and hardness where there were different thicknesses of casting.

He had consolation in the fact that he had seen many castings made by other foundries, and found that they all suffered from the same troubles. It seemed to be only at meetings that people made all good ones.

He was in entire agreement with Mr. Smith about casting a cylinder crown down, but at the same time the use of chills applied to that method as well as to the other.

In the modern engine it was essential to get every part of the castings alike. The Germans had discovered a wonderful process for accomplishing that very thing, namely, the making of all sections of a casting exactly the same. It was impossible to do it by metal alone, and therefore the only alternative was to use chills or else this German process, and chills had very great limitations and disadvantages.

Some of the members had been talking about porosity and blow-holes in castings, whilst others had referred to the density of the metal. If the cylinder was cast crown up there was bound to be trouble with blow-holes and at the important parts of the casting at the top of the mould. Chills would do no good in these respects. When cast crown down the gases and dirt rose to the top of the mould, namely, to the unimportant part of the cylinder. Also the important parts were "fed" by the metal above acting as a "head."

Mr. James Smith said he would like to know why Mr. Frier had used chills in the first instance.

Responding, **Mr. Frier** said that after the castings had been machined he had the opportunity of seeing that there were different sections of metal, and that the grain was not all the same. It was to overcome this and to close up the grain of the metal at these sections that he had tried the effect of chills. The chilling might not close up the grain of the iron on the inside as much as desired, but if it closed up the grain on the outside it would give some benefit, and it *had* done so. The chills had certainly served their purpose. He had knowledge of many castings where they had effected a great improvement.

Mr. James Smith said that his point was that if it were possible to get a sound cylinder by casting it crown down, why bother with the use of chills at all? Mr. Wood had stated that casting cylinders crown down meant scrapping the patterns. He (Mr. Smith) did not think that this was at all necessary.

The Lecturer said that they were all of the same opinion as Mr. Smith, namely, that to cast a cylinder crown down was the more perfect method, but nevertheless it was not the one they were using, and what he was trying to do was to remedy the difficulties in their present method. Everyone knew that the bottom part of a casting was always the soundest part, and it was only natural therefore that to make a cylinder crown down was going to give a better casting.

Object of Chills.

Mr. W. J. Paulin said they all remembered the lecture M. Ronceray gave to the Newcastle Branch. In this lecture it had been pointed out that, if greater attention were paid to the methods and rate of pouring, very much sounder castings would be obtained, and that the use of chills could be done away with. He (Mr. Paulin) could hardly agree with M. Ronceray on this point, because, as Mr. Young had pointed out, there was the difficulty of the different sections of metal to contend with. It was impossible to get these different sections the same when cooled unless chills were resorted to. One experienced the same thing in tempering tool steel.

He would hardly put it as Mr. Frier had, namely, that the chill was used to close up the porosity of the metal, because he thought that it was more to hasten the period of cooling in a particular place that really mattered. When defects were present in a casting they were generally found at the junction of sections where the metal was thick, and, consequently, took longer to cool. If one could get uniform cooling conditions of both thin and thick sections, then the demand of the thin section for more metal from the thick section ceased.

There were many advantages in the use of chills, and these had been touched upon by Mr. Frier. The lecturer had shown a section of a cylinder where the junction took place between two sections running towards the cylinder bore. Care had been taken by the engineer to separate these two sections and to form a fillet, but, as Mr. Frier had quite rightly pointed out, such a fillet was very difficult to maintain in sand. By chilling he had not only produced a very uniform section, but he had got more uniform cooling, which meant that the junction was made perfectly sound. What he (Mr. Paulin) liked about chills was that they provided a margin of safety.

He had had the same experience as Mr. Frier, only with smaller castings, and they had had ample evidence that chills overcame the trouble entirely. They had first tried to alter the mixture by reducing the silicon, and although they got a very close-grained iron there was still a leakage in the cylinder, but the application of chills had removed that entirely. Chills did not produce the effect that many people thought they might, namely, produce hard spots. If the thickness of chill was carefully determined beforehand it brought about all that was desired in the way of hurrying up the cooling without altering the machining qualities of the iron.

Mr. Frier was correct in mentioning that a chill should not be used too many times. Although there was nothing visible in the chill to show that it was defective, if it had been used too often it would give off gases. That was almost the only point which he thought required watching, and it was quite a separate question from that of undue thickness of chill.

Mr. Wood said that the argument seemed to have been raised against the lecturer that he was using chills to save castings from the scrap heap. Mr. Smith had overlooked one fact, however, and that was that the lecturer had shown on the screen at least one core where the chills had not been used to resist porosity, and he would like to hear the lecturer express his opinion upon those chills.

Mr. Frier explained that in the particular casting which Mr. Wood referred to they had gained experience from the trouble which other people had had, the casting not being one of their own making, but from another firm. They had cut it up, and had been able to overcome the trouble successfully by applying chills.

Wales and Monmouth Branch.

SEMI-STEEL.

By H. Field (Member).

No apology is needed for adhering to the name by which every foundryman and most engineers still call this particular type of iron. That the name is indefensible on technical or metallurgical grounds is readily admitted, but it is nevertheless better than some of the complex and compound alternatives suggested. If it gives no idea of the ultimate properties of the metal it does at least give a truthful picture of the component elements of the mixture, and the time has long passed by when any but the very simple might buy it under the impression that they purchased a ductile metal.

The material semi-steel is in fact a cast iron made by melting together ordinary pig-iron and steel in varying proportions according to the work to be cast. The object of making this mixture is to produce from *cheap pig-iron* a final material with some or all the virtues of more expensive pig-iron mixtures, and inasmuch as these latter never give any ductility worth measurement, foundrymen neither expect nor obtain ductility in semi-steel. What is obtained is a very close-grained iron, with tensile strength improved in varying degree up to 50 per cent. increase, and transverse strength also improved in a lesser but nevertheless a valuable degree. The increased closeness of grain also gives to some extent an iron more capable of withstanding hydraulic or pneumatic pressure and the action of acids and heat. A consideration of these benefits enables it to be confidently stated that semi-steel is a valuable addition to the materials available to both engineer and ironfounder.

It has been frequently stated that there is no difficulty in making semi-steel, and while this is in the main true, there must be difficulties, since all who attempt do not succeed. It is not unknown to hear of engineers who will have no more to do with this material because in past trials they have found hard spots, even *white* sections and blow-holes. These are just as much the possible results of improper choice of materials and defective melting practice as they are acknowledged to be with ordinary iron.

The most ready method which suggests itself for making semi-steel is to mix together molten steel and molten cast iron, but such a method can only be practised where the materials are available. It might be supposed that under such conditions the ductile properties of the steel would be retained, since it has not been passed through the cupola, but such is not the case. Even if a soft grey iron be used, the resultant metal tends to be white in fracture if any considerable proportion of steel is used. It is, however, an excellent method for making strong, close-grained cast iron.

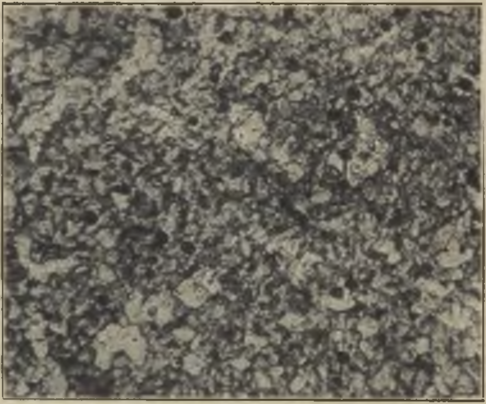


FIG. 1.—MILD STEEL (C = 0.28 PER CENT.) USED FOR THE EXPERIMENTS × 100 DIAS.

This method, however, evidently appeals to many foundrymen, and they use the nearest approach possible by adding solid steel to molten cast iron in the ladle, a method to be strongly condemned. The only quantity of solid metal which a given quantity of liquid metal can raise to melting point and convert into liquid is so small as to be without influence on properties. Should an attempt be made to use a larger quantity, say 10 to 20 per cent., the fluid metal is robbed of so much heat as to become useless, and is also filled with shots of partly melted steel. Scientific melting practice, *i.e.*, practice which seeks to do the thing rightly and to follow the same course from day to day, must look askance on the addition of solid metal to well-melted metal in the ladle. It is rarely that any molten metal has any surplus heat available for such work.

FIG. 2.—MILD STEEL RECOVERED FROM THE CUPOLA. THE PIECE WAS JUST ON THE POINT OF MELTING. (C = 0.26 PER CENT.) × 100 DIAS.

The air-furnace offers the best medium for melting semi-steel, because there the desired materials may be thoroughly mixed and melted and the mixture tested to ascertain if suitable for the work in hand. By this type of furnace a true low-carbon metal can be obtained, a difficult feat in cupola practice. This is an ideal metal when so melted for the purpose of chilled castings, rolls, etc.

Semi-steel melting on a large scale has been adopted by some makers of so-called refined and special pig-irons. The steel in this case acts as a diluent, proportionally reducing the quantities of phosphorus and manganese and to a slight extent in good practice the carbon, but as to whether or not a really improved metal for foundry practice is obtained by such a process depends on one important question—Do the improved properties obtained by melting steel with cast iron persist on re-melting?

Cupola not a Mixer.

Semi-steel, like cast iron, is generally made in the cupola. Whilst it may be true to say that no special form of cupola is necessary, this statement is correct only because of the modifications wrought in cupola practice during recent years. The old-fashioned cupola, with its small-area tuyeres and hurricane blast, would indeed have produced a material hard and full of blow-holes had our forefathers used it for melting high steel-mixtures. If we accept present-day conditions of melting good iron, namely, a tuyere area about one-fourth the area of melting zone and a blast pressure of 12 ozs. per sq. in., with the requisite volume of air, then semi-steel may be safely melted under similar conditions. The hearth of the furnace should in all cases be sufficiently large to accommodate a complete charge when melted, as this mixture should not be run out at the spout until it has had some chance to become uniform. The cupola is not a metal mixer, and such mixtures as pig-iron and steel, high- and low-phosphorus pigs, or pig-iron with rich ferro-alloys, should not be cast until they have had every facility for mixing both within and without the cupola. A very convenient method for small foundries is to mount a 5-cwt. shank on trestles before the cupola spout and run the metal from the furnace into the shank, and thence into the ordinary hand ladles, so using the shank as a receiver. A comparison between samples taken at intervals during a run under these conditions will show that successive casts are much more uniform than when taken direct from the cupola with hand ladles.

Strict attention must be paid to the choice of materials in making semi-steel. A comparison between the relationship of chemical and physical properties in a straight grey iron and a semi-steel shows that at once the increased physical qualities of the latter are due to some other influence besides that of the alteration in composition caused by the steel additions. Even so, there are two elements which must be adjusted on the same principles and with the same care as in ordinary iron. The influence of silicon on hardness and its regulation according to section undergoes no change because of the steel present, and the same is true of phosphorus and its relation to fluidity. Light castings in semi-steel must have high silicon and phosphorus as in grey iron, and the reverse is true for heavy work. It is therefore necessary to start with a pig-iron which contains a greater quantity of each of these elements than is finally required, since they will both suffer a reduction in precisely the same proportion in which steel is added, for the latter contains only a negligible amount of each. With high percentages of steel, it will be necessary to commence with a soft open-grained pig of high silicon-content, if the product

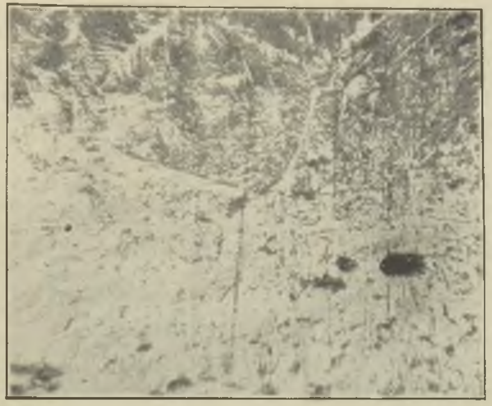


FIG. 3.—SIMILAR TO FIG. 2, SHOWING THE DECARBURISED AND OXIDISED EDGE (BOTTOM) × 100 DIAS.

is to be of machinable quality in ordinary sections and if the phosphorus is to be of the order of 0.8 per cent. in the finished metal, there will need to be over 1 per cent. in the pig-iron. It is also advisable to keep a fair percentage of manganese, say 0.6 per cent., in the finished semi-steel, but since most mild steel contains this amount, the steel addition will not rob the pig-iron, and an initial content of 0.6 per cent. manganese in the latter will be quite suitable.

To a large extent the increased physical properties are due to a reduction in total carbon, which is reflected in a decreased content of graphitic carbon, the most weakening constituent of cast iron. In fact, it is only by modifying either the quantity or quality of the carbon that any considerable improvement in cast iron can be obtained. To this end it is well to begin with a pig-iron low in carbon, and certainly not with hematite pig-iron, which is amongst the highest in this respect. The high-phosphorus pig-irons, which the author uses and recommends for this work, are generally lower in carbon than most other irons, although not lower than special cylinder pigs, themselves often made by steel additions. This reduction in total carbon is essential if the best physical qualities are to be obtained, but it often does not take place, and there is, in fact, an increase when the melting practice is not good. For this purpose it is necessary to keep the coke at a minimum, which in its turn can only be accomplished when the air supply is regulated, for excess air either demands excess coke or results in oxidised iron. It should be possible to melt with 10 per cent. of coke, exclusive of bed, and if this be much exceeded it will be difficult to effect a reduction in carbon and obtain strongest metal. The strength of semi-steel is very largely dependant upon the percentage of graphite, but this point is common also to ordinary iron; between 3.2 and 2.7 per cent. of this constituent it has been found that each 0.1 per cent. reduction is worth an increase in strength of one ton tensile.

Character of Steel Additions.

The quality of steel to be used calls for attention. In his earliest experiments, the author found that thin material, the waste from machine presses, is not suitable to use, for it suffers heavy oxidisation due to its relatively large surface, and to the rapidity with which it reaches an oxidising temperature. Foundries working in conjunction with engineering shops are often put under pressure to use this steel, but will be well advised to resist, or trouble will be encountered. This same material is, however, sometimes available in tightly compressed bundles, about 30 in. long and 6 in. square, similar to pig-iron in shape and weighing roughly ¾ cwt., and is then very suitable for the work.

Whilst superintending cupola work, the author has seen this very light steel become very highly oxidised, even before it disappears from view below the charging door, and on such occasions the slag will be black, the cupola lining very severely attacked, and the metal little, if any, better for its quota of steel. It is from such melting that castings spoiled by blow-holes are obtained, and only naturally so when the conditions in the cupola hearth are considered. Very small material, such as boiler punchings, is also condemned for semi-steel work. The least harm that it can do is to slip down through its companions of the charge, and so cause unequal proportions of steel at different points, whilst there is a possibility of a quick descent right through into the molten bath before complete carburisation is accomplished. In such cases the pieces are often only partly dissolved by the molten metal, and hard spots result; this again being a frequent cause of complaint against semi-steel. The ideal form of steel for general work in cupolas up to 40 in. dia. is the scrap from constructional work, plates, angles, etc., of about ½ in. thickness, and this steel can usually be relied on as regards composition. For larger cupolas, rail ends, etc., are used with success, but are not, in the author's opinion, so good as the constructional steel. The use of tool steel, files, etc., is usually condemned, but there seems no legitimate reason for so doing except the fact that such higher carbon material will have a lower melting point than mild steel. At any rate, it is evident that at some stage between charging and tapping the mild steel itself must contain just that proportion of carbon which is in tool steel; and, furthermore, what of the

3 per cent. of carbon in pig-iron? Moldenke[3] condemns the use of such steel on the ground that it gives trouble when exposed to high temperatures with only a little oxygen.

Various workers have stipulated that for best results the steel should have some definite position in the charge—above the coke, below the coke, or between pig and scrap. The experiments now to be described attempt to show what happens to steel in the cupola, and will have a bearing on the order of charging. Prior to these experiments, the author had held the view that the steel, gradually descending in the cupola shaft, was rapidly carburised on its surface in the solid state by gases or by solid carbon, and that when it reached a zone with a temperature corresponding to the melting point of such a high carbon metal, melting took place. Thus, with 1 per cent. carbon absorbed, melting would take place at 1,450 deg. C., with 2 per cent. at 1,380 deg. C., with 3 per cent. at 1,300 deg. C., as shown in the equilibrium diagram for the iron-carbon alloys.

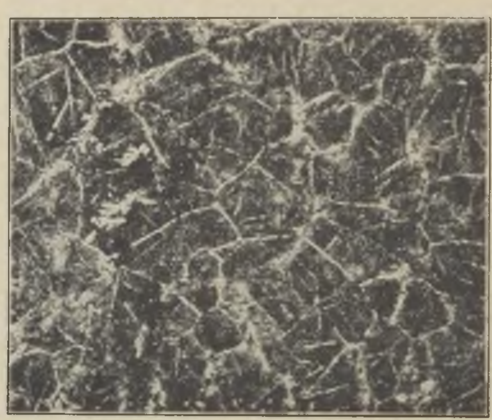


Fig. 4.—Microstructure of a Small Sample of Molten Steel Recovered at the Tuyères with a Spoon (CC = 0.82 per Cent.) × 100 dias.

Cupola Experiments with all Steel.

The author, having a small drop-bottom cupola at his disposal, charged it with steel only, separated by small coke charges. Metal appeared at the tap hole in normal time, accompanied by a wild firework display, and the iron when cast was found to be hard, white in fracture, and full of blowholes. The tap hole was kept open, so that the metal ran out as quickly as it melted, and did not lie in the furnace bottom. It showed an analysis 2.8 to 2.9 per cent. of carbon, all combined, and when annealed in a malleable oven, gave a reasonable ductile metal. No doubt the blow-holes could be eliminated by a deoxidiser such as aluminium. About half-way through the heat the furnace was drained and the bottom dropped, so as to obtain the remainder of the steel in the unmelted and partly melted condition. The metal so recovered in the form of plates 6 in. round, $\frac{3}{8}$ in. diameter, showed a thin scape of oxide, probably formed in the higher regions around the charging door, and when broken had the typical large crystalline frac-

Fig. 5.—Cast Iron at the Tapping Spout (CC 2.90 per Cent.). It is the Result of Melting Steel in the Cupola.

ture of burnt steel, although still quite tough and ductile. Samples were taken for carbon, but no increase was shown over the original amount in the steel, viz., 0.28 per cent.; this being true even of spongy pieces which were actually partly melted. Sections under the microscope showed instead the faint beginnings of oxidation at the edges, and beneath the oxide the carbon still remained at its original figure. Steel can be melted in the cupola, and during its descent from melting zone to hearth there is absorbed 3.0 per cent. of carbon.

This experiment was repeated, but arrangements were made to catch falling drops at the tuyere. For this purpose a small iron spoon lined with sand being used and pushed through the tuyeres. Four samples were taken progressively through the heat: the first two were hard and brittle, showing respectively 2.65 and 1.86 per cent. of carbon, the third was slightly malleable with 1.35 per cent., and the last quite ductile and soft with 0.82 per cent. carbon. These results suggest that the melting zone had gradually fallen during the heat, so that the metal was melting at a less height above the tuyeres, and in falling through a smaller range of incandescent coke, had absorbed less carbon. The author, like many other workers, has in view the production of malleable metal direct from the cupola, and if iron with 0.8 per cent. of carbon, which is certainly malleable, can be withdrawn at the tuyere level, it may be possible in a cupola with very shallow hearth to tap off a metal which is still sufficiently low in carbon to be of some service as a malleable product. It is of interest to note that the melting point of a pure iron-carbon alloy with 0.8 per cent. carbon is not much below 1,500 deg. C., and an indication of the temperature at tuyeres in cupola is thus given. In the first experiment the slag frothed up, and was just into the tuyeres when the cupola bottom was dropped; it showed SiO_2, 45; FeO, 30; and CaO, 17 per cent. In the second experiment, drops of slag caught at the tuyeres were found to contain SiO_2, 47: FeO, 33; and CaO, 10 per cent., whilst that tapped out after melting was much more normal with SiO_2, 55; FeO, 7.5; and CaO, 22 per cent. All these indicate the heavy risks of melting high-steel percentages, and show the necessity of avoiding an oxidising atmosphere. The results of the experiment are shown in Tables I and II.

The author has two samples of metal showing the result of melting light steel in a cupola, without any particular precautions being taken. They show 1.53 per cent. and 1.93 per cent. of carbon respectively, and constitute the lowest carbon cupola melted metal of which he is aware. Experiments are now in hand to improve upon these figures, and at the same time to obtain sound metal of commercial value.

TABLE I.—*Chemical History of the Carbon Content.*

	Carbon. Per cent.
Original steel	0.28
Molten metal at tuyeres 1	2.65
" 2	1.86
" 3	1.35
" 4	0.82
Metal at spout	2.90
Partly melted steel, spongy	0.26
Steel from top charge, no signs of fusion ..	0.28

These experiments very closely confirm those of Cameron[1], who found only very low carbon-absorption in semi-melted metal. On the other hand, J. Grennan, of U.S.A.[2], concludes that steel when melting in the cupola contains at least 1.25 to 1.35 per cent. carbon, with which the author's results do not agree, for some of the steel obtained by dropping bottom was clearly caught just at melting-point and shows no increase of carbon except on an edge of microscopic thickness. Moldenke[3] claims to have melted many tons of steel for castings in a cupola, using two to four times the usual amount of coke, a precaution necessary to avoid scaffolding through solidification of low-carbon material. It is doubtful if such metal can be cast free from blowholes without using a deoxidiser, such as aluminium.

Since, then, steel melts with the absorption of little or no carbon in the cupola, there is no need to place it either above or below the coke in order to bring it in contact with the solid carbon. In fact, the carbon which may be absorbed in its solid state is certainly the result of contact with gases rather than with coke or solid carbon. Thin steel, provided it is not oxidised in descent, will melt quicker than grey pig-iron, and this is probably true of any steel under 1 in. in thickness. The order of charging may be determined as in straight pig-scrap mixtures with this proviso, that steel over 1 in. to 1½ in. thick be treated as pig-iron and charged with it, whilst in thinner sections it should be above the pig-iron either second or third in order, according to its relation to the scrap.

TABLE II.—*Slag Conditions.*

	FeO. Per cent.
Slag—frothed over into belt	30
,, caught at tuyeres	33
,, tapped at spout	7.5

In casting semi-steel, provision must be made for an increased shrinkage over grey iron. This applies to both liquid and solid shrinkage, for semi-steel is more prone to those defects known as "draws and shrinkages" than is straight grey iron. Larger feeding heads are required and increased fillets in angles, and it must be admitted that this tendency to draw is one of the most serious troubles with these mixtures.

The analysis and physical properties of a series of semi-steels are shown in Table III, the amounts of steel used being 10, 20, 35, and 50 per cent. respectively, and the pig-iron, No. 3 Sheepbridge, which may be regarded as a normal foundry iron. The author's purpose in using steel has always been to improve the properties of the cheaper pig-irons and bring them up to the level of the better class irons, thus producing a high-grade material at lowest cost. Steel can be bought at quite as low a price as Northampton or Derbyshire pig-iron, and by the production of such mixtures as those now outlined an iron of excellent physical properties costs less than £5 per ton. Not only so, but the improvements obtained with high-class iron as a base are much less noticeable than with cheap irons, and high steel-percentages cannot be used with low-silicon irons.

The mixtures consisted of steel, pig-iron, and ordinary foundry scrap in the proportions shown in Table III, the scrap containing a large proportion of Sheepbridge iron and showing about 2.8 silicon and 1.4 per cent. phosphorus. The silicon was kept as nearly constant as possible, within the limits allowed by the three materials chosen. Manganese is fairly constant, and phosphorus drops regularly in proportion to the diluting effect of the steel. The percentage of total carbon also shows a continual decrease, and these mixtures may on this account claim to be well melted and to be true semi-steel, for with indifferent melting the high-steel mixtures might easily show no reduction in carbon and give consequently lower tests. The combined carbon shows a gradual increase more pronounced in the 50 per cent. mixture, but the combined effect of this increase taken together with the falling total carbon is to give a very rapidly diminishing graphite content, amounting to 27 per cent. in the 50 per cent. steel mixture. This is a most important factor in the improvement of the metal.

TABLE III.—*Analysis and Properties of Semi-Steel.*

Pig-iron	65	55	45	35
Steel	10	20	35	50
Scrap	25	25	20	15
Analysis :				
Silicon	2.65	2.25	2.20	2.0
Sulphur	All under 0.08%			
Phosphorus	1.38	1.14	1.01	0.91
Manganese	0.63	0.51	0.57	0.51
Combined carbon	0.33	0.35	0.37	0.57
Graphitic carbon	2.92	2.72	2.53	2.13
Total carbon	3.25	3.07	2.90	2.70
Physical Properties :				
Tensile strength tons	11.9	14.4	16.0	18.3
Transverse ,, lbs.	2.600	3.025	3.360	3.640
Deflection ins.	0.090	0.106	0.119	0.110

The physical properties improve steadily with the increase in steel, the increase in tensile being 54 per cent. and in transverse 40 per cent. It is particularly noticeable with what regularity the improvement takes place, and it does not seem that there is an abrupt limit to the amount of steel which can be usefully added, and certainly not with this particular pig-iron. The tensile bars are cast $\frac{7}{8}$ in. dia. and machined to 0.564 in., the transverse bars 12 in. by 1 in. by 1 in. It is admitted that tests on this size of bar give a false idea of the value of this metal for heavier work, but they are comparative, and are of a section equal to that of the general run of castings at the author's foundry. The improvement in transverse strength is distinctly encouraging, as it is often stated that there is no improvement in this test, but it is conceded that such improvement may be largely due to the gradual reduction in phosphorus, and would take place in some degree if this element were similarly reduced in any manner other than by steel additions.

All irons were readily machined at normal speeds in the $\frac{7}{8}$-in. size, and the machinist was unable to detect any hardness greater than in the ordinary grey irons which he regularly works upon, except in the case of the 50 per cent. one, which was rather hard. There is no difficulty in making 50 per cent. semi-steel, with high-phosphorus and low-carbon, suitable for light castings and easily machinable, provided that the silicon is kept at a sufficiently high figure. This is the obstacle over which many foundrymen stumble; a pig-iron of close grain and low-silicon is chosen for mixing with steel in the belief that this is the best basis for the production of a strong material, and the final metal with its silicon reduced more or less by steel addition is consequently too low to give softness, with the result that the mixtures are condemned as impracticable. The pig-iron, on the contrary, must be of a much softer and more open grade than would ordinarily be used for the work in hand, and if over 25 per cent. steel is to be used there should at least be 1 per cent. silicon in the pig-iron. This, of course, refers to heavy work.

There is nothing difficult about the law governing this point; it is simply a case of the laws of proportion and average. Steel contains no silicon, or, at any rate, an inconsiderable amount, and it reduces the silicon in the mixture, over and above the ordinary melting losses, by precisely the proportion in which it is added thereto. Some workers have concluded that high-phosphorus pig-irons are unsuitable for using in semi-steel mixtures, and the author has therefore especially chosen this series, made from such a pig-iron, for detailed consideration. It is difficult to see what greater improvement could be expected if hematite iron were used, but, so far as the author's foundry requirements are concerned, the metal would then be unsuitable, as it is there often used for the lightest types of casting of the order of one or two ounces in weight and $\frac{1}{4}$ in. thickness. For such work there must be a final phosphorus content near 1 per cent. to give necessary fluidity and life, and the silicon must always be over 2 per cent. It has not yet been possible to use 50 per

Fig. 6.—Semi-Steel × 100 dias., highly Etched to Reveal Graphite.

cent. steel in such work owing to high combined-carbon and consequent hardness. This difficulty can be easily understood when it is seen that in a ⅞-in. test bar the average combined carbon reaches 0.57 per cent., and would be considerably higher on the skin.

Physical Properties of Semi-Steel.

The physical properties recorded show improvements on materials of similar analysis made without steel, except that it would be difficult in a cupola to produce for comparison a low-carbon material like the 50 per cent. sample by any method other than steel addition and give the required softness. Carbon reduction alone is not responsible for the increase in properties; the author daily melts on the same cupola first of all several tons of 10 per cent. semi-steel, which gives 14 to 16 tons tensile, and afterwards a quantity of grey iron which shows about 11 to 12 tons. The pig-irons are the same, although rather more pig and less scrap are used with the steel, and the final analyses, including both total and combined carbon, are also the same within ordinary working limits, and yet the steel mixture shows always from 3 to 4 tons added strength. Reverting to the series shown in Table III, the only constituent other than carbon which varies to any extent is phosphorus, which it has already been admitted may in part be responsible for the improvement in transverse strength. The same does not hold true for tensile strength, which within the author's experience is not influenced in any marked manner by rise or fall in phosphorus, and in his opinion it is possible to obtain equal tensile strength notwithstanding the phosphorus.

Figs. 1 *et seq.* show the structures of the 20 and 50 per cent. mixture, and a straight grey iron mixture of approximately similar analysis for comparison. This series taken at 100 magnifications presents a range from 12 to 18 tons tensile. There is no greatly marked difference in the size of graphite, although in the stronger bar this is indeed a little smaller; on the other hand, there is a noticeable decrease in its quantity as steel increases, and also in the general compactness of structure and network effect of the phosphide eutectic. These sections were only very lightly etched in order to leave the graphite prominent; the arrangement of phosphide eutectic is more clearly shown in a further etching (Fig. 7), which depicts the 50 per cent. mixtures.

Whilst most workers have agreed that the fine graphite is a necessary constituent of strong semi-steel, the Editor of THE FOUNDRY TRADE JOURNAL has gone further in using this characteristic as a basis for his definition of semi-steel. He submits the following:—"Semi-steel is a cast iron which has had its graphitic structure modified—that is, made finer—by the incorporation of steel into the charge during its manufacture." This would be an excellent definition, inasmuch as it would preclude the putting forward of mixtures containing only very low percentages of steel or of cold cast metal which does not show such fine graphite, but the author questions whether it is at all workable. Ironfounding has not yet reached the stage at which its products may be either accepted or rejected by a miscroscope test, although the advent of Lanz pearlitic cast iron may be one more step towards such an end, and, furthermore, no such definition

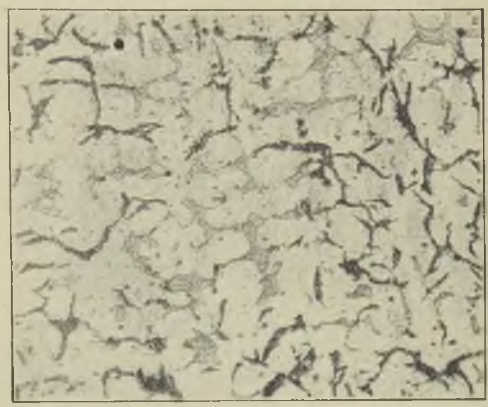


FIG. 7.—50 PER CENT. SEMI-STEEL HEAT-TREATED FOR 12 HOURS AT 800 DEG. C. × 100 DIAS.

as the above could be adopted without standardising the terms fine and coarse graphite. It does not seem necessary to so define semi-steel or to insist on the modified graphite, so long as the required improvement in physical properties is obtained and if both transverse and tensile strength show increases of 25 per cent. over the same mixture without steel, then genuine semi-steel has undoubtedly been produced.

TABLE IV.—*Re-melting of Semi-Steel.*

——	Semi-Steel.	Grey Iron.	Sheep-bridge and Semi-steel.	Sheep-bridge and Grey Iron.
Silicon	2.60	2.97	2.86	3.22
Sulphur	0.072	0.086	0.065	0.070
Phosphorus	1.44	1.63	1.47	1.61
Manganese	0.59	0.67	0.61	0.70
Combined carbon ..	0.35	0.30	0.30	0.30
Graphitic carbon ..	2.49	2.87	2.78	3.0
Total carbon	2.84	3.17	3.08	3.30
Tensile strength, tons	14.5	12.5	12.0	11.7
Transverse strength, lbs.	2.860	2.410	2.700	2.600
Deflection, ins. ..	0.100	0.117	0.099	0.110

For heavier work such as that familiar in South Wales the lower steel-mixtures are not suitable, as their grain would be too open in thicker sections. The stronger mixtures are, however, used very largely in these cases. This is especially so in U.S.A., and foundrymen are familiar through their literature with the breadth of adaptation which foundrymen there have found for semi-steel. It is used for all their large machinery, agricultural work, and for chilled car wheels and chilled rolls.

The high steel-mixtures respond well to heat treatment, of the order of 12 hours at 800 deg. C., and produce an iron which takes a permanent set under the bending test and can be quite easily riveted. Fig. 7 shows such a bar from a 50 per cent. steel mixture which gave 14.1 tons tensile strength and 3,250 lbs. transverse after 12 hours' annealing. The pearlite has all disappeared, and the whole area is occupied by ferrite and graphite, the latter being of much greater size than in the "as cast" condition. Such a material is often very useful in light engineering and electrical work.

Casting Temperature.

It is well known that all classes of cast iron give best test results when cast hot, but these steel mixtures are particularly sensitive to temperature, and cold metal will cause all the beneficial results of the steel to be lost. Iron which gives 14 to 16 tons tensile when properly cast, will yield only 12 tons at lower temperature, and this is due to a growth both in the size of graphite and in the general grain structure.

Remelting Semi-Steel.

In making high steel-mixtures, the result of a first melting of steel and pig-iron is often put through the cupola to make a more uniform material, or a very high-steel pig is diluted with further pig-iron to the required degree. Similar procedure is adopted when "refined" pig-irons, which are actually nothing but common pig-iron with steel, are purchased and used for the best classes of castings. If the most important constituent of good semi-steel is the fine graphite induced by the introduction of steel into the cupola charge, then on what ground can it be claimed that pig-irons above referred to will retain their maximum properties after that remelting which is necessary to convert them to castings? Any increased value due to low silicon, low phosphorus, or even low carbon may be retained and reproduced after remelting, although in the case of carbon there will be an increase if the percentage is less than that normally found in cupola-melted materials, but a claim that fine graphite could be reproduced would be refuted by the general belief that all carbon in molten iron is in solution, and even if that be not the case, it has been seen in the paragraph on heat treatment that rapid growth in graphite takes place with a temperature much lower than that to which the iron will be exposed in its descent of the cupola. The author is not quite clear how the fine graphite is originally produced—it appears to be the result of breakdown of fine structure cementite and eutectic in the just-solidified material—but certainly the conditions on remelting are quite different, for there is then no steel as such present in the charge. Experiments seem to show a balance of evidence against the retention of either fine graphite or maximum physical properties after remelting, and the result of one such experiment is outlined in Table IV. Semi-steel and grey iron of known physical properties were carefully cast into pig form, and each was then remelted with pig-iron under conditions as nearly identical as works practice would allow. The results on the two new materials so obtained are very nearly equal, and it is constantly observed in works practice that foundry scrap from castings in either grey iron or semi-steel may be indiscriminately mixed and again used in the production of either mixture without prejudicing the results in any way. It would be unfair to criticise on these grounds all so-called "refined pig-iron," but it is perfectly legitimate to issue a warning note against any which owe their enhanced properties to steel additions alone.

The author desires to thank Messrs. John Harper & Company, Limited, Willenhall, Staffs, for permission to publish the results of experiments made at their works.

References.

(1) Inst. Brit. Found., 1921-22.
(2) American Found. Assocn., Reprint 411, Oct., 1924.
(3) Principles of Ironfounding.
(4) "F.T.J.," September 13, 1923.
(5) Principles of Ironfounding.

Birmingham Branch.

THE FORMATION OF GRAPHITE IN CAST IRON.

By J. E. Hurst (Member).

The most important constitutional feature in all forms of cast-iron alloys is the formation of graphite. This fundamental feature is often spoken of as the "graphitisation phenomenon." When we consider that all experience, investigation and discussion of all the factors controlling the physical and mechanical properties of castings lead us to the one conclusion that these properties are ultimately controlled by this graphitisation phenomenon, we at once realise the importance of this subject.

The exact nature of the mechanism of the formation of graphite in cast iron has long been a matter of considerable complexity, and even to-day has not been completely elucidated. The many and various views as to the nature of this phenomenon which have been expressed from time to time by investigators are often conflicting to such an extent that it is difficult for the foundryman to form any reasonable working hypothesis to guide him in his routine work.

The only way of clearing up the present conflicting and confusing position is by further research and direct experiment, and those who have considered this phenomenon at all deeply will realise the stupendous difficulties which are involved in further direct experiment.

It is the author's intention in this note to endeavour to review the whole subject of graphitisation in cast iron, and if possible to present the situation in such a way as to enable the reader to obtain a satisfactory working hypothesis of the nature of this phenomenon in so far as the facts as we know them will permit.

In considering the graphitisation phenomenon in cast iron it is convenient to divide the subject under four headings, which are the principal features in the phenomenon with which we are concerned as follows:—(*a*) The actual formation of the graphite; (*b*) the quantity of the graphite; (*c*) the size of the graphite, and (*d*) the distribution of the graphite.

These features strictly relate to the graphitisation phenomenon, and are admittedly the features controlling the physical and mechanical properties of cast iron.

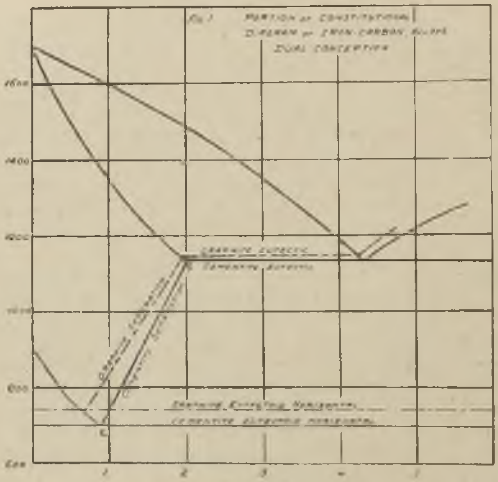


FIG. 1.

The Formation of the Graphite.

It is necessary in view of the complications introduced by the various elements present in commercial cast iron to consider in the first place the formation of graphite in the pure iron-carbon alloys, neglecting the influence of any of the additional elements above referred to. It will be clearly understood that unless otherwise referred to the following considerations are confined to the fundamental pure iron-carbon alloys.

Broadly speaking, there are two modern views held on the mechanism of the graphitisation phenomena. The older of these two views considers the iron-carbon alloys as capable of solidifying when cooling down from the molten state along two distinctly different lines. Under ideal conditions principally slow cooling, during which ample time is allowed for the various constitutional changes to take place to completion, the solid alloys at the temperature of the completion of the solidification consist of two constituents,

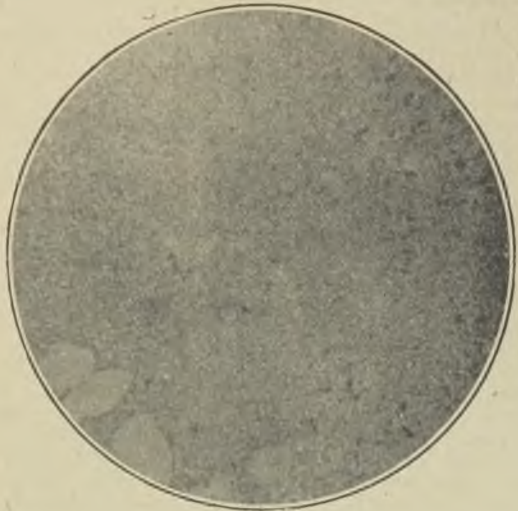


FIG. 2.—STRUCTURE OF SWEDISH IRON HAVING THE APPEARANCE OF GRAPHITE — AUSTENITE EUTECTIC.

namely graphite and a solid solution of graphite in iron, which is well known as Austenite. Under conditions of comparatively rapid cooling the constituents existing in the solid alloys immediately after the completion of the solidification period are the solid solution austenite and the carbide of iron known as cementite. This conception, known as the dual conception of a stable and meta-stable (or semi-stable) system of constitution, is embodied in the well-known constitutional diagram. (Fig. 1.) In this diagram, dotted lines represent the stable conditions in which solid alloys at the eutectoid temperature consist of austenite and austenite-graphite eutectic and the meta-stable conditions are represented by the continuous lines in which the constituents at the eutectic temperature consist of austenite and austenite-cementite eutectic.

Condition of Carbon in Solution in the Liquid Alloys.

The assumption of a complete stable system of iron and graphite in accordance with the above demands the conditions that the carbon is in solution as graphite and not necessarily as the carbide. This was practically the original suggestion of Roozeboom.[1] Roozeboom finally abandoned his further suggestion that the formation of the carbide of iron resulted from a reaction between the solid solution and the graphite at a period subsequent to the formation of the eutectic, and agreed with the dual conception substantially as above.

Up to the present no attempt to retain the stable state at the eutectic temperature by the method of rapid quenching of the alloys has been successful in retaining the austenite-graphite eutectic. In all cases the two phases separating out under these conditions have been found to be austenite and cementite the carbide of iron. These are the constituents of the eutectic of the meta-stable system. The explanation of this by Continental workers is that undercooling always takes place at least down to the eutectic temperatures resulting in solidification according to the meta-stable conditions, and the graphite found in cast iron results from the dissociation of this primarily formed carbide.

The impossibility of the existence of an austenite-graphite eutectic has not yet been finally disposed of. Austenite-graphite structures are frequently met with having all the appearances of a characteristic eutectic structure. A case has been reported by Levy and a photograph of such a structure met with in one of the author's own experiments on a hypo-eutectic Swedish iron of the following composition is given in Fig. 2 :—Tot.C., 3.40 : Gr., nil : Si, 0.37; Mn., ·0.30; S., 0.65 per cent., and P., nil.

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[1] J.I.S.I., 1900, No. 2, page 311.

The structure shown in Fig. 2 was obtained in a sample of this material melted at a very high temperature in the muffle of a Brayshaw injector furnace, and allowed to cool slowly in the crucible in the atmosphere. The mass of the sample was 300 grammes.

Further evidence on which the dual conception is based is to be found in the fact that the hyper-eutectic alloys containing carbon in excess of the eutectic percentage deposit graphite, which rises to the surface of the molten metal immediately on commencing to solidify, producing the well-known "Kish" phenomena. These phenomena have been amply substantiated, and superficially would appear to support the belief that the carbon is dissolved in the molten iron as graphite.

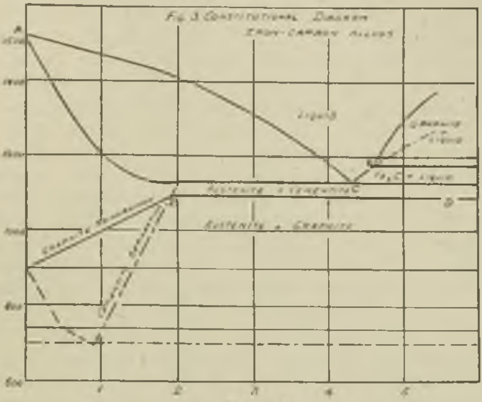

FIG. 3.

It has already been mentioned that the rapid quenching of the molten alloys from all temperatures down to the final solidification point results in the production of austenite, austenite-cementite structures with no free carbon. This fact is interpreted as indicating that the carbon is in solution in the liquid alloys as the carbide of iron probably identical with cementite, and that its formation in the quenched alloys is the normal state of affairs and not necessarily the result of undercooling. Most British metallurgists have adopted this view, and it has been confirmed recently by Honda[2] and Cesaro.[3] Under this conception the carbide of iron is the stable phase down to temperatures slightly below the final solidification range, and the subsequent appearance of graphite is due to the breakdown of these austenite, austenite-cementite structures at lower temperatures.

The explanation of the formation of kish in the liquid hyper-eutectic alloys under these conditions is met in several ways. It is primarily suggested that this may be due to the presence of such elements as silicon.

This is admittedly quite a plausible explanation. as almost all the alloys which have been used in investigations contained at least traces of such impurities. This suggestion has been largely made by Hatfield. It must be remembered, however, that Professor Howe called attention to the difficulty of preserving the hyper-eutectic carbide in alloys without at least a trace of manganese. Dr. Hatfield agreed with this, and the writer has never had the opportunity of obtaining hyper-eutectic cementite in alloys free from manganese.

A somewhat different suggestion has been made by Edwards,[4] Gonterman, Andrews[5] and others. These workers assume that cementite is the stable phase down to temperatures somewhat below the eutectic temperature, approximately 1,100 deg. C., according to Andrews. This is illustrated in the diagram, Fig. 3, in which the lower limit of stability is indicated by the line B.D. The formation of kish has been met by Edwards by the assumption of an upper limit of stability of the carbide, as indicated by the line C.E. in the diagram, Fig. 3.

According to this assumption, at temperatures and concentrations but little in excess of those of the eutectic alloy, the cementite carbide is stable, and crystallise from the molten liquor. The break at the point in the liquidus curve would under these circumstances indicate a reaction of

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[2] J.I.S.I., No. 2, 1920.
[3] J.I.S.I., No. 1, 1919.
[4] Physico-chemistry of Steel, London, 1914.
[5] Carnegie Memoirs, J.I.S.I., 1917.

the type $Fe_3C \rightleftarrows$ graphite and molten liquid according as to whether the alloy is being heated or cooled.

The existence of such an upper limit has not yet been demonstrated by experiment, and in fact the experiments of Ruff and Goecke and Hannemann into the hyper-eutectic regions of these alloys have shown no break in the liquidus curve corresponding to such a reaction.

The stupendous difficulties involved in experiments in this region, however, have so far prohibited the use of sufficiently sensitive and accurate methods necessary to detect such a point.

The diagram propounded by Upton[6] has often been referred to, and is another case which has the merit of avoiding the dual conception referred to earlier. Whilst this diagram involves further complexities and postulates the existence of certain complex carbides other than Fe_3C, the method of dealing with the alloys at the solidification point is worthy of reference here. In this conception the phases separating out from the hyper-eutectic alloys under stable conditions are considered to be austenite and graphite. In the light of this diagram the structures of white cast iron and quenched cast iron are due to undercooling, and consist of austenite and under-cooled liquid. The production of free carbon during subsequent annealing is presumed to be due to reactions which were otherwise suppressed during solidification.

There is no doubt that the weight of the evidence is in the favour of regarding the carbon as existing in the liquid iron as the carbide of iron, and for this reason the omission of the lines indicating the graphite-austenite equilibrium from the upper portion of the diagram is the most rational way of interpreting the facts as we now know them.

The possibility of the existence of free graphite, either suspended in the molten iron or in some colloidal form, as has been frequently stated by recent workers, must be dismissed as entirely without proof, evidence or foundation. In fact, the whole mass of evidence plainly negatives such suggestions.

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[6] J. Phys. Chem., 1908-12 and 1909-13.

Temperature at which Graphite Commences to Form.

The fact that no well-defined arrest point corresponding to the precipitation of graphite is to be found in the cooling curves of the iron-carbon alloys is in a large measure responsible for the conflicting views as to its formation. Experience conclusively demonstrates that the formation of graphite is continuous for a considerable temperature range below the solidification, which at once explains the absence of anything in the nature of a definite arrest point on the cooling curves.

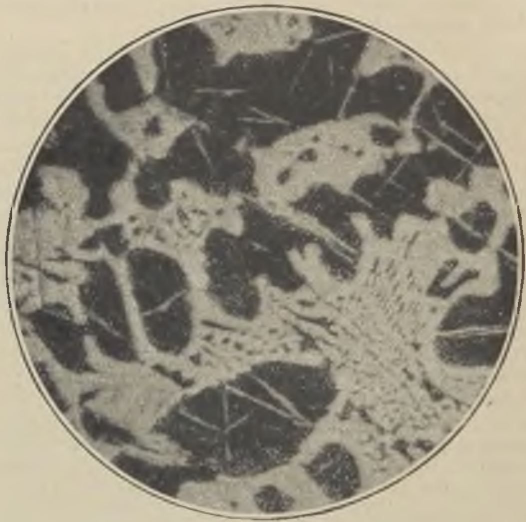

Fig. 1.—Swedish Iron, showing Cementite Needles Deposited from Solid Solution.

By means of quenching experiments the temperature of the commencement of graphitisation has been shown by various investigators. From such experiments Andrews concluded that graphitisation commenced after the final solidification point at temperatures between 1,150 and 1,100 deg. C. Honda,[7] placed this temperature somewhat lower between 1,130 and 1,050 deg. C.

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[7] J.I.S.I., No. 2, 1920.

The recent experiments of Northcott[8] with ordinary grey irons place the temperature at 1,145 to 1,000 deg. C. These observations are in agreement with the diagram of the Gonterman-Edwards type, and the conclusions of Cesaro[9] from certain mathematical considerations.

Experimental evidence definitely places the commencement of graphitisation and the stability of the carbide at some distance below the solidification point at least 5 or 10 deg. C.

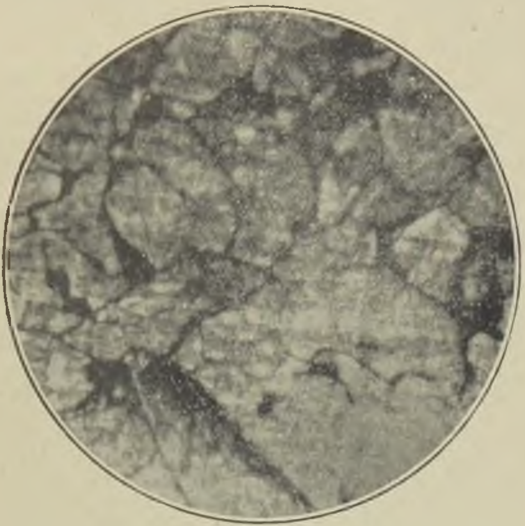

FIG. 5.—AUSTENITIC STRUCTURE IN QUENCHED GREY CAST IRON.

The Formation of Graphite from the Primarily Formed Carbide.

There is now to consider the formation of graphite as found in all commercial grey cast irons from the stable structure austenite and cementite. The general view is that the graphite arises from the dissociation of this primarily formed carbide according to the rate of cooling in these lower ranges of temperatures.

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[8] I.B.F. Proc., 1924.
[9] J.I.S.I., No. 1, 1919.

Here, again, there are various opinions as to the exact nature of this dissociation. The simplest case is the assumption of the direct dissociation of the carbide into ferrite and graphite in accordance with the equation:—

$$Fe_3C = 3Fe + C.$$

An alternative suggestion has been made that the cementite carbide dissociates into graphite, and the solid solution of carbon in iron as represented by the equation:—

$$Fe_3C = C + \text{solid solution of C in Fe.}$$

A totally different suggestion has been put forward by Honda and his various Japanese collaborators in which the dissociation of the carbide is the result of a reaction between the dissolved CO_2 gas and the carbide. This suggestion will be dealt with under a separate heading.

The two former views arise out of the difficulty of explaining the presence or absence of free ferrite. If the former view is accepted it would appear inevitable that all alloys containing free graphite must contain free ferrite. It is known from experience that this is not the case, and for this reason the second view more nearly fits in with the facts as they are known. Under these circumstances free ferrite arises from the secondary precipitation of graphite from the saturated solid solution.

A very brief picture of the sequence of events in the solidification of liquid cast iron can now be made. The liquid alloy, consisting of a solution of carbide of iron in iron solidifies as a stable mixture of the austenite solid solution and the austenite carbide eutectic. This condition is stable at least down to a temperature in the region of 1,100 deg. C. Then, according to the rate of cooling, the free carbide of the eutectic dissociates into graphite and a further quantity of the solid solution.

We have now to consider what happens to the solid solution, or austenite, in cooling down from the eutectic temperature. As the temperature gradually falls, the solid solution becomes saturated with respect to carbon, and the line SE in the diagram, Fig. 1, shows the extent of the decrease in concentration of the saturated solid solutions with a decrease in temperature. The excess carbon in solution in pure iron carbon alloys is deposited in the form of carbide needles which are very familiar in case-hardened steel samples, and are readily seen in the primary austenite areas of hypoeutectic white irons. An example of this is illustrated in Fig. 4, showing the cementite needles in a slowly cooled pig-iron. It is quite rational to assume that the secondary carbide deposited by the solid solution decomposes in a like manner to the primary carbide already referred to. This does not help to explain the formation of free ferrite, as under these circumstances it will be appreciated at once that the structure at the pearlite change point would consist of purely graphite and pearlite.

If the reverse process of heating up specimens of grey cast iron is considered, it has been frequently shown that the free graphite redissolves in the cast iron. This phenomenon was shown by Mr., now Sir Robert, Hadfield[10] in connection with malleable cast iron, and further amplified by Dr. Hatfield[11] and the writer.[12] Details of a further experiment on this subject, conducted by the writer, are worthy of reference here. In this experiment small ½ in. square by 3 in. long bars of a grey hematite were heated to a temperature of 1,015 to 1,025 deg. C. in an exhausted tube. The photograph, Fig. 5, shows the microstructure of the bar quenched in water from 1,025 deg. C., after maintaining at this temperature for one hour, and one after slow cooling without quenching. The analyses of the various specimens are given in the following table:—

	Original.	Quenched.	Slow cooled.
	Per cent.	Per cent.	Per cent.
CC. ..	0.17	0.90	—
Gr. ..	2.93	2.20	—
Tot. C...	3.10	3.16	3.15
Si ..	1.18	—	—
Mn ..	0.26	—	—
S ..	0.077	—	—
P. ..	0.04	—	—

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[10] J.I.S.I., 1894, No. 1, page 156.
[11] J.I.S.I., 1906, No. 2, page 162.
[12] J.I.S.I., 1917, No. 2, page 125.

The quenched sample showed a distinctly austenitic structure composed of polygonal austenite grains with the undissolved graphite presumably existing round the grain boundaries. The extent of the re-absorption of the graphite in this case amounts to 0.73 per cent., and in a further experiment of 6 hours duration the combined carbon figure in the quenched sample was 1.02 per cent. indicating a re-absorption of graphite to the extent of 0.85 per cent.. Prolonged heat treatment experiments at temperatures in the neighbourhood of 1,000 deg. C. have failed to bring about the absorption of graphite in amounts exceeding the amount required to satisfy the saturated solid solution at this particular temperature, and such experiments have failed to bring about the reproduction of the free cementite carbide. Such experiments have been repeatedly confirmed, particularly recently by American workers, notably R. S. Archer[13] and Merica,[14] and they serve to demonstrate that a portion of the graphitic carbon (not necessarily in the so-called temper-carbon form) is directly soluble, without the intervention of the free carbide stage forming presumably the austenite solid solution.

From experiments of this nature it is therefore quite rational to conclude that the solid solution is capable of depositing graphite directly without the intervention of the intermediate stage free carbide. This being the case the presence of free ferrite is capable of simple explanation as resulting from the reduction in concentration of the solid solution due to the direct deposition of graphite, the solid solution after passing the pearlite transformation resolving itself into ferrite and pearlite.

American workers apparently still lean towards the dual conception of the constitution of these alloys previously referred to, and consider that the solid solution resulting from the re-absorption of the graphite is different in character to the normal austenite solid solution, which has been regarded as the solid solution of carbide of iron in iron. To such an extent is this view held in America that they have suggested the title Boydenite for the

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[13] Amer. Mining and Met Engs., February, 1920.
[14] Amer. Bureau of Standards, No. 129.

former solid solution. It is only right to state here that recent American work leads to the assumption that "the presence of silicon is a requirement of Boydenite," Schwartz, Payne & Gorton,[15] and, indeed, the writer's experiments and most others have been conducted on irons containing at least small quantities of silicon. In the first place it does not appear necessary to postulate the existence of two solid solutions, for if cementite carbide is unstable in the free state, it might be expected to be equally if not more unstable in solution. Secondly, in so far as foundrymen are concerned, as silicon is invariably present in the alloys with which they are called upon to deal the necessity of the presence of silicon to ensure the precipitation of graphite in this manner with the concurrent formation of ferrite is not of much importance.

Before leaving this section of the subject we have to consider the recent suggestion of Honda that the production of graphitic carbon is due to the catalytic action of the dissolved gases on the free carbide. The mechanism of this suggested action is briefly stated as follows:—As the temperature of the specimen falls below the melting point a minute quantity of free CO_2 co-existing with CO soon reacts on the free cementite and produces CO by the equation:—

$$Fe_3C + CO = 2CO + 3Fe$$

The alteration in equilibrium conditions by the disappearance of free CO_2 as a component causes further dissociation of CO in accordance with the equation:—

$$2CO = CO_2 + C.$$

reproducing the CO_2 which again reacts with the cementite, thus maintaining the continuity of events.

The catalytic action of this nature is admittedly only a suggestion, and whether or not it is a correct picture of the actual mechanism of graphitisation direct experiment only can decide.

On consideration it will be seen at once that this suggestion refers solely to the manner of the dissociation of the free carbide, and even this suggestion is open to the difficulty of explaining the

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[15] Amer. Inst. Min. and Met. Engs., August, 1923.

presence of free graphite in the presence or absence of free ferrite.

Apart from this, the suggestion of this catalytic action is open to the serious objection that for its reception and continuation it requires certain well defined limits of temperature and ratio between the amount of CO_2 and CO present in the iron. It does not seem reasonable to expect that the ratio of CO_2 to CO present in these iron-carbon alloys prepared in all varieties of methods should be invariably within these limits, and yet under correct cooling conditions graphite is invariably produced, whatever the source of the iron-carbon alloy.

The formation of graphite by the intervention of these catalytic actions is merely a suggestion. and has not been definitely proved. In the author's opinion it is very unlikely that this is a reasonable explanation and until further evidence either way is forthcoming it does not affect the conception we have tried to draw from the facts as we know them at present.

Summarising these facts, we must admit that the evidence is in favour of regarding the carbon in solution in the liquid metal as the carbide of iron. This carbide of iron is the stable phase deposited on passing the temperature of the final solidification point and forming a constituent along with the solid solution of the eutectic. On further cooling down the carbide dissociates into graphite and the solid solution, which in its turn is capable of depositing graphite directly.

On passing the eutectoid point the solid solution resolves itself into pearlite ferrite and graphite according to the extent of the dissociation of both the carbide and the solid solution, which, of course, depends upon the rate of cooling.

DISCUSSION.

The President said the meeting of the Branch was held in conjunction with the Staffordshire Iron and Steel Institute, and he hoped that if any members of the Iron and Steel Institute were present they would take part in the discussion as freely as the members of the local Branch of the Foundrymen's Institute. The problem with which Mr. Hurst had dealt was one which had exercised the minds of metallurgists in this country and in America, and his contribution would be read with interest and appreciation. There was no doubt many would not agree with some of the arguments advanced, and healthy criticism would be welcomed.

Mr. Arthur Marks described the Paper as an excellent explanation of the modern work connected with the graphitisation of cast iron. As to the explanation with regard to free ferrite, he did not see any need for worry about free carbon being formed prior to the formation of Fe_3C. In his opinion the amount of carbon present, 4.3 per cent., was insufficient to saturate all the iron, and therefore the possibility of free ferrite being present was quite explicable from a chemical point of view. The question of the decomposition of carbide by CO_2 and CO was bound up with the question of the dissociation of CO_2 into CO. He had not the figures by him, but, speaking from memory, he thought the percentage of CO_2 which was present at the temperature of the reactions, 1,150 to 1,100 deg., was not sufficient to account for the reaction $Fe_3C+CO=2CO+3Fe$. He thought the degree of dissociation of the CO_2 to CO would be too high, and that the excess CO would not render that reaction so comfortable as it could be written on the blackboard. To-day there were very few castings which were made with graphite as high as 4.3 per cent.; in practice one would be immediately in trouble in various directions. With regard to centrifugal cast iron, he did not think the speeds of rotation were sufficiently high to give the separation in view of the thicknesses involved and the rapidity of cooling. As a matter of practical politics he considered there could be no practical separation of the graphite under the speeds used and the rapid cooling when casting under these conditions. No doubt it was a matter for experiment; he was only giving his own personal view of the case.

Mr. E. Longden said Mr. Hurst had referred to the quenching of a stream of molten iron by immersion in iced brine, and had pointed out that no graphite was discovered in that metal. To his mind that was no proof that graphite did not exist in the molten iron before solidification. He thought it did, and that by quenching the iron from a high temperature they exerted a pressure, preventing the formation of graphite. In the case of mottled iron, which was on the border line of white iron and grey iron, they again saw two conflicting forces. The graphite was attempting to expand, and the white iron, the white matrix, refused to allow the graphite to expand. He asked Mr. Hurst whether he would think it possible to produce a casting weighing about 8 cwt., 17 in. or 18 in. in diameter and 13 in. or 14 in. deep, without any attempt to feed it. If he informed the lecturer that he (Mr. Longden) had been able to secure that mass of iron absolutely solid without attempt to feed, how would he explain that contradictory conclusion, because they were given to understand that there was liquid shrinkage in grey iron. In his (the speaker's) opinion there was none. What shrinkage there was was due to gases. The question of the formation of kish went some way, in his opinion, to prove the theory that graphite was present in iron in the molten state. All the graphite did not come to the top. There were all sorts of pressures and tensions which prevented its doing so. His view was that kish in a very high silicon iron was being formed all the time and the metal was not solidified. Take acid-resisting metal with a silicon content of about 15 per cent. In that case they found the cupola after blowing down a mass of graphite flakes which were being formed while the metal was molten.

Mr. J. B. Johnson proposed a vote of thanks to Mr. Hurst for his address, and Mr. F. C. Edwards, in seconding, contended that carbon dissolved in iron in the same way as salt or sugar dissolved in water. There were good grounds for holding that at a high temperature the carbon in cast iron was in solution. It was not suspended, it was dissolved, and as they lowered the temperature the carbon was thrown out. The Paper went a long way towards popularising the most advanced knowledge, and anyone striving to popularise advanced knowledge was performing a great work.

The President having added an expression of his appreciation of the Paper the resolution was heartily agreed to.

The Author's Reply.

Replying upon the discussion, **Mr. Hurst** referred to the suggestion made by Mr. Marks that the speed of centrifugal casting was hardly sufficient to separate the graphite. Mr. Marks rather implied that the casting was thin, but he (the lecturer) had dealt with centrifugal castings which could not be so described. For example, a casting with a radial thickness of, say, 12 in., was hardly thin, and a good many castings had been made with that thickness in which there had been no graphite separation. The remarkable thing was that there had been a considerable amount of sulphide separation, practically the whole of the sulphide segregating to the inside surface of the casting. The difference in the specific gravities of manganese sulphide and graphite is so great that one would expect graphite freely to separate before the sulphide. This is not the case. All varieties of grey pig-iron in Great Britain had been used in the production of these centrifugal castings, and they had never yet found a pig-iron which was of such a nature that the graphite would separate out in the centrifugal process. He was inclined to think that the structures which appeared to be Austenite graphite eutectic structures were not eutectic structures at all, but were structures brought about by a state of affairs in the cooling down, in which the graphite was deposited from the solid solution in this very finely divided form. The rate of cooling had been such that there had been very little opportunity for any of the graphite plates to congregate together and to present themselves more or less in the characteristic form of graphite plates. In other words they should be regarded as transition stages. They did not know just how much excess over the eutectic percentage of carbon was necessary to bring about the phenomenon of kish. They did not notice the phenomenon of kish in any ordinary commercial foundry iron, except the silicious irons. It was only when carbon was in excess of the eutectic percentage that this phenomenon was observed. Mr. Longden's supposition that graphite may exist as such in the liquid iron before solidification is answered in a very practical manner by the experience with centrifugal castings.

Mr. Longden's other point is rather outside the scope of the paper. There is no doubt that such a casting can be produced perfectly sound without any attempt to feed it. Presuming that the casting is cylindrical the best way is to cast it centrifugally. The other common way is to provide a shrinkage head. All the other alternative methods can probably be summarised in the following words: to pour the casting in such a manner that the majority of the liquid shrinkage of any portion of the metal already in the mould has taken place before the next portion of metal enters the mould.

Lancashire Branch
(BURNLEY SECTION).

CASTINGS FOR MACHINE TOOLS.

By H. Jowett (Associate Member).

It may be of interest to describe why a holding down plant is essential, and to illustrate one installed by the author at his works. It is surprising the large number of foundries which are making castings up to 10 tons in weight and still rely on the old-fashioned way of weighting the moulds. There has to be only one mishap from a mould top-part lifting and causing a waster casting to be produced, and the price of an adequate plant is lost. Obviously, such a plant is not an expensive proposition. There are foundries specialising in certain classes of machine tools which make complete boxes, drags, special grids and copes to mould the majority of their castings, but such a firm making a variety of machine tools and special machines is at a disadvantage in that respect. For a moulding box 20 ft. × 8 ft. it requires that first of all the moulder must dig out the hole the depth and width required for the largest casting. Then the long bars, which are 10 ft. 6 in. long × 6 in. wide × 7 in. deep, must be fixed in position at the bottom of the hole. These are fixed 6 ft. apart from centre one from the other, and it is essential to have them level, one with another. The hooks, which are 2 in. sq. and made of steel or wrought iron, are then fixed under the weights, yet wedged to their sides. These are 5 ft. 6 in. long, which fixes the depth of the hole. The moulder must give a thorough good ramming of sand all round to the top of the bars, so that there is a straight and level surface. Then the grids, which are of cast iron, are fixed from one bar to the other. The pillars are placed directly on the surface of the bars. These pillars are 4 ft. 6 in. long and 6 in. dia., with a 10-in. dia. flange $1\frac{1}{4}$ in. thickness and 1-in. metal in thickness in the diameter of the pillar. Everything being fixed, it is advisable to ram a small layer of sand to the top of the grids or to the height that is chosen for the position of the coke bed. The coke bed is directly on the small layer of sand which covers the grids. It is put over the full surface of the hole, and is 6 in. deep.

Vent pipes, at each side of the plant, are placed in the centre of the holding-down hooks, about 1 ft. away from the outside, so that when the top box is in position, there is no difficulty in finding the hooks. Again, it gives room to put down broad bars similar to the bearers to stop in the box and to prevent run outs. Having made the coke bed, it is essential to cover the coke with a good layer of hay, straw or shavings, so as to prevent the sand from getting inter-mixed with the bed, because it is necessary that the air should have a clear course into the pipes, as quite often this bed is called upon to bring air away from cores in the mould. It may be thought that there should be cast-iron plates round the sides and ends of the hole, but the author only uses such plates fixed in certain moulds that require reinforcement in parts where the strain applies most—in fact, he has had 1-ton weights at parts of the moulds, and rammed round them and then staked behind them. If it is not desired to have the floor level on the top of the pillars, packings

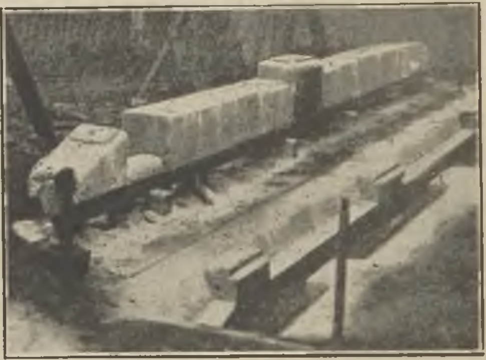


FIG. 1.

or 56-lb. weights on the pillars can be fixed, but it is essential that the top box touches the packings, if not they must be wedged with wrought iron.

This done, bars are fixed on the top box similar to those actually in the plant. They are arranged on a 56-lb. weight opposite the **2**-in. sq. wrought-iron hook. Then an endless chain is fixed through the hook on to the top of the bar and wedged up between the bottom of the bar and the top of the 56-lb. weight, the crane taking care of the bar with a hook in the centre. Having wedged up, the crane lowers off, but all then is tight; the links of these chains are ¾ in. in thickness. Fig. 9 shows such a mould ready for casting. Having seen two or three of these bars break with the crane lifting the hook in the centre, it is better to use a chain round the bar. The hooks cast in these bars are handy for lifting purposes. Another design of a holding-down plant comprises a cast-iron stay 4 × 12 in. and is 4 ft. in depth × 7ft. wide. This plant compels one to use same top box, no matter what kind of a pattern there is in the plant, causing more ramming than necessary at times, where, as with the other design, one can use any top part necessary, as the pillars can be fixed in the hole to suit any box. But care must be taken to see that the pillars or stands are always fixed below the pattern.

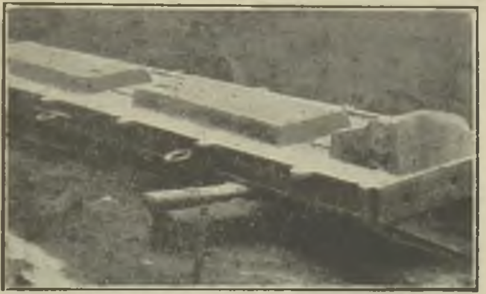


Fig. 2.

Lathe Bed Mould.

Fig. 1 shows bed mould for an 11-in. turret combination lathe, the length of the pattern being 20 ft. 9 in., 12 in. wide, and 19 in. deep. Primarily a hole is prepared and the coke bed placed in position. Black sand is then rammed to about 2 in. from the face of the mould. From the bottom of the slides of the mould it is best to fix two straight edges the full length of the pattern and give the necessary camber, which in this case $\frac{1}{2}$ in. was allowed. Then the facing sand is prepared 1 in. above the straight edges and a good venting into the coke bed is given. The vent holes have to be made up and the sand made firm, in order that the moulder can strickle off the whole surface ready for fixing the pattern in position. Two lifting plates were made to lift out the inside of the mould, shown in Fig. 1. Additionally, grids were made to bed on the top of the lifting plate over the inside of the slides, as they form a superior support in binding the sand together

Fig. 3.

than relying solely on loose irons. The plates are only 4 in. wide and are bedded in the mould, so that the top of the lifting plate is a little below the bottom of the slide. These plates were rammed up in suitable sand, so that when they were finished and wet blacked, they were removed to the core stove and dried. The weights shown in Fig. 3 are cast "open-sand," and just allow for a wedge at each side of the lifting plate which holds them in position either on the outside of the mould or on the stove carriage. Then, again, they fill the purpose of weighting small moulds when not in use for this practice. The slides are $2\frac{1}{4}$ in. thick, 6 in. wide, and are the full length of the pattern. The sides of the mould are $\frac{5}{8}$ in. thick with a $\frac{3}{8}$-in. facing 1 in. deep the full length. The inside of the mould is well strengthened, as there is $1\frac{1}{4}$ in. bar of metal every 13 in., and the space seen at each end is plated at the bottom, the core being fixed on double studs at the bottom and then wedged with them on each side of the mould. The bottom is rammed up to the top of the slide, then a row of irons laid on slide to hold in position after the withdrawal of the pattern. Fig. 2 shows the top part used for this mould; there is a 6-in. lift, except at each end, which is about 11 in. The box is a fast-barred one, being 23 ft. long, 3 ft. 3 in. broad, and 8 in. deep. Fig. 3 shows the mould with the inside set in

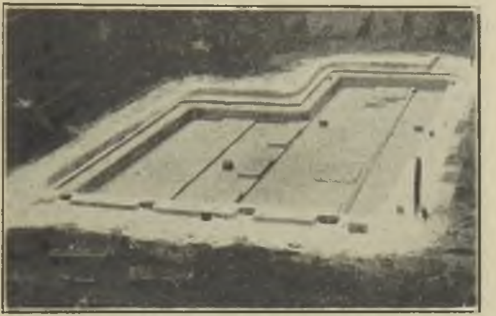


FIG. 4.

position ready for top part to be returned. The weight of this casting is 35 cwts. and is practically straight.

Foundation Plate for Heavy Lathe.

Fig. 4 illustrates the construction of a mould of a foundation plate for a heavy lathe. The pattern which formed the mould is 13 ft. 9 in. long, 7 ft. 6 in. broad, 9 in. deep, with a 3-in. broad flange all round, $1\frac{1}{2}$ in. in thickness. This pattern was placed on a similarly prepared bed, but where facings are seen, was cut out, and then bedded on the surface to suit the pattern. Four 2-in. sq. runners and two oblong runners (3 in. by $\frac{3}{4}$ in.) were then rammed up to the joint. Grids were made to lift the sections out of the top, and to save a certain amount of lifting or gaggering, as it is sometimes called. Fig. 5 illustrates the grid section and the bars which form it in the top of the mould. It also shows a 4-in. broad flange in

FIG. 5.

the centre rib, but loose cores were made with the flange fixed in position and made the depth of the pattern. These were dried, put in the pattern and bolted up in the top part with the other grids. If this had not been done, it would have entailed more work, as the grids would have had to be rammed up and a joint made over the whole surface, then the top part would have had to be rammed up and lifted off, the flange drawn out, and finished off and blacked, then the top would have had to be put back again and the grids bolted to the top and finished off. This top was wet-blacked and fixed on stands, fires were put beneath it. A 5/16 in. camber was allowed and the weight of the casting was 55 cwt.

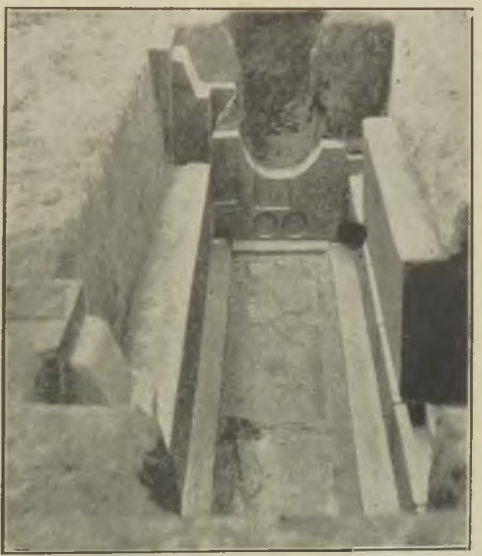


Fig. 6.

Slotting Machine Cross Slide.

Fig. 6 relates to a cross slide pattern for a loco-frame plate slotting machine. The length of the pattern is 12 ft. 3 in., the width 3 ft., and the depth 3 ft. 7 in. The dimensions of the slide on the side of the pattern are 4 in. by 7 in. on the extreme bottom. From this slide run ribs up to the other slide, which is 3 in. sq.; all these are made in short lengths and given plenty of taper, which is of considerable assistance to the moulder, as all these pieces have to draw towards the mould. Fig. 6 illustrates the bottom part of the mould; the side where the pieces have been drawn from the mould can be seen. On the opposite side at the extreme ends of the mould

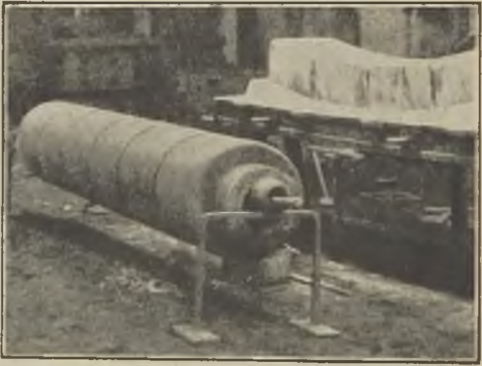


Fig. 7.

the tops of cores are shown. These have been fixed in core prints and held in that position with two hooks from the cores to the back of stakes, with a fish plate across the stakes, as about 8 in. of core comes forward and projects into the mould. The runners, 3 in. by 2 in., are fixed at the bottom of the slide, and are ironed down the sides and on the top, down gates connected to them, and bushes rammed round to the top of the joint, except for about 3 in., to enable the moulder to cut channels to the down runners. The core-print at the bottom of mould is 23 in. wide, 12 in. deep, and made in six cores. They are vented into the coke bed with 2-in. tubes rammed round the centre of core, and made up on the top surface and dried. This method prevents metal getting into vents, except, of course, if the cores lift, which is prevented, as double studs are required on these cores. These studs are the thickness of metal between the barrel core and the top of the core where the double studs are nailed on. The half-round core-print is to hold a barrel core, 15 in. in diameter, with a swell on $22\frac{1}{2}$ in. diameter, and a $2\frac{3}{4}$-in. flange in depth of core every 23 in. in length. Under this core-print, a pillar-stand is rammed in position, which is fixed 6 in. below the depth of the pattern. This is to prevent any sign of a crush.

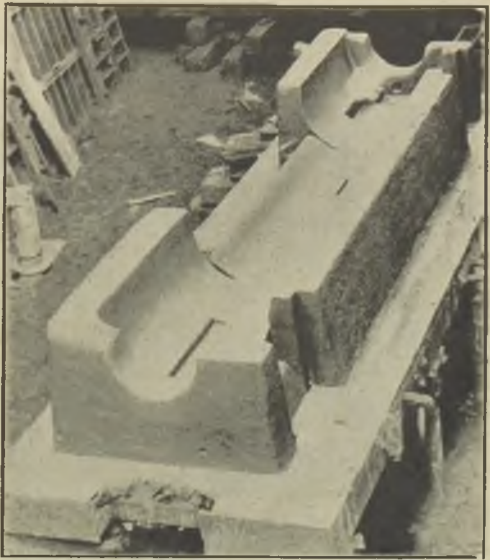


Fig. 8.

Fig. 7 illustrates the core which was used in this mould; the core barrel was 13 ft. 6 in. long and 11 in. in diameter. Straw ropes, clay and loam were used, also a number of straight irons in between the flanges, which were wired round the barrel for support. To prevent the core barrel from lifting, six 3-in. sq. packings were placed in equal distances on the barrel to the surface of the core, and the chaplet stalks in the top box are placed to be central with these packings. They were wedged to the bearers which hold the top box in position. Each end of the barrel is wedged similarly. The gas was brought away from each end of the core, but it is essential to wedge loose barrels in the existing barrel, as it was short of length. The bottom part of this mould was made in green sand, and required neither fires nor mould-driers. Fig. 8 illustrates the top part of the mould; the box is 15 ft. long, 5 ft. 2 in. wide, and 8 in. deep. Grids were made to put on the joint for this lift, with prongs cast on, and 2-in. sq. prongs were prepared to wedge to the bottom bars of the top box to keep it from slipping or giving way. The deepest part of this lift was 24 in. Lifters were also used over the top of the grids and hooked on to the box-bars to help to bind and hold the sand together, as a few flanges had to be withdrawn from the mould during the finishing operation. The sand used to line the face of the pattern was made up of

Fig. 9.

equal parts of facing sand and core sand. It was wet-blacked and finished, and Fig. 8 shows the part ready for turning over and fixing on stands to be dried. Fig. 9 illustrates the mould put together and practically ready for casting. Fig. 10 is a view of the casting in the machine shop, where it has been marked out and is ready for planing. The weight of this casting was 85 cwt.

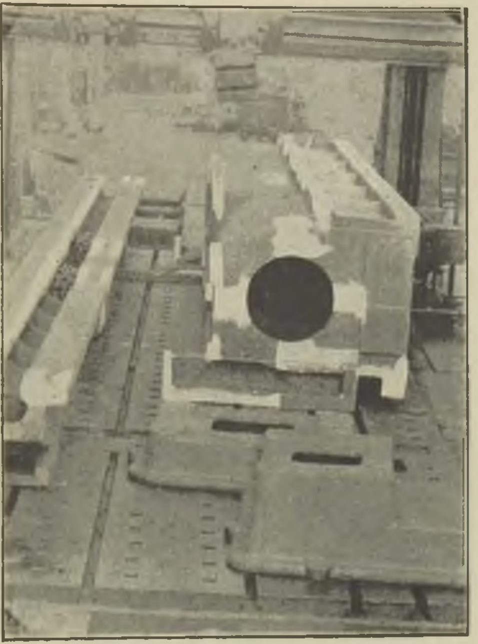


FIG. 10.

Loco-Frame-Plate Slotter-Bed.

Fig. 12 is a view of pattern of a bed for a loco-frame-plate slotter, the length of which is 20 ft. 3 in., the width 6 ft. and the depth 19 in. The pattern is in one whole length, which is satisfactory from the foundry business standpoint. It is a different proposition when there is only a half-pattern delivered to the foundry, especially for beds that reach 30 ft. in length. Engineers also restrict the machining allowance to too fine a limit for the length of such castings. Limiting the foundry to a $\frac{1}{2}$-in. machining allowance is too little

FIG. 11.

when it is realised that there exists no hard-and-fast rule for the setting of camber. This is gained by experience and by making a study of section and design. This pattern, too, was placed in the plant described, the advantage being that the coke bed was fixed. The hole was dug out and straight-edges were set the whole length of the pattern. The straight-edges having been bedded down and the required camber arranged (in this case $\frac{5}{8}$ in. was allowed). This can be obtained by holding a line-band the full length of the straight-edge and then set down by a gauge. Having set these, the moulder fixes the facing sand and vents the face of mould. He then strickles off the whole surface, ready for bedding the pattern in position. The pattern is fixed on the bed, the core-prints are marked and cut out, and the patterns re-bedded on the surface. Weights are put on the centre of pattern, and care must be taken to see that the pattern is pressed on the sand bed. The line-band is used on top of the pattern to ascertain that the camber is the same as the bed. Then the runners can be fixed and the job rammed up to the joint. The sides of the mould are vented into the coke bed, or ashes are fixed half-way the depth of mould, to bring gas away from the sides of the mould. Fig. 11 illustrates the mould, which shows on one side that the cores are fixed in position to shorten the width of the bed. These cores were held by spikes, and studs fixed to the body cores. Their size was 5 ft. 8 in. broad, 3 ft. 3 in. wide, and 15 in. deep. Six of them filled the whole mould, leaving $1\frac{1}{2}$ in. bar between each core. The thickness beneath them varied from $1\frac{1}{4}$ in. to $3\frac{1}{4}$ in.; the chaplets shown set in position, hold the cores and give the thickness

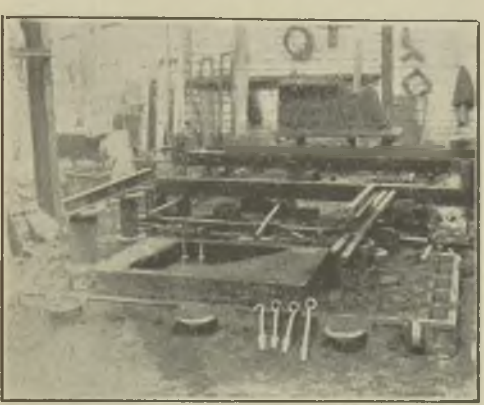


Fig. 12.

referred to. At the end of mould the runners are set at the bottom. At the opposite end the runners are 12 in. from the surface, as it proves to be the most effective course to arrange the setting of the runners, owing to pouring with two ladles. Generally the foundry commences pouring where the largest runners are, and has the required weight of metal in the mould before it starts pouring, with the second ladle at the other end of mould. Fig. 12 is a view of this mould closed, and ready for casting. Two moulding-box top-parts were used, one being 22 ft. by 8 ft., and the other 12 ft. by 6 ft. The largest box is clamped with the chain round the bearers, and the small box is shown ready for weights to be placed on the bars. Plugs are always fixed in the runner basins, as they can be regulated to suit individual ideas of teeming speeds. The weight of the cast-

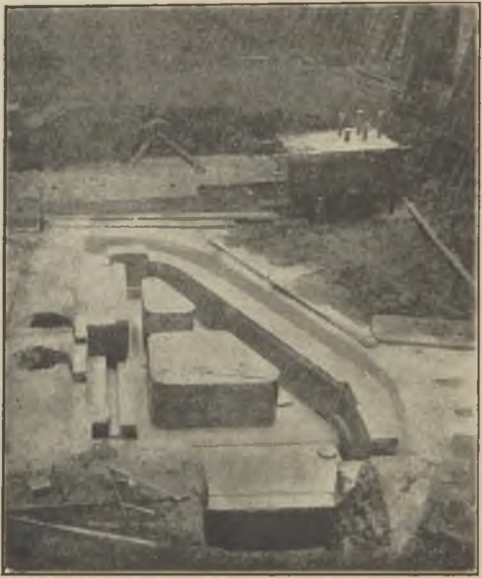


FIG. 13.

ing is 8 tons 15 cwt., and showed only a $\frac{1}{4}$-in. in variation with line band, which is satisfactory from the foundry point of view.

Cheek for Milling Machine.

An upright or cheek for a plain milling machine presents several features of interest. The pattern

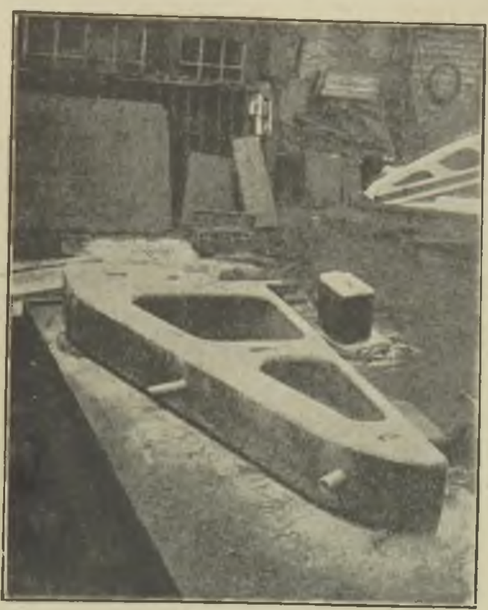


FIG. 14.

is 7 ft. 3 in. long, 4 ft. 2 in. wide, and 3 ft. 2 in. deep. Fig. 13 illustrates the mould, with the cores set in position at the deep end of mould, and one side core in position on the slide part of the casting. The core on the slide overhangs in the mould from the core-print, and is fastened back by hooks in the core, and bolted through a fishplate and screwed up, so that the core will not overbalance. The main body core rests on chaplets on the bottom mould, only $\frac{3}{4}$ in. metal being allowed. It also rests on the bottom core at the deep end. This core is narrow between the slide core and the panel in the mould. It is too narrow to run a thickness of cast-iron core-grid. Two pieces of $\frac{3}{8}$ in. wrought iron were cast in the core-grids, and loose irons were laid in between for support. They act as binders, so that the pressure of metal will not break the core.

Fig. 15.

A small layer of fine ashes was laid between the irons and a few wax vents to ensure the gas getting away from the core at that particular point. Fig. 14 shows the core ready for lowering into position in the mould. Owing to the length and to the vent having to come away from the bottom print, it is essential to have two 2-in. pipes to assist getting the gas quickly from the core. These holes also help the dresser to break the core-grid with a long chisel. Afterwards they are plugged. The depth of this core is 11 in. and the width $1\frac{1}{4}$ in. in the narrow part. The thickness of metal round this core averages about $\frac{7}{8}$ in.

Cheek for Milling Machine.

Fig. 15 shows the top part and the pattern, which illustrates the depth of the foot (3 ft. 2 in.). The bottom part of the mould was cast green-sand, but the top was dried, as it is advisable when the number of chaplet stalks that have to be fastened are considered. They numbered seventeen in all, as there are two loose cores, in addition to the body core, to be held down. The chaplets are wedged under bars that are across the moulding box. Weights are placed on the bars to hold the

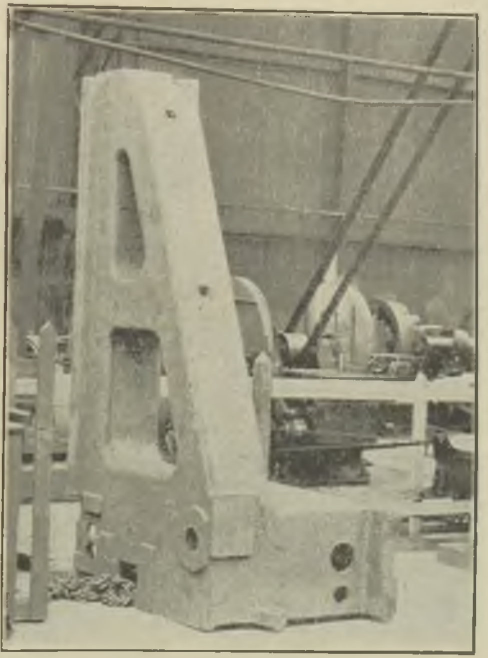


Fig. 16.

box from lifting. Fig. 16 shows the finished casting, two of which are required for the actual machine. The flange on the side of the casting, as shown, was dovetailed on to the pattern, to allow the moulders to draw forward after the pattern had been withdrawn. The circular holes on the side of casting are those referred to as being necessary for getting the gas away from the main core. The two holes against the flange were the only outlets, except for the holes opposite. This core is 20 in. deep, 13 in. wide, and 18 in. in breadth, and was made in oil sand, as also were the cores on the side of the slide. The opposite core was 2 ft. 5 in. by 22 in. by 18 in., and is rather deeper. The weight of the casting is 36 cwt.

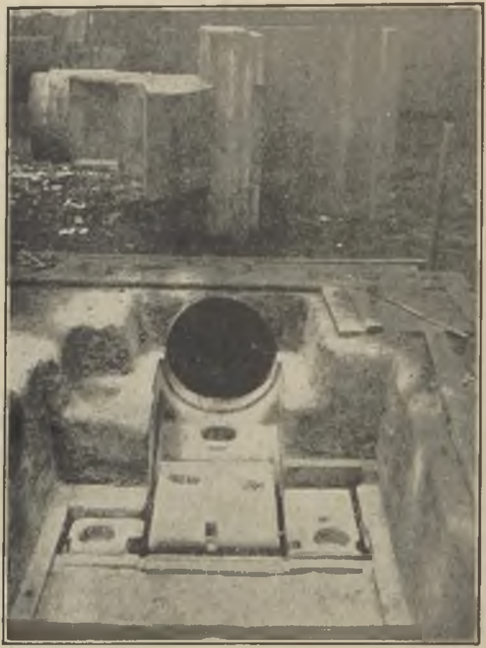


Fig. 17.

Cross-Slide Head.

Fig. 17 illustrates a head that is fixed on a cross slide. This pattern is of rather peculiar design from a moulder's standpoint, especially when it is realised there is no moulding box to turn or roll over in a top and bottom box part. This makes it worse to bed-in, owing to the vee-shaped appearance at the entire bottom of the pattern. The depth of this pattern is 4 ft. 2 in., the length 6 ft. 1 in., and the width 3 ft. 10 in. It was bedded-in the floor and rammed to the top of the tapered part, then lifted out and the surface made hard and vented. It was finished off, as it is undoubtedly very awkward to finish if it is left over until the pattern has been rammed up to the joint, because, underneath it, the slide-part has

Fig. 18.

to have a layer of ashes fixed for taking gas away from the cores at the side. However, by finishing the bottom first, the moulder gained the advantage of room, and it was better for him to fix the bearings under the core-prints. The half-round core in the illustration is not in position in the centre of mould, but Fig. 18 shows that part with the core in position, and illustrates the top half of the mould. The top box is 8 ft. sq., 9 in. deep, and is a fast-barred box. The lift was 26 in., and grids were made to save lifters being used, as the author insists that a grid is far better if packings are rammed on the top of it and are wedged underneath the box-bar. They can then be hooked and bolted to the top of the box. If they are screwed up tightly, it is then impossible for them to give or overhang. At the front of Fig. 18 are a few of the core boxes,

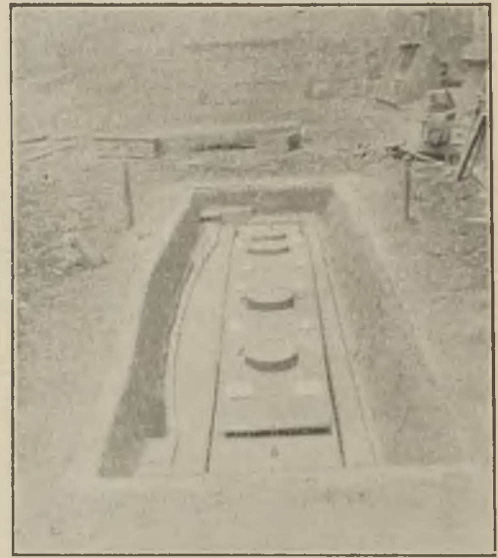


Fig. 19.

which formed the cores shown fixed in the mould in Fig. 17. The chaplet stalks are fixed in the top half, to prevent the cores from lifting. The bottom part of this mould was cast green-sand, but the top was dried. The weight of the finished casting was 29 cwt.

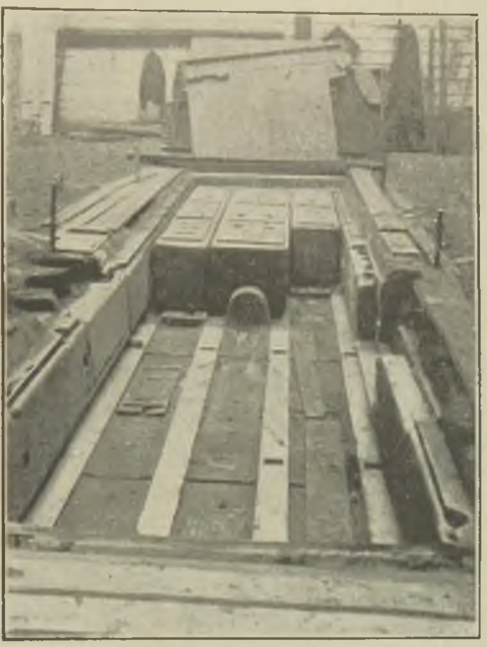


Fig. 20.

Plano-Milling Machine.

Fig. 19 illustrates the mould for a cross slide for a plano-milling machine, the length being 13 ft., the width 25 in., and the depth 18 in. It is flanged on each side of the mould and underneath the flanges there are slides 3 in. sq. the full length of the casting. The mould is cored up ready for the top part being lowered in position.

There is a lift in the top part of 10 in. The size of the cores under the ones shown are 17 in. wide, 5 in. deep. They are bracketed round the corners for strength, and the gas is sent into the coke bed. The cores shown are placed on $1\frac{1}{4}$-in. double studs, this being the thickness of the flange on each side of the mould. All round the cores there was a thickness $1\frac{1}{4}$ in., except where the 7-in. diameter core is shown. This latter cuts through on the top, the air coming away from tubes rammed through the top part after being lowered in position. The plates, $\frac{1}{8}$ in. thick, are galvanised, and

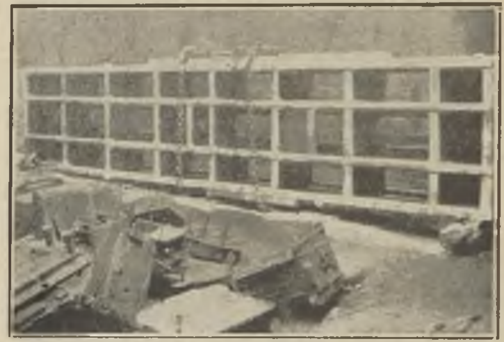


FIG. 21.

a $\frac{5}{8}$-in. iron stalk in the top part rests on the centre of the plate to hold the core in position. It is wedged under the weights on the moulding box to prevent them from lifting. These cores are 2 ft. 6 in. long, 18 in. wide, 10 in. deep, and are all made in oil sand, which gives a harder core and saves dressing. The weight of this casting was 39 cwt.

Bed for a Plano-Milling Machine.

Fig. 20 illustrates the making of a bed for a plano-milling machine. The length of this mould is 26 ft. 6 in., 5 ft. 3 in. wide, and 2 ft. 3 in. deep; whilst the pattern was only 14 ft. long, it entailed double work for the foundryman. In the first place, it is necessary to level a bed for the whole length of the mould, and allow the amount of camber required, which was $\frac{5}{8}$ in. in this case. The pattern was put on the bed, rammed up and withdrawn. Two wings were fixed on each side of the pattern, and then the pattern was put on bed again, checked for length, and rammed up again. The outside slides on the bottom are 9 in. wide, 4 in. thick, and on the inside are 7 in. wide, $3\frac{1}{2}$ in. thick. The small oblong cores are oil wells on the slide. The wing cores on the side are 4 ft. 4 in. long, 16 in. deep, and 7 in. wide, and are bolted back and then wedged on the inside to main cores with double studs and chaplets on the top. Underneath the cores there was only 2 in. of sand, which was very awkward for ironing, and good, long, loose irons had to be used both ways to stop the sand from washing. Round the sides of this mould a layer of small ashes was laid about the centre, to help to get the gas away better. Four runners were placed about 2 in. from the bottom of the mould, 5 in. long, 1 in. thick, with down runners to correspond. At the other end of the mould there were two similar runners 15 in. from the bottom of mould. The reason for runners being in these positions was to allow for one ladle to get a certain amount of metal in the mould before the other ladle commenced to pour. If both runners were put at the bottom, it would involve both ladles commencing to pour mould simultaneously. This would have put more strain on mould. Fig. 20 shows the mould partly cored up; the thickness of metal on the outside was 1 in., and $\frac{7}{8}$ in. was the thickness of the centre bars, which were flanged all round the top of the cores. The arch core also has a 1-in. flange, 4 in. broad, on every section of core. Slot cores 14 in. by 12 in. by 3 in. were fixed in prints to allow for flanges on the bottom of mould. The air from these cores was led out through the top box, whilst tubes were rammed up to prevent metal from getting into the vent. Two top parts, 20 ft. by 8 ft., and 10 ft. by 8 ft. by 9 in. deep, covered this mould. The bottom part of mould was made in green-sand, but the top part was dried. Fig. 21 shows a full view of the casting in the dressing shop; its weight was 10 tons 15 cwt., and it was practically straight. In conclusion, the author would like to express his sincere thanks to his employers, Messrs. John Holroyd & Company, Limited, Machine Tool Makers, Milnrow, for assistance given, and especially in the preparation of the illustrations.

DISCUSSION.

Mr. J. Hogg said one of the lantern slides showed the bed for a Plano-milling machine, the length of the mould being 26 ft. 6 in. He observed that while the top part was cast in dry sand the bottom part was in green sand. That led him to wonder to what lengths Mr. Jowett would go in casting in green sand, because he recollected that Professor Rhead, at Manchester, some years ago, stated that green sand moulding was the cheapest if it could be carried out successfully. Obviously Mr. Jowett's experience was that he could do it successfully, so it was no use to put it to him that it was better to use dry sand for these heavy jobs. In certain parts of Yorkshire, where they had many castings of this nature, green sand was used, and the practice had evidently extended to Rochdale, but he had not observed that foundrymen elsewhere were prepared to go to the same extent. Perhaps Mr. Jowett would explain his reason for adopting the practice. Was it because it was the cheapest method, or was it because he had confidence in his ability to do it successfully?

Mr. Jowett had mentioned that the amount of camber required in this case was $\frac{5}{8}$ in., and it came out correct within $\frac{1}{4}$ in. His own experience was that there was no hard and fast rule for camber, whether side camber or bottom camber, and he thought there were foundrymen who had had to make these big castings and who would agree with him on that. But Mr. Jowett had certainly solved the problem very nicely.

One very significant remark deserved to be emphasised. Mr. Jowett said before he started on a certain job he looked at the structure of the casting. That was very necessary. The structure had much association with the camber.

Then there was the statement that in many of these jobs the draughtsman did not allow enough machining to the foundrymen. He quite agreed that there was not enough machining allowed to enable them to get the beautiful highly-finished castings which the engineer demanded to-day. Nothing had been said about test bars in the casting of these jobs. Perhaps Mr. Jowett would say what he considered to be a fair tensile or transverse test in such cases.

Mr. Jowett replied that green sand was the cheapest. It was used in the Yorkshire district for castings weighing as much as 30 tons. It was a question of training. Having been trained to it one naturally adopted it. They got a good skin for the green sand castings. Two jobs, an internal grinder and an external grinder, were so cast, and were very favourably reported upon. Camber, on odd occasions, they did not get quite correctly. It was only fair to say that. But, taking the number that they made of different design, he thought they were successful.

They had test bars on some jobs that were coming along now. Usually they had 28 to 30 cwt. on a transverse test, and sometimes as much as 32 cwt. The bars were 14 in. long. They generally used Glazebrook, hematite and Thornhill. All the pig-iron was tested by a laboratory chemist before it went into the furnace. They had tried semi-steel, but it was never a success.

Mr. McVie observed that he had got 33 and 34 cwt. on a 1-in. bar.

Mr. Wilson said he was told by the chemist that 30 cwt. was obtained on a bar 1 by 1, 12-in. centres.

Mr. J. Pell said the foundries in the Burnley district were mainly concerned with textile machinery work, and did not make jobs similar to those Mr. Jowett had described. Possibly for that reason the discussion would be restricted. There were certain jobs in the engineering line, such as valves for pumps, etc., which could be cast in green sand, if one chose to do so, but for which he should prefer to adopt dry sand as being far safer. The extra cost of drying it was small. Another point which attracted his attention was the facing sand. There must be a special class of facing sand with many sprigs, and a special preparation of the face of the mould, particularly where the runners were. Much depended on the temperature at which the metal was poured in.

It was liable to burn the sand and cause a collapse. That was due to the sand not being sufficiently refractory. He would like Mr. Jowett to give the mixing of the sand he used for heavy castings in green sand.

Facing Sands.

Mr. Jowett said for facing sand they used a mixture of three barrows of black sand, one barrow of red sand, and one bucket of coal dust. It gave a very porous sand. Sprigs were placed practically flush with the metal where there was any real weight of metal and up the sides as well. The core sand was composed of:—8 parts of black sand, 4 of red sand, 2 of manure, and 2 of coal dust. He also used manure in the ordinary facing sand, using about a bucket where there was a good thickness of metal. For loam sand he used a mixture of 8 parts of red sand, 2 of manure, 2 of coal dust, and 1 of sea sand. For small shops he used a yellow refractory sand. They always ordered No. 1 or No. 2 yellow sand. The mixture was one barrow of yellow sand with one barrow of superfine coal dust and one spade of ornamental blacking. They obtained a very good skin on their castings. They did not dry the small ones.

Mr Pell asked for information as to Mr. Jowett's practice in the use of oil-sand cores.

Mr. Jowett stated he put ashes in oil-sand cores. The heaviest core he had made was 8½ cwt.

A vote of thanks was accorded the lecturer.

Sheffield Branch.

GATES AND RISERS.

By F. C. Edwards (Associate Member).

Gates and risers may be placed in that category of things which one would gladly do without, but with which it pays to cultivate a very close acquaintance.

It pays—technically, as well as commercially. For although the mould itself may be perfect, and the metal composition and temperature everything that could be desired, it is by these factors—their design, number and location—that the production of good or bad castings is ultimately determined.

The function of the gate is to introduce the molten metal into the mould. To employ metal in gates, therefore, beyond that required for the fulfilment of this object is not economical; for re-melting entails expense and loss of metal. The riser facilitates the escape of gas from the mould, and takes charge of the dross. It may be regarded as an insurance. Here, again, where no risk is actually incurred, such insurance obviously spells unnecessary expense. It consequently follows—since, in selling castings, one cannot include the weight of those accompaniments of production—that the foundry in which they are cut down to the lowest efficient limits has a definite advantage over its less scientific competitors.

Now, while there are certain general principles which govern the efficient employment of gates and risers, their correct design is largely a question of individual consideration. Sometimes, indeed, a variety of methods have to be actually tried out before satisfactory results can be attained. A system of gating which is found to answer very well in one case may prove, in another, to be altogether inapplicable.

Hence the futility of such arguments as to whether this or that particular type of gate (considered by itself) is best, whether slow or quick running is preferable, or whether the riser makes for economy or is a wanton waste of metal. And hence, also, the reason why a large percentage of scrap can be definitely traced to improper gating.

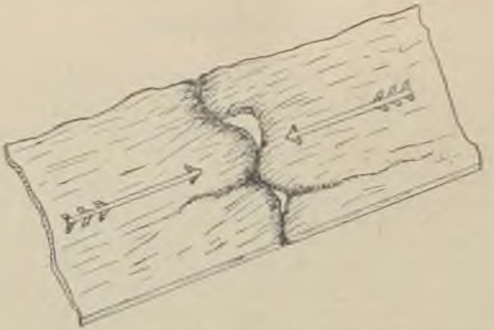


Fig. 1.—Misrun Caused by Bad Gating.

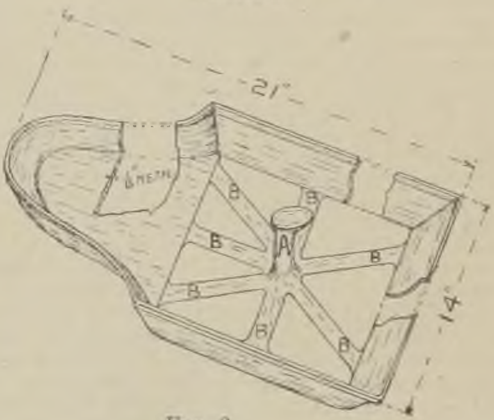


Fig. 2.

Such questions are not amenable to any stereotyped rule. Just as castings vary in weight and innumerable details of form, so must appropriate gating ever vary likewise. In short, every casting has its own peculiar gates.

Fundamental Principles.

Nevertheless, in gating a mould, one must always keep in view several common fundamentals.

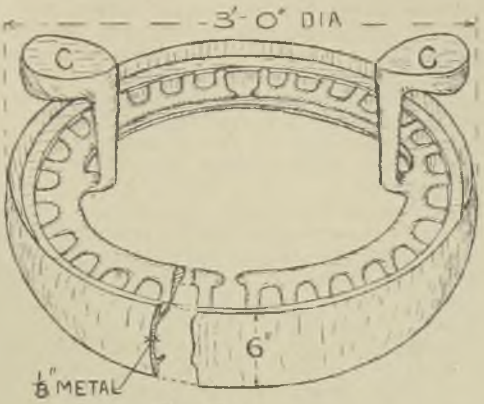


Fig. 3.

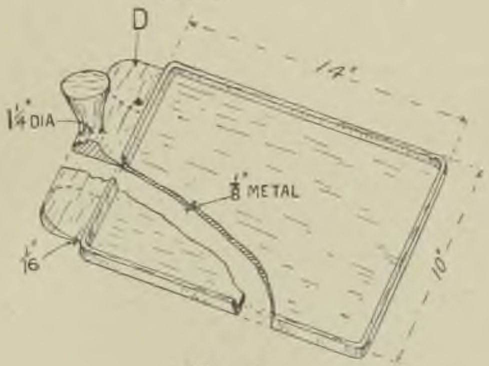


Fig. 4.

For instance, the outer orifice of the pouring gate should be situated above the level of the highest point of the mould. Otherwise the latter could not be filled with fluid metal. Generally, of course, this is completely assured by the addition of the gate box to the top of the cope. The pouring gate, again, should have a larger cross-section area than that of the ingate—or of the combined ingates. This ensures the pouring basin being kept full during the process of casting, and, by throttling the flood, allows time for the lighter scum to float to the top of the metal in the basin instead of passing into the mould; thus promoting clean metal. Incidentally, this explains how a reduction either in the number of individual area of the ingates often proves a successful remedy in the case of dirty castings—the dross has more time to escape.

It is also essential that the pouring gate—or gates (for the larger castings are poured from one or more widely-separated ladles)—should be so arranged as to deliver the metal to all parts of the mould at the same time. With light work especially, this is vital. Its neglect may lead to a "mis-run," or to the less obvious but equally fatal form of the latter, known as a "cold shut." It can easily be understood that when a thin stream of metal is made to traverse a large area of mould it quickly becomes chilled. Where two such streams meet there is a probability that the result will be similar to that shown in Fig. 1. Junction may taken place—but not coalescence.

Hence the extreme desirability of arranging the runner gates so as to restrict within narrow limits—depending, of course, upon the thickness of metal—the area of mould served by any single gate. A good example of this is illustrated in Fig. 2, which shows the gating of a grey-iron base of very light section.

The job is poured from a central downgate (A), 1 in. in diameter. Seven spray gates or sprues (B) are so arranged as to conduct the metal immediately to all parts of the mould. The sprues are "knife-edged"—*i.e.*, at their junction with the casting they are less than $\frac{1}{16}$ in. thick. These fine apertures serve as strainers. They also enable the sprues to be neatly broken off without injuring the casting. Since all parts of the mould are simultaneously flooded with metal, it follows—with a uniform section—that cooling in every part commences at the same moment, and proceeds at the same rate. Uneven shrinkage stresses are thus obviated, and maximum efficiency secured from the metal employed.

A somewhat similar example is shown in Fig. 3. Here, again, the thickness of metal is but ⅛ in. In this case, however, in order to furnish the requisite supply of hot metal to all parts of the mould, two downgates (C) are employed. The knife-edged sprues are also placed closer together than in the previous example. The pouring basin has a comparatively large area, which enables dross to be accommodated on the top of the metal in the basin instead of passing down into the mould. The job is poured simultaneously from two shanks—one at each side.

Downgates.

Downgates should be circular in cross section, as this form presents the least refrigerating surface for a given area. They will vary in diameter, of course, with the nature of the job; the greater the cooling surface of the mould relatively to the weight of the casting the larger must be the diameter of the gate. This point may be best illustrated, perhaps, by a comparison of two rather extreme cases, in which satisfactory results were only obtained after much careful experiment.

Fig. 4 represents a plate casting, 14 in. by 10 in. by ⅛ in. in thickness, with a shallow rib round the outer edge. It will be noted that the sprue (D) extends across the full width of the plate. It is but $\frac{1}{16}$ in. in thickness at its junction with the casting. Two sprues, each about 2¼ in. wide, were, in the first place, tried with this job. These were placed at each side of the plate (as shown dotted). It was found, however, that the castings were more or less "channelled" from the sprue end to about half-way along the surface of the plate, on the bottom side, as moulded, and in a line with the centre of each sprue. Various experiments were made before a perfectly smooth surface was obtained. It was proved, by the way, that the evil was accentuated by hard ramming. The channelling was finally overcome by extending the sprue right across the plate, as shown. The weight of this plate is about 5 lbs., and the diameter of the gate at its juncture with the sprue is 1¼ in.

Comparing the above with the gating of a 56-lb. weight, as shown in Fig. 5. In this case a central ingate was first tried. This was abandoned later in favour of the two sprues E. There is here a cross gate (F)—which also serves as a skimming gate (which will be referred to later). The downgate is 1 in. in diameter. Thus a light plate weighing 5 lbs. requires a downgate of 1¼ in. in diameter (1.22 sq. in. area); whilst a compact block, ten times the weight of the plate, is poured from a downgate 1 in. diameter (0.78 sq. in. area).

Another point of interest is the way in which both these examples conform to a principle previously enunciated—namely, that the area of an ingate should be less than that of its respective pouring gate. In the case of the weight, each ingate, at its junction with the mould is ⅜ in. wide by ⅞ in. deep, which gives a combined ingate area of 0.65 sq. in., against a pouring gate area of 0.78 sq. in. The gating of the plate shows a still greater difference. The ingate, at its junction with the mould is 9 in. by $\frac{1}{16}$ in., an area of 0.56 sq. in.—or less than half that of the pouring gate, which is 1.22 sq. in.

It may be mentioned that these castings are made in large quantities, and must be definitely perfect. With the weights especially, the smallest pinhole leads to their rejection.

In heavy work downgates should be placed several inches from both the mould and the side of the box. It is also advisable to reinforce the mould around the gate so as to guard against the possibility of the metal breaking through the walls of the gate. For this purpose a tier of small box parts is sometimes rammed up in the mould with the gate pattern in the centre.

A better method, however—since it obviates the risk of the mould peeling away from the flat walls of the small box parts, and facilitates the escape of gas—is to ram up the downgate pattern in the centre of rough cast-iron prodded rings, say, 6 or 7 in. in diameter, as shown in Fig. 6. The larger space between the prods at G enables the ring to be placed over the ingate core, to which it affords a certain support. These rings are built up, one above the other, to suit the height of the job.

Yet another, and still more reliable, method is to employ sleeves of loam cores. For instance,

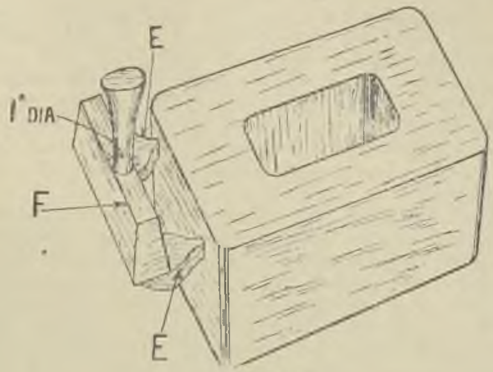


Fig. 5.

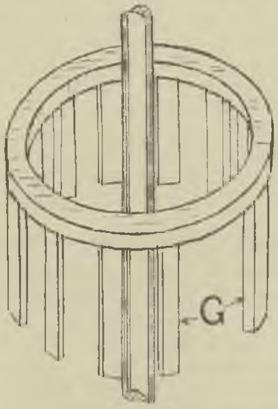


Fig. 6.

if the gate is to be, say, 1½ in. in diameter, the core would be spun up on a barrel 1 in. in diameter, over a thin layer of hay band. When dry the core is sawn round into, say, 12-in. lengths and slipped off the barrel. These sleeve cores are rammed up inside the prodded rings (Fig. 6). The gate stick is not then required. Whilst ramming up each sleeve, however, the moulder plugs the top of the hole with hemp or cotton waste to keep sand out of the gate. Arrangements are made, of course, to lead the metal into the mould through channels formed in separate cores. To prevent the falling metal from digging up the bottom of the gate a blacked brick is sometimes employed. In the case of moulds for heavy steel castings, firebrick gates are employed.

The necessity for the above precautionary measures can be realised when it is remembered: (1) That the downgate is subjected to higher temperature metal than any other part of the mould; (2) the high temperature is continuously maintained as long as pouring lasts—*i.e.*, during the passage through the gate of (in some cases) several tons of metal; (3) there is more risk of attrition here consequent upon the violent motion of the falling metal; (4) an internal pressure is set up owing to the throttling of the stream at the ingate, and, to some slight extent, to the head of metal. Among other things there is always a possibility of the metal bursting through the joint of the box. This is known as a "run-out." Should this occur, though it may be promptly arrested, sufficient time may have elapsed to produce solidification of the sprues before the mould is filled—and the result is a "mis-run."

Impact effect of Metal on Mould.

A prolific source of scrap is that arising from the under-estimation of the impact effect on the mould, or cores, of the incoming stream of metal. This impact effect is greatest, of course, in the case of direct running. And, in order to obviate scabbing, the careful moulder will see to it that the region of the mould upon which the falling metal impinges is well studded with sprigs or otherwise reinforced. There are moulds, however, such as those for fine fluted plates, where sprigs cannot be used. In such cases scabbing can be prevented by using more than the usual amount of coal dust in the facing sand, and giving greater attention to venting. Here, the old maxim that "one vent is worth a dozen sprigs" is peculiarly applicable.

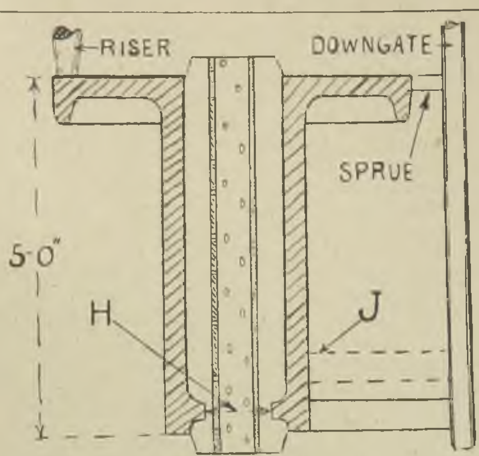


FIG. 7.

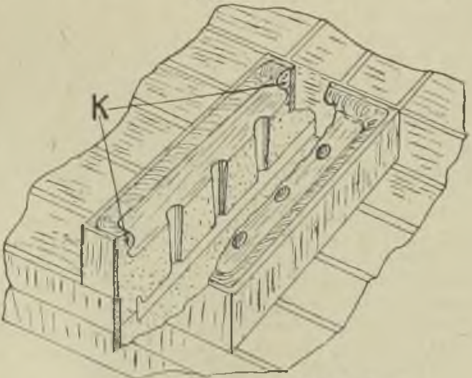


FIG. 8.—DIRECT GATING.

Similarly with regard to cores. These should be made so that the risk of washing or displacement by the incoming metal is reduced to a minimum. Moreover, it is sometimes necessary to lead the metal through one or more of the cores in the mould. For these and other reasons efficient gating calls for the closest collaboration between moulder and coremaker. Obviously, the coremaker can render the best service only if he is perfectly clear as to the line which the moulder intends to take on any given job.

It may here be of interest to refer to an actual case in point, where an inadvertent lack of the above-mentioned co-operation produced, among other things, one of those well-known pyrotechnic displays which usually follows when molten metal finds its way into a core barrel.

Briefly, the mould for a cast-iron flanged pillar. 5 ft. high and 9 in. in diameter (shown in Fig. 7), was being poured. Just as the appearance of the metal in the riser indicated that the mould was full an explosion took place. Molten metal shot upwards from the core barrel to the foundry roof. The heavily-weighted cope was distinctly seen to heave up at one side. Fortunately, however, for those standing around it immediately recovered its equilibrium.

Strange to say, when the casting was stripped it was found to have suffered no permanent ill-effects from its stormy birth. Subsequent inquiry proved pretty conclusively that the cause of the explosion was as follows:—

(1) On account of the comparatively small diameter of the neck (H) at the bottom of the core, and the need for employing a strong core barrel the loam here was necessarily very thin. (2) The moulder had inadvertently placed the ingate so that the incoming metal was led directly on to this weak neck. As a consequence the continuously impinging molten metal upon this part gradually wore away the loam. The hay band would immediately be consumed, and the entry of the molten metal through the vent holes into the core barrel would inevitably follow.

The core barrel was found firmly attached to the neck of the casting, and some of the hay band had been converted into beautiful cast-iron spirals. Subsequent castings were gated a little higher up the core, as at J, where the loam was thicker, and, therefore, better able to withstand the impact of the incoming metal. The coremaker also employed string instead of hay band at this neck, thus allowing for more loam.

Direct Gating.

With shallow work—such as plates of large area—direct gating is found to give the best results. Fig. 8 represents a section through the gate box for casting a plate 8 ft. by 9 ft., and $\frac{3}{4}$-in. in thickness, with $\frac{3}{4}$-in. deep chequering on the bottom side, as moulded. It will be seen that six downgates, each $\frac{3}{4}$-in., are employed to run this plate. In order to obviate washing, the mould, directly under each downgate, is well studded with sprigs. As the metal is literally thrown from the ladle into the pouring basin (so as to run the job as quickly as possible), the basin is formed with overhanging lips (K), which prevent the overflow of the metal. In order to ensure clean castings, "run-offs" (not shown) are resorted to—one at each corner of the plate. A "run-off," it may be observed, is a form of riser whose outer orifice (contrary to the general rule) is below that of the pouring gate. Each run-off aperture is stoppered, *i.e.*, sealed with a brick, until the mould is filled with metal. The brick is then removed, and from 2 to 3 cwt. of metal allowed to escape. In this way stray scum—besides that collected by the metal as it passes over the mould—is eliminated. At the junction of each gate with the mould a small fillet is formed, which prevents the gate from "breaking into" the casting as it is being knocked off.

Combined Top and Bottom Gating.

For many kinds of deep work a combination of top and bottom gating is advisable. Figs. 9 and 10 show plan and side elevation respectively of a case in point. The casting is 11 ft. long, 4 ft. wide, and 3 ft. deep. It is cored out to leave internal ribs and bosses (not shown). The general thickness of metal is 1 in. All external faces are machined. It will be seen from Fig. 9 that bottom and top downgates (L and M respectively) are employed at each side of the job. The gates are "broken" on the cope joint (Fig. 10) to reduce the depth of the fall. In order to exclude the scum from the mould all gates are stoppered at the commencement of pouring. Two kinds of stoppers are shown—the plug (N) and the block (O). The removal of the block is not so likely to disturb the sand at the top of the gate as is the withdrawal of the plug; though it offers, of course, greater resistance to removal on account of its larger area. The stoppers are well blacked and dried before using, to shield them from the action of the molten metal to which they are exposed. Fusible stoppers are sometimes used. The block of tin, for instance (melting point 232 deg. C., exposed to molten cast iron, say, at 1,330

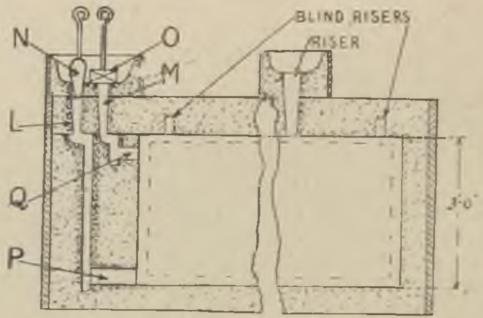


Fig. 9.—Plan of Gates and Risers.

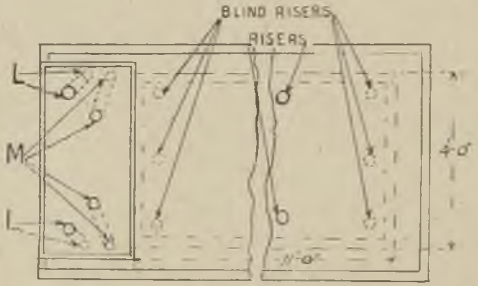


Fig. 10.—Side Elevation of Fig. 9.

deg. C.), prevents the metal from entering the gate a sufficient length of time before melting away to enable the basin to be well filled.

The job is poured as follows:—When the pouring basin is nearly filled, plugs N are withdrawn

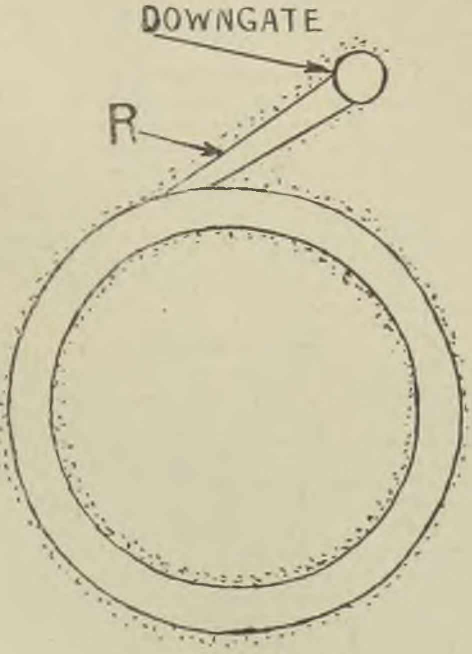


Fig. 11.

to allow the metal to enter the downgates L From thence it flows through bottom ingates, P, into the mould. When the mould is judged to be about three-parts filled with metal stoppers O are removed. This admits the metal to downgate M, and thence to the top of ingates Q. This fresh stream of hot metal breaks up the crust on the top of the metal rising in the mould and prevents lodgment of dross near the top of the job.

In the above example ingates P and Q were formed by cores, this method being safer than that of ramming up tapered gate plugs and withdrawing after the pattern is removed. Two risers were employed over heavy sections in the centre of the job, and three "blind" risers, 3 in. high, formed at each end to take care of the scum.

Tangential Gating.

With cylindrical work it is generally the best practice to introduce the metal at a tangent to the circumference. The ingate is then arranged as at R, Fig. 11. This method has at least two advantages over that where the metal impinges directly on a core. There is less risk of mould disturbance, and, if there is any dross present, it is not so likely to become attached to the sides of the mould, but is carried upwards by the swirling motion of the metal.

Stepped Downgates.

In gating deep moulds it is advisable to form the downgate by steps, after the manner shown in Fig. 12. The upper section of the gate is arranged so as not to come directly over the next lower section, but, say, several inches to one side of it. By breaking the fall of the metal in this way there is less likelihood of the formation of hard shots, or of the digging up of the mould at the bottom of the gate. In order to break up the scum crust on the rising metal it is usual to employ several pouring gates in the same gate box. These gates are separately plugged at the commencement of pouring. When the basin is nearly full, the plug leading to the lowest ingate is withdrawn. And, as the metal rises in the mould, the other plugs, in their order of ascent, are successively drawn. In this way fresh hot metal is introduced at increasing heights.

Skimming Gates.

Skimming gates are employed to trap scum which would otherwise enter the mould. They are formed upon two main principles—specific gravity and centrifugal force. In the case of specific

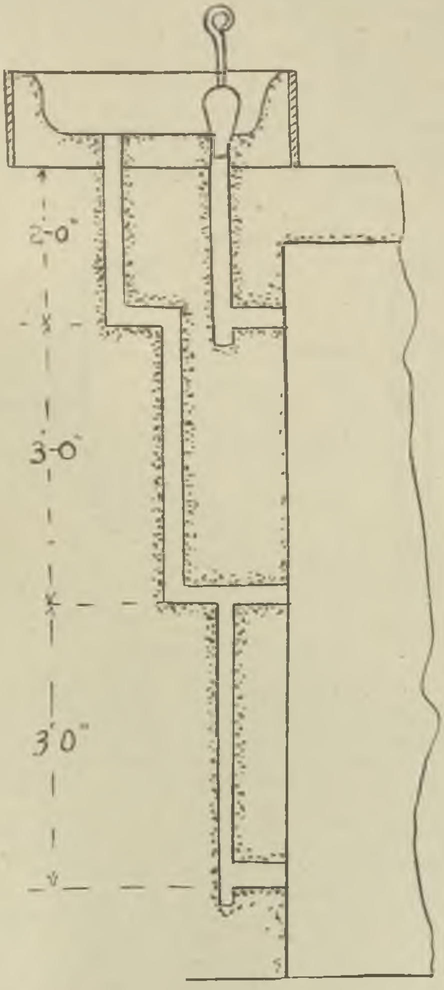


FIG. 12.

gravity, the exterior portion of the pouring gate is made of a much larger area than would be necessary if it were employed merely as a pouring gate. Its function is, then, that of a reservoir, from which the mould is supplied with clean metal. The interior portion of the gate—the passage leading to the mould—is no larger than would ordinarily be required. The supply of metal being greater than the demand, therefore, the lighter scum is given time to ascend to the top of the gate, whilst the heavier, *i.e.*, the cleaner, metal passes on to the mould. An example of the gravity form of skimming gate is shown at F, Fig. 5.

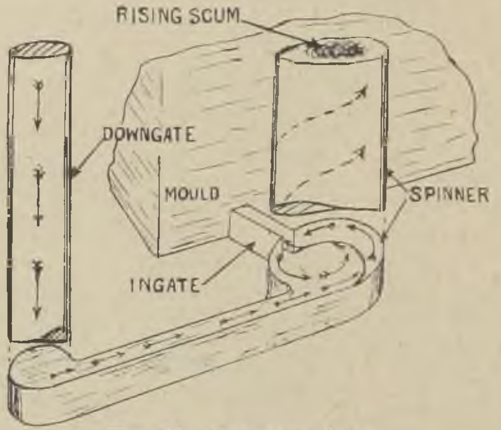


FIG. 13.—SPINNING GATE.

The principle of centrifugal force may be applied by forming a spherical chamber between the mould and the pouring gate, the chamber being suitably connected to each by sprues. The sprue from the pouring gate is led into the chamber at a tangent to the outer edge. The sprue to the mould is taken out radially from the axis. The rotary motion which is thus given to the incoming metal causes the heavier (clean) metal to fly to the outside of the spherical cavity, and from thence into the radial sprue leading to the mould. The sprue to the mould should be placed at the back of the pouring-gate sprue. This ensures that the metal is given at least one turn round the sphere before it can enter the mould. The lighter scum is thus trapped in the centre of the skimming gate.

Another kind of skimming gate, formed on the centrifugal force principle, is seen in Fig. 13. Here a cylindrical "spinner," about twice the diameter of that of the pouring gate, effectually traps any dross *en route* to the mould.

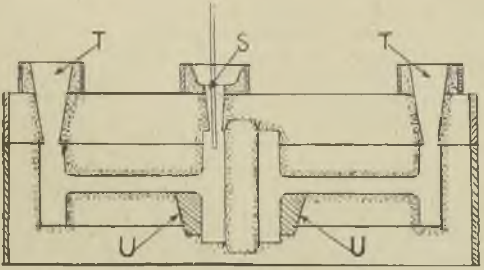


FIG. 14.

Risers.

A riser is an air gate, or opening placed at the highest point of a mould to facilitate the escape of gas and dross as the metal fills the mould. In this way it prevents the straining of the mould and the formation of blow holes in the casting. Incidentally, it indicates when the mould is full. The sectional area of the riser should be greater than that of the runner gate. The riser box should also be deeper than the pouring basin.

An example of the employment of risers is shown in Fig. 14. These castings are machined all over. Originally they were gated in the web (the boss being considered rather small for this purpose). When the castings were machined, however, about 30 per cent. were rejected on account of dirt in the rim. Finally, the castings were obtained perfectly clean by gating at the boss, as at S, and placing two risers (T) at opposite points of the rim. The employment of denseners (U) was found necessary in order to obviate "drawing" in the fillet where the bottom boss adjoins the plate.

In green-sand moulds—particularly where the upper internal surface of the cope is exposed to the heat of the rising metal—the riser should be stoppered down. This is effected by placing, say, a piece of paper or an iron plate over the aperture and adding a suitable weight, such as a ball of sand or a brick. The weight is removed as the metal ascends the neck of the riser. If the riser is not stoppered, or if the weight is inadvertently removed before the mould is full, the top of the mould is likely to fall in, *i.e.*, to peel off in patches, and the result will be a scabbed casting.

The explanation would appear to be as follows:—In a green-sand mould with a flat upper surface the suspension of the sand below the box bars depends upon the mutual cohesion existing between it and the sand that is tightly wedged between the box bars. This cohesive power of the sand is largely a function of its moisture content. Now, when the ceiling of a mould is subjected to the fierce desiccating heat of molten metal immediately below, it rapidly becomes denuded of its moisture. As a consequence, there is a general shrinkage of the surface layer, *i.e.*, the thin stratum hanging below the bars. There would be a tendency for this layer to peel off. And, in the absence of other sustaining forces, patches of the mould become loosened and may fall away owing to the influence of gravity.

A counteracting force, however, is normally available. The rapid displacement of air in the mould by the entry of the metal—in addition to gases carried into the mould along with the metal—and the evolution of immense volumes of gas by the action of the molten metal on the combustible constituents of the mould, sets up an internal pressure which is usually sufficient to neutralise the influence of gravity. The stopped riser may be regarded, therefore, as a kind of safety valve, which must be loaded sufficiently to prevent the easy exit of gas through the top part before the mould is filled with metal.

Whistlers.

The smallest risers are commonly referred to as "whistlers"—from the hissing sound which usually accompanies the exit of gas under pressure as the job is being poured. Examples of these diminutive, but very useful, risers are shown in Fig. 15. Here the whistlers (V) are shown on the casting as it is taken from the mould. The job is cast with the bearings upwards, in order to ensure a perfectly clean surface on the plate. The moulder forms the whistler apertures by pushing a large vent wire right through the cope at the highest points. This prevents the formation of gas pockets, and thus secures sound bearings. If the top edges of the casting from which the whistlers project are very thin, a small cleaner (say, $\frac{3}{16}$ in.) is used to pierce the cope.

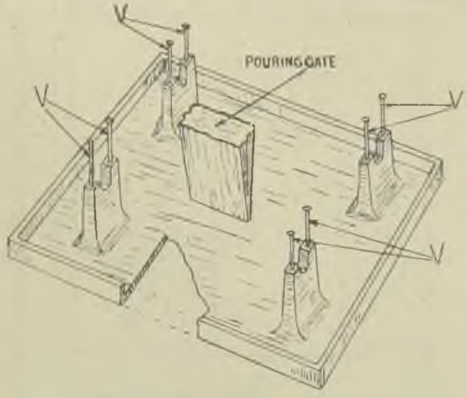


FIG. 15.—CASTING WITH WHISTLERS (V) ATTACHED.

Feeding Heads.

At the other extreme there are the massive feeding heads, as employed on large cylinders, rolls, etc. The head serves as a reservoir of metal upon which the casting may draw to make up for liquid shrinkage. The diameter of the head should increase from that of the casting upwards. The depth varies with the job, and may be from 3 in. to 12 in., or more. In the "feeding" of a chilled roll, for instance, such as that shown in Fig. 16—

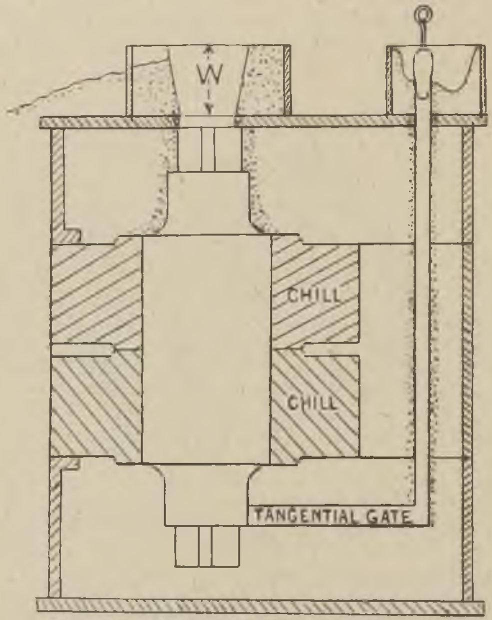


Fig. 16.—Showing Feeding Head W.

which may occupy a dozen hours of continuous work—the choked up head mould (W) is from time to time replaced by a new one. These head moulds are usually made in loam. Incidentally, a small cupola is generally employed to keep up the supply of hot, fresh metal.

How Gating May Cause or Correct Camber.

Incorrect location of gates sometimes produces camber troubles in an otherwise well-proportioned casting. Conversely, castings that are inclined to warp may be kept true by suitably arranging the gates. An example is shown in Fig. 17. The pattern for this light, narrow frame was made straight. The job was gated at the end, as shown dotted at X. The castings came out rather badly cambered. The flange side being hollow, of course. By gating at the side with several sprues, as at Y, instead of at the end, and by employing "dummy" sprues on the opposite side, as at Z, perfectly straight castings were obtained. The method, of course, is admittedly wasteful, and would only be employed for a few castings, or where time precluded the preparation of a metal pattern with the sides cambered just sufficiently to bring the casting straight. The case, however, strikingly illustrates the importance of correctly positioning the gates to suit the job. It also indicates how the gate may be instrumental in setting up or in nullifying contraction stress according to its location. The gate imparts heat to that region of the casting to which it is connected. Such heat may be utilised to correct the effect of differing metal sections in a casting of uneven design. By placing the gate on the thinner section a more uniform rate of cooling is induced throughout the casting, which tends to eliminate the possibility of contraction stress.

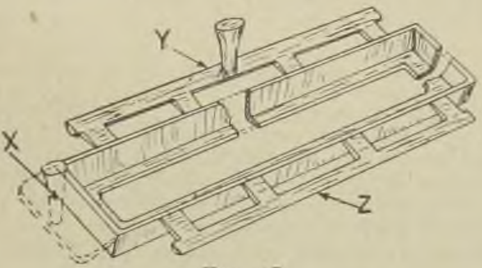


Fig. 17.

From the foregoing examples it will easily be realised how indispensable is the study of gates and risers to those who desire to become *au fait* in foundry technique. The young student will find that this branch of his curriculum teems with interest, and that just as the gate leads the metal to the mould, so will a clear understanding of its functions and potentialities pave the way to a sound grasp of foundry phenomena in general. Then the moulder, by acquiring clear views on the subject, will be enabled the better to anticipate his share of that large percentage of scrap for which bad gating is notoriously responsible; he will find, by acting on the sound old maxim that "prevention is better than cure," that his pay envelope will insensibly grow, whilst the occasions for cursing his ill-luck will increasingly diminish.

DISCUSSION.

Dr. Desch, at the conclusion of Mr. Edwards' address, said there was no doubt it was a very practical one and one which he was sure appealed to many of those present. He then invited the members present to discuss the points which had arisen in their minds.

Major Rhydderch, in opening the discussion, said there was no doubt the Paper had been a very interesting one, and a large number of points had been raised of interest to every moulder, but more particularly he thought to the cast-iron moulder. The subject of gates being constructed so to avoid the smashing up of the mould because of a big drop was being overdone, because there was no reason for it if a fine oil-sand core were used, and it would not be necessary to have three or four separate drops. He agreed, however, that one or two might be useful. With regard to the example given in Fig. 7, it appeared to him that that figure was cast upside down. He believed that if that casting was turned the other way the trouble mentioned by Mr. Edwards would have been avoided altogether. With regard to the use of risers to take away scum, he was of the opinion that it took a very large riser to take away the scum which formed. He did not think skimming gates were very effective. With regard to Fig. 14, he was rather interested in what Mr. Edwards had to say, and it reminded him of the *effet Leonard*, that is the defect was not due to shrinkage but to trapped air. The reason why the dry sand at the top did not break down was simply due to the fact that there was rapid heating and they expanded so rapidly that they ruptured and were held by the clay bond. When running in from the bottom there was always a fine, thin channel going up in the middle—it was always fluid in the middle, and therefore the centre of the mould would always show a pipe and be full of segregate.

Mr. Edginton said he did not like the idea of ribbing the core on the barrel and using it as a runner, because obviously one got a dirty metal and that would not be for the good of the casting as it escaped out. In a previous lecture they had there they had had an interesting discussion on gates and risers and about gates being smaller than the down riser. Mr. Edwards had shown them gates with a bigger area than the riser, and he also spoke of throwing coal dust at the front of the gate to prevent scabbing. He (speaker) did not think the use of more coal dust would prevent scabbing. With regard to Fig. 6, he certainly thought it should be made the other way up, because he could imagine the trouble which would arise with the metal going in on that narrow neck at the bottom. He thought that would be asking for trouble to put a runner in where the narrow neck was. He agreed with the last speaker that risers would not take scum off, and neither did he see the use for blind risers.

Mr. J. Shaw said he, too, was in agreement with the previous speakers that risers were not of much use in taking away sullage. They cleaned local spots, but beyond that they were of no use. He was also fairly in agreement with the other speakers about the Fig. 7 being cast the other way up. There were times, of course, when the small bottle-neck was bound to be cast at the bottom and one had to make provision for it. He agreed with Mr. Edginton on the question of the cores. He saw no benefit to be derived by stepping. There were a number of other points in reference to which he was afraid Mr. Edwards would come off badly if they were discussed fully. With regard to the question Mr. Edginton had mentioned about the diameter on the end of the down runner, he thought that depended entirely on the type of runner used. Frankly, he did not see why one should be an inch and another an inch and a quarter. Gates and risers were very important things and had been realised to be such especially by repetition people, who have special designing departments for their patterns. They should, in fact, be on the patterns themselves for such work, say, as typewriter parts and other small work, and not left to the moulder, however experienced he might be. A man may be skilled enough, but in repetition work he might easily have variation. There should be special designs on the pattern.

Mr. Ollerenshaw expressed the opinion that too much coal dust was used sometimes in moulds. He thought it would be better to use less coal dust and make further use of coke dust. Coal dust created too much gas.

Mr. P. Green said it could not be definitely stated that the size of the in gate should be larger than the down gate, for whilst this was desirable for some castings it was disastrous for others.

Mr. W. H. Bowe thought there was some difference in the viewpoint of Mr. Edwards and the previous speakers. Some were talking from the angle of the steel moulder, and others were talking from the cast-iron point of view. The result was rather confusing. In one it was advisable to have the runner from the bottom and in the other from the top. There were times when risers were essential. With regard to the Fig. 7, it might have been for the sake of economy that it was done the way Mr. Edwards had indicated, especially if machining was to take place at the bottom where the collar was. He had been interested to hear of a blow being covered and regaining itself. He had never heard of such a thing before and it had greatly interested him.

Mr. W. Cowley also expressed the belief that Fig. 7 should be the other way round.

Mr. Hoyland said it appeared to him that in green-sand castings blind risers were useful. In thin sections, if a whistler were used there was a tendency to blow through them. It was very handy to have a blind riser or whistler. With regard to the position and uses of gates, a round downright was preferable in steel, though they used skimming runners on a heavy job. Dr. Moldenke, he thought, advised top pouring to get castings which would machine up properly.

The Author's Reply.

MR. EDWARDS, in the course of his reply, said he was glad to see that his Paper had evoked so much discussion, which he hoped would do good. What he had had to say was based chiefly on actual experience of works practice, and though some could not agree with him on some points, he could assure them the results were satisfactory. He noticed that opinion was fairly divided in reference to Fig. 7. What had been said for and against may be said to have cancelled each other. On the subject of breaking the joint, he would like to point out that with metal dropping down several feet there was the probability of little pieces of shot flying up and they would find them in the casting. The break of the joint depended on the drop. With reference to the remarks that in spinning gates there was a lot of waste metal. he could only say that in practice the method answered very well. In general he thought that each casting must be dealt with on its merits. Each had its own peculiarities which should be considered. The cases he had cited were those in actual practice. With reference to the chills on wheels, all he had to say was that the chills were placed on the bottom and they worked satisfactorily. A dry-sand top would fall in like green sand. On the subject of coal dust, he would like to point out that the moment it was brought into contact with molten metal combustion took place. This prevented the metal from eating into the sand. For light jobs or very thin work one did not want very much coal dust. There could not be one definite specification for all jobs. His experience of dummy risers was that they gave clean castings and were economical, and did not let the foundry profits go to the machine shop. With reference to the large gates, the advantage was when you had to get thin metal: there was an inner core of hot metal. The prodded ring gave the gas a better chance of escape than the bush. One reason why Fig. 7 was run from the bottom was because they wanted the metal at the bottom to be the best. He thought 12 hours for chilling some rolls was not out of the way.

On the proposal of Dr. Desch, a vote of thanks was passed to the lecturer.

Newcastle Branch.

THE ELECTRIC FURNACE IN THE IRON FOUNDRY.

By Victor Stobie (Member).

As a foreword to this Paper, it should be stated that much of its contents is of the nature of suggestions; much is based on purely experimental work, and the balance is fact. As, however, the whole of it is based on many years' experience with electric furnaces in steelworks, it will probably give some food for reflection.

Among the facts which will be presented are data, which have been culled from the author's works' record books, in the manufacture of synthetic pig-iron, the refining of ordinary pig-iron, and the manufacture of some small and large castings from both the above kinds of irons.

Maximum Carbon Content in Synthetic Iron.

It will be of interest, firstly, to consider the question of the carbon content of some irons. The highest combined carbon met with in a commercial way is 4.6 per cent. It may be that a still higher carbon could be obtained experimentally in commercial plant, and it is known that a higher carbon content is present in cementite. Perhaps a recital of the circumstances under which the 4.6 per cent. carbon iron was produced will be of interest. Some 15 years ago in a Sheffield steelworks an electric furnace (not of the author's system) in which the whole of the current used for melting passed through the lining of the hearth of the furnace gave much trouble in consequence of the current overheating and softening the hearth. The people responsible for the furnace, being at their wits' ends in consequence of the continual loss of steel through its finding its way through the softened hearth, called in a certain consulting metallurgist to see if he could make suggestions to avoid a repetition of their troubles.

The consulting metallurgist decided that the difficulty would be overcome if the hearth were made of a material which would not soften at any temperature to which the plant might be subjected. Looking around, mentally, he found that carbon was in no way affected in solidity, all other matters being constant, by any temperature which could occur in the furnace, so he decided to make the hearth of the furnace of carbon. He also realised, with undoubtedly great pleasure, that carbon offered little resistance to the passage of current and that a hearth built of it would not, therefore, tend to overheat as a result of the current passing through it.

Carbon Hearth Used.

The hearth was ultimately constructed of graphite mixed into a paste with anhydrous tar. The hearth was shaped by means of rammers, and then the whole was heated up in order to drive off the volatiles from the tar and leave the hearth in a solid condition.

When the furnace was ready the steel scrap was charged into it for melting down in the ordinary way. When scrap is melted in an ordinary electric furnace some of its impurities are oxidised out by the addition of iron-ore or rolling mill scale. There is a slag on the material which takes up the impurities as they rise out of the molten steel, and it is necessary for this purpose that the slag be in a fluid condition. In the present case, however, the slag would not remain fluid, and considerable quantities of mill scale, iron ore, and sand were added to try to maintain liquidity. Almost as quickly as the mill scale melted and fluxed the slag the latter would return to its previous condition of solidity. This battle went on between the furnace and the metallurgist for about an hour after the steel was melted.

Ultimately, a sample was taken from the furnace and poured into the usual small test mould. On pouring the sample it was found to shoot stars of metal in every direction, and it was apparent that the conditions were by no means those normal at such a point in electric steel making.

The laboratory report was that the sample contained 1½ per cent. of carbon. At this period in a normal way there would be nearer 0.15 per cent. carbon.

Instead of realising what several onlookers had seen, the consulting metallurgist concluded that some of the graphite used in making the hearth had been left loose on the bottom of the furnace and, being absorbed by the steel, had upset the normal conditions, so he added a cargo of iron-ore to the bath. Matters did not progress and, after adding another shipload or two of iron-ore to the furnace, a laboratory report gave the steel as having reached something over 2 per cent. of carbon. From that point no further materials were added to the furnace, and the consultant went into the laboratory to check over for himself the method for determining the carbon. He found the method was, of course, quite a correct one, but another sample had to be taken out of the furnace and put through to satisfy him that he was not being misled. By the time that sample had been analysed, it showed a carbon content of about 3 per cent. The next test gave over 4 per cent. carbon, and the ladle was called up to the furnace. The ladle took about a quarter of an hour to prepare, and the furnace was tapped into it as soon as it arrived. The final sample taken of that steel showed it to contain 4.6 per cent. of carbon. The steel and not the furnace now contained most of the hearth!

One often learns by others' failures, and from this the author learnt to what extent combined carbon could exist in synthetic cast iron.

Many heats of synthetic pig-iron have been made since in electric furnaces in the author's works, but a higher carbon content than about 3½ per cent. has not usually been obtained. A higher percentage could regularly be produced if the cost of raising the carbon by such a method were not prohibitive. The commercial range of carbon in synthetic pig-iron is from about 2¼ to 3 per cent. In all cases, this carbon was combined, but grey iron can be produced if required. The reason for the carbon being combined will easily be appreciated from the fact that all other non-ferrous contents of the metal were kept low.

Alternative Methods of Producing Synthetic Cast Iron.

Two methods of producing synthetic pig-iron have been worked out by the author, one consisting in melting and refining steel scrap and then, after the slag has been run off the metal, adding anthracite to the bath. The other method consists of melting and refining the steel scrap in one electric furnace, filling another electric furnace with the anthracite and getting the latter red hot, then taking the refined metal from the first furnace and pouring it over the red-hot anthracite in the second furnace. Both these methods give an ultimate product which is exceptionally strong and uniform in physical qualities. It is interesting to know that to obtain 3½ per cent. carbon in such pig-iron entails 50 per cent. more current being used than to obtain 2½ per cent. carbon iron. This is because the absorption of carbon by iron becomes slower the higher the carbon content of the iron, and, as current must be maintained throughout the whole of the process, the cost of producing synthetic pig-iron containing more than 3 per cent. carbon is uncommercial.

Oxygen in Cast Iron.

It will be remembered that during the discussion of Mr. Logan's Paper the author stated that experience in the manufacturing of synthetic pig-iron led one to the very definite conclusion that oxygen could easily exist in high carbon metals. Whether that oxygen is in combination or in solution in the metal perhaps cannot definitely be stated, but it would seem that as oxygen in combination could (if at all) exist in iron in much greater quantities than oxygen in solution, the probability is that oxygen exists as iron oxide in high carbon metal. When the synthetic pig-iron was made by adding anthracite to the refined metal, the resulting material contained what is usually but, in this case, would be erroneously called blow-holes. By adding a very small quantity of aluminium to the bath, the so-called blow-holes disappeared, and the metal became close grained. This closing of the grain did not result, in all probability, from any alloying of the aluminium with the metal as only the slightest traces of aluminium were found in the finished product, practically all having been oxidised in decomposing the iron oxide which was previously in the metal.

The synthetic pig-iron produced by the method of pouring the refined metal on to the top of the red-hot anthracite in a second furnace contained fewer blow-holes and required less aluminium to absorb the oxygen and close up the grain.

The iron produced by both these processes gave, in every case where it was tested, between 20 and 30 tons tensile on test pieces, cast in sand, having a cross-sectional area of $\frac{1}{2}$ sq. in. turned from about 1-in. diameter.

Using up Burnt Metal.

For the purpose of making some special iron castings weighing each six or seven tons, the author has melted scrap cast iron in an electric furnace with a good measure of success.

The charge for these castings consisted of a mixture which would probably make many iron foundrymen shiver; it consisted of a little ordinary machinery scrap, a quantity of burnt metal and old ingot moulds. If it had not been that quite a lot of machinery scrap was at hand, the charge would have consisted entirely of the poorer cast-iron scrap and a few old ingot moulds. The reason for deciding on using the burnt metal was purely the commercial one of wanting to make as much profit as possible. The reasoning was as follows. The author never had any prejudice against what is called burnt metal. Burnt metal simply means cast iron which had been exposed in a solid state at red heat to oxidising influences. Burnt metal, when molten, appears to be just the same as any other metal of the same composition except that it is accompanied by a greater loss of weight in melting. Any shortage of silicon in that metal can be replaced on remelting by adding high silicon scrap to the charge, and any shortage of carbon can equally easily be made up. However, the proof of the pudding is in the eating, and those important castings made out of a major portion of burnt metal came out true to the required severe mechanical and physical tests.

Practical Difficulties.

The melting of cast iron in an electric furnace is different from the melting of steel in such a furnace in several ways. Perhaps the most noticeable is that resulting from the stillness of cast iron in the furnace as compared with the liveliness of steel during all the stages of the process. This results from iron being chemically much more stable when molten than is steel, principally due to the oxygen content of the iron being in equilibrium in the molten mass, whereas in molten steel oxygen is only in equilibrium when present in the most minute quantity. This statement is diametrically opposed to the generally held belief in regard to the effect of resident oxygen in such molten materials, but the many opportunities afforded of watching at great ease the behaviour of molten baths of cast iron and baths of steel in electric furnaces make the author assert the fact very dogmatically.

Resulting from the stillness of cast iron in the electric furnace, greater effort has to be made than with a bath of molten steel in order to get the greatest heat into the molten mass. This will easily be understood because in a furnace filled with molten steel the movement in the steel resulting from the chemical activity of the oxygen therein causes fresh parts of the bath always to be brought near the source of heat, whereas with the quiet molten cast iron one would have very highly heated iron near the arcs and relatively cold metal at a distance from them unless the furnace were efficiently stirred by rabbling, so as to bring all parts of the bath in turn near the arcs. If sufficient rabbling is not effected, the current consumption for melting cast iron will be as high as that required for melting steel, notwithstanding that the former melts at a much lower temperature.

Diesel Engine Iron.

In addition to the electric furnace being the only plant which can produce very high tensile synthetic pig-iron, the plant has many possibilities in an iron foundry for improving the quality of ordinary pig-irons.

For certain purposes, such as special Diesel engine castings, some metallurgists believe in using cast iron with a lower sulphur content than is normally available. It is realised that other and equally eminent metallurgists believe the exact reverse. It is not proposed to step in where doctors disagree, but for those who desire a low-sulphur iron this can be produced by using the electric furnace as an auxiliary to the cupola. The metal can be melted in a cupola in the usual way and then poured into an electric furnace. Under the influence of the electric arcs and a high lime slag, the sulphur can be considerably reduced in the iron. At the same time, the oxygen content of the iron can be reduced and the resulting product made to give a distinctly higher tensile result.

For the metallurgist who does not require to reduce his sulphur or may even desire to increase it, the electric furnace used along with the cupola will enable him very conveniently to increase his sulphur by additions of sulphurous materials to the iron after it is poured into the electric furnace, and at the same time he will have available the means of degasifying the cast iron and so considerably improving it prior to filling his moulds.

Melting Cast-Iron Borings.

Another direction in which the electric furnace should be of great help in iron foundries, especially those attached to large engineering works, is in re-melting cast iron borings. The author is not aware of the market position of cast iron borings on the North-East Coast, but he was told by the head of one of the largest British engineering concerns a few years ago that borings were such a glut in his district that he was actually disposing of as much as he could for nothing and that it was being used for the making of country lanes and roads. In any district where this condition does not obtain, these observations will, of course, have to be viewed according to the circumstances.

To melt cast iron borings in an electric furnace would require about 500 units of electricity per ton. With current at about ½d. per unit, the cost of the melting medium would be, approximately,

£1. On the surface, this would seem to be a very good commercial proposition.

Making True Semi-Steel.

The subject of semi-steel is highly interesting in connection with electric furnaces. It will be apparent, from what has so far been said, that any intermediate composition between the usual steel and cast iron ones can readily be obtained by means of the electric furnace. It would seem difficult when making semi-steel in a cupola so to operate the plant as to obtain a reasonable degree of regularity in the molten material delivered by the cupola. By adding cast iron, melted in a cupola, and steel scrap together in an electric furnace, one can be sure of homogeneous metal being available for the foundry, and, if considered necessary, an analysis can be made of the material before the electric furnace is tapped so as to assure the desired composition of true semi-steel being obtained. Should the analysis when received from the laboratory not be that desired, it is the simplest matter to add either a little more steel or a little more cast iron to the furnace in order to adjust the composition. This may seem much extra work, but it must be realised that it is only by such control of metal that a thoroughly regular result can be obtained from a foundry The cost of making the necessary analyses is indeed very small when one considers the enormous advantage to a foundry of knowing what the metal actually is and, if necessary, adjusting it before the moulds are filled.

Better Control Instituted.

When melting cast iron in the electric furnace the foundryman is able to control the depth of chill which will be obtained in his metal when he is using chills in his moulds. This control is obtainable by taking out small samples of the molten metal from the furnace and casting them in small chill moulds. If the desired depth of chill is not obtained, small additions of known materials to the bath will quickly give the required chilling results. This would seem to be a most important matter in large castings when chills might have to be used at or near places where the castings have to be machined.

Another utility of the electric furnace in the iron foundry is where it is desired to make a heavy addition to the iron of some alloy such as chromium, silicon, manganese, etc. Adding such alloys to a cupola is most inconvenient, because one is never sure of the extent to which the alloys will be oxidised and slag off; also there is the loss of money which results from such slagging out of added alloys It must also be remembered that the cupola cannot deliver cast iron alloys having the regular composition which the electric furnace product will give.

Another advantage of an electric furnace to an iron foundryman is that he will have at hand apparatus which enables him, if he so desires, of turning his attention at any time to steel foundry work, which probably is a better paying proposition than iron foundry work!

IMPORTANCE OF VENTING, WITH SPECIAL REFERENCE TO DEFECTIVE CASTINGS.

By E. Longden (Associate Member).

In this Paper a little information will be given with a view to focussing attention on the effect of gases, especially those given off from the mould during pouring, on the soundness of grey iron castings. Personally the author is convinced that mould gases are responsible for a far greater percentage of the defective casting trouble than has been generally recognised.

The conclusions are based on a number of simple experiments and a very fortunate and exceptional experience with small and large castings of simple and intricate designs. From the evidence so collected the author has been forced to associate the defects which are usually described as liquid shrinkage cavity and porosity to gases generated in the mould and those occluded by the metal during cooling. Interaction between mould and occluded gases is very probable, and if it were possible to eliminate mould gases the amount of liquid shrinkage in grey iron would be negligible, and the problems which beset the metal founder would be very considerably reduced.

Soundness increases progressively with a reduction in mould gases. From such deductions it would follow that, if we cannot altogether eliminate these gases, provision must be made for their speedy evacuation through the pores of the sand and vents.

When molten metal enters a sand mould large volumes of gases are formed, generated from combustible materials and chemical decomposition of substances composing the mould, to which can be added gas occluded by the cooling metal. To minimise the effect of such gases on the soundness of castings forms a very important part of the moulder's work. Great care and ingenuity is exercised in conducting gas away from cores and moulds.

Defects Attributable to Gases.

Defects which could be attributed to gases are very numerous, and could be said to be caused by:

Insufficiently dried cores and moulds when dry-sand and loam moulding is attempted; excessively hard-rammed cores and moulds; in some instances lack of ramming locally, because a pocket of loosely-rammed sand provides an easy exit for the gases generated in the harder surrounding sand, so that the gas easily flows forward into the mould cavity and metal; abuse of the swab locally or too much moisture in the sand generally, especially when green sand moulding; lack of the natural venting properties of moulding sand; omitting artificial venting; improper use of the vent wire, because if deeply probed it will be found that quite an appreciable percentage of blow holes are due to the over sharp vent wire which is so often thrust through the sand and penetrates the pattern; the fine holes so formed are easily passed over by the moulder, and when the metal enters the mould the generating gases blow through into the mould cavity and later the metal; incorrect sand mixtures for the particular type of casting; faulty sand mixing; faulty and wrong mixtures of mould dressing; allowing metal to penetrate subsidiary and main vents in core or mould, choking of vents by sand due to unskilful manipulation; blow holes from inserted solid metal which has not received correct treatment such as, denseners, chills, nails, studs or chaplets, also these pieces of metal in spite of much care attract and condense steam created

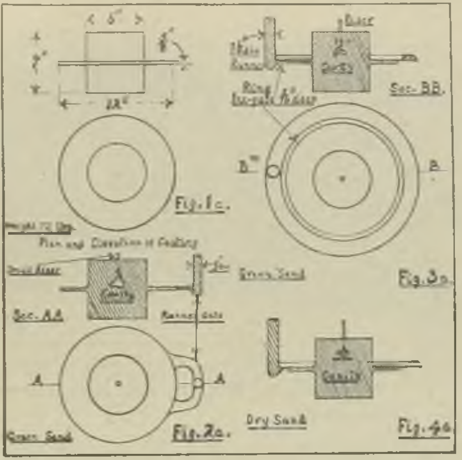
FIG. 1.—VARIOUS SECTIONS SHOWING POROSITY.

in a green sand mould in which has been placed a warm core, or from an imperfectly dried mould, closed warm and then allowed to stand so that it cools before receiving the metal; blow holes from wet loam stamps which are placed on cores to make up the common errors in size between core and mould print; absence of openings or risers for exhausting mould gases quickly, particularly in confined sections of the mould and especially if the nature of casting compels rapid pouring; insufficient fluid head pressure; escape of metal from mould with the consequent arrest or ebb and flow of the molten iron; incorrect gating so that metal enters mould wildly, or too slowly, perhaps the metal enters and impinges on the mould or cores eddying and churning so that air and other gases are mechanically mixed with the metal, or it may be that the gate is so concentrated on one portion that sand becomes overheated and the gases escape from the mould face into the metal rather than through the back sand which has become unduly overburdened with gas generated at very high pressure; it may be that metal has such a tortuous passage due perhaps to wrong location or insufficient git that it becomes lifeless and unable to expel collected gases, for it might be said that the very act of pouring tends to create blow holes because of agitation; omitting to feed metal through riser gates to replace escaping gases and badly located feeders; dull iron because there is always much more difficulty in obtaining castings free from blow holes when the moulds are poured with sluggish iron for whatever might be the cause the gas cannot find its way out if the metal is viscous—good hot iron hides much faulty venting, etc.; wrong mixture of metal for the particular type of casting and last but not least the difficult, and very often absurd, design of casting which makes it practically impossible to conduct gases rapidly enough away from the mould or core.

Mould Gas and Moulding Sands.

The moulding material from which gases are generated is worth a little attention. What are termed "natural moulding sands" consist of, before preparation, substances in something like the following proportions:—Silica 73 to 92, clayey matter 6 to 14, oxide of iron 2 to 5, lime 4 to 2.5, magnesia up to 1, and water up to 10 per cent.

Sands are specially prepared for facing the metal. When mixing facing sands other materials are added depending on the class of mould or core such as:—Coal dust, manure, sawdust, hair and artificial binders like core gum, molasses, flour, sugar, resin, vegetable and mineral oils, etc. Then there are the various refractory materials which are applied to protect the face of the mould and give a good looking finish to the casting which are:—Plumbago, charcoal, and mineral blackings, ground silica, core gum, etc.



Each of these materials have special virtues when rightly used, and give a combination of properties required in moulding materials, the desirables being:—Refractoriness, porosity, plasticity, adhesiveness, cohesiveness, power of taking up water to about 6 per cent. by weight, and resistance to distortion at high temperatures.

The most successful sands and refractories are those which give above properties with the maximum connected pore spaces around the sand grains for gas exit when metal enters the mould. A large average porosity could be obtained by a number of large unconnected pore spaces.

Sands and refractories may lose as much as 15 per cent. of weight when subjected to molten metal temperatures and the facing sand for a considerable depth from the surface is very much changed in physical properties chiefly due to ignition and burning of coal dust and organic matter and dehydration of the iron oxide and clay bond. Water (mechanically mixed) is dried out at a low heat and the water of combination lost at a temperature of dull red heat.

FIG. 2.—THE LEFT-HAND FRACTURE IS FROM A GREEN-SAND MOULD, AND THE RIGHT DRY SAND.

These chemical changes are accompanied with the formation of large volumes of gas although infinitesimal in weight. An idea of the space these gases occupy can be gauged by considering several substances. At a temperature of about 880 deg. C., the aqueous bond (water) is broken up into its constituents hydrogen and oxygen, and if allowed to expand freely would occupy about 9,000 times its original volume. Much of the water is, of course, only converted into steam, even so the steam occupies about 1.440 times the space as the water from which it is formed. Coal dust when heated may give a gas volume, chiefly hydrocarbons, of something like 400 times its bulk, and expand considerably more at high temperatures. Gases expand very much more than liquids or solids within very wide ranges of temperatures and with very uniform expansions; also changes of pressure which have practically no effect on the volume of liquids and solids have an enormous effect on the volumes of gases. If the gas be confined, and is prevented from expanding a tremendous pressure is possible, and when ignition takes place violent explosions may occur especially if gas is contained in a closed vessel.

Hydrocarbons are decomposed by the hot metal and graphite deposited on the face of the sand. It is considered that this change is not quite the same if the sand is too damp and graphite is not deposited. This would account in some instances for the burning-on of sand as in the case of loam and dry-sand moulds which have been insufficiently dried. Steam is discharged from the surface of the mould and is decomposed by the hot metal, and probably the oxygen combines with the graphite at its ignition temperature, thereby robbing the mould surface of its refractory cover, resulting in the grey burnt-on sand appearance. With green sand in the ordinary way carbon from the coal dust would appear to combine with the oxygen which is liberated when water is split up into its elements and also with the oxygen in the pore spaces of the sand, the pore spaces in good moulding sand being about 25 per cent. of the bulk and

FIG. 3.—FRACTURES FROM MOULDS CAST IN GANISTER (LEFT) AND PLUMBAGO (RIGHT).

in cores about 40 per cent. Additionally, the combustible substances may burn in the air contained in the pore spaces, and under certain conditions prevent burning-on of sand. The coal gas forms a film on which the metal flows, thereby protecting the sand.

When considering the volumes of gases generated in dry- and green-sand moulds the author is inclined, when examining superficially, to state that greater volumes of gas would be formed in the green-sand mould than the dry-sand mould, but this must be modified, because the cooling effect of the damp backing sand in a green-sand mould will tend to reduce the volume somewhat. The heat from the metal which volatilises the coal dust and converts the water to steam absorbs heat for the time being, thereby cooling the sand and preventing burning-on of sand.

Fig. 4.—Fractures of Spheres, the Left being Poured in Green Sand and the Right in Dry Sand. The Top of the Latter is Marked with a X.

Gases occluded by metals are stated to be:—Hydrogen, nitrogen, carbon monoxide and carbon dioxide. Gases can be noticed escaping during feeding operations, but are mainly mould gases.

Instances are on record where gas emanating from pig-iron after drilling amounted to 75 per cent. in volume of the metal removed and when a flat drill was used, thus crushing the metal thoroughly in removing it, the volume rose to 600 per cent. of the metal removed.

Combustion is defined as vigorous chemical combination attended with light, and that chemical combination is often attended with evolution of heat.

In thermal chemistry it is laid down that: Every chemical change without the intervention of extraneous force tends to produce those bodies the formation of which will evolve most heat. This is called law of greatest energy, and is considered of great importance. From it it follows that reactions which are exothermic tend to take place more readily than those which are endothermic, and also that bodies which are formed with the absorption of heat are usually less stable than those in the formation of which heat is evolved and that heat of reaction depends on temperature.

FIG. 5.—FRACTURES OF SPHERES. THE LEFT HAS BEEN CAST IN PLUMBAGO AND THE RIGHT IN GANISTER.

It is considered impossible for two different gases to remain in separate layers however much their densities differ, and that diffusion takes place rapidly. One only needs to think of the impossibility of life with industry if this were not so. The air in industrial districts would soon be displaced by the heavier gases. Agitation assists diffusion.

The agitation which occurs at the overheated sections of a mould or core due to gas blowing into the metal assists in diffusion of gas into the metal. Gases have the power both of diffusing through and of being retained by solid substances. Hydrogen can be readily diffused through cold cast iron.

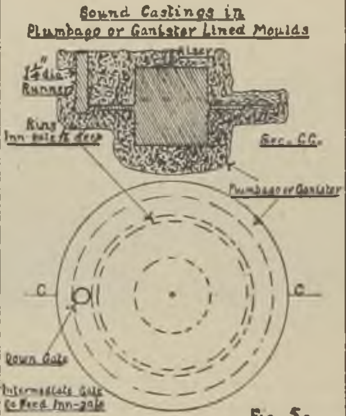


Fig. 5a.

Bearing these points in mind, one would be bold to state that it is not possible for reactions to take place between carbon in the metal and oxygen from the mould which might be blowing into the metal at great pressure. Other heat-forming reactions are possible with other gases. A kind of local Bessemerising is possible. If such changes take place it would account for the sponginess and cavity in certain sections of grey iron.

One need not be surprised at the feasibility of such reactions mentioned when considering the practicability of partly desulphurising a ladle of molten cast iron by merely placing soda ash or sodium carbonate on the surface of the metal. It does appear that the supposed liquid shrinkage in grey iron could almost be ignored if mould gases could be eliminated. Graphitisation of carbon in iron is mainly responsible for the low shrinkage compared with other metals. Elements in grey iron such as silicon tend to reduce the effect of gases.

It is not impossible that graphite is present in grey iron a little before solidification. The author is aware that he is ploughing a lone furrow when he makes such a statement, and that he will be reminded of the "common salt in water" diagrams; but cast iron is not a simple solution like salt in water, and conditions may obtain in a complex mixture like grey iron which are not explained by the iron-carbon equilibrium diagrams. Grey iron consists of, in addition to iron, an average of 7½ per cent. by weight of impurities made up of carbon, silicon, manganese, phosphorus, sulphur, traces of other impurities and gases. These elements can be twisted and altered in so many ways that grey iron is still insufficiently understood. Others, again, will recall the very meagre experiments carried out whereby a thin streak of molten grey iron has been suddenly cooled from a very high temperature by allowing to pour in iced water, and that all carbon was obtained in combination with the iron. Possibly this is not sufficient proof, because by suddenly chilling an enormous pressure is applied by the envelope of the metal contracting instantaneously and preventing deposition or growth of graphite. It is a well-established rule that pressure in and by itself favours the formation of the less bulky of the possible conditions, or state, or phases.

It is most likely that carbon is in solution with iron at the high temperature of melting, but it is also possible that a certain amount of graphite is formed or precipitated during the temperature interval between the highest and the point of freezing at something like 1,130 deg. C. If grey iron melts at 1,500 deg. C. there is something like a fall of 370 deg. C. of heat before setting; this means that grey iron freezes at a lower temperature than its melting point, because the carbon must first be dissolved before the metal will melt. So that the dissociation of carbide is accompanied by an evolution of heat. *i.e.*, is exothermic. This dissociation can be recorded after solidification, showing several volumes changes, but dissociation before solidification is much more difficult to record, and critical solution temperatures at which a special form of graphite is deposited is possible before solidification as well as after solidification.

Kish is described as excess carbon, and is due to certain forms of carbide. Here is an instance where proof is given that under certain conditions graphite is formed before solidification. The growth and precipitation of graphite on the cooling metal envelope exerts a pressure internally, thereby compensating for liquid shrinkage.

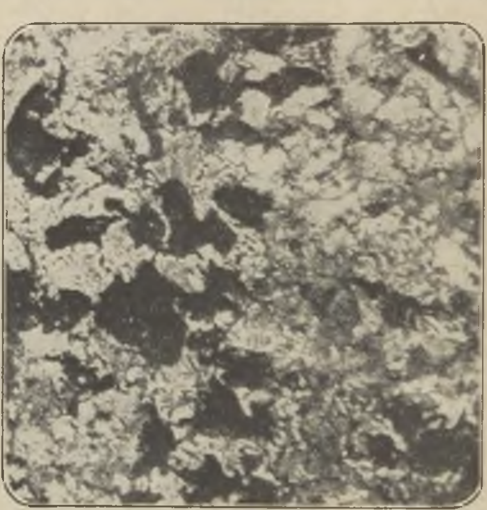


FIG. 6.—CAST IN GREEN SAND. × 250 DIAS.

In a Paper read before the Faraday Society on November 12, 1918, on the "Occlusion of Gases by Metal," Sir Charles Parsons, F.R.S., said:—

"If a small crucible containing ordinary cast iron is intensely heated in the electric furnace and then quickly placed while molten under hydrogen at 2 tons pressure per sq. in. a very large amount of graphite is ejected in a dense layer below the metal, which wells up and overflows the crucible. Finally, the iron is white and hard, containing much combined carbon. If, on the other hand, carbonic oxide is similarly admitted instead of hydrogen, no layer of graphite is formed, and the metal remains grey cast iron."

" Dr. Hatfield undertook the analysis of the samples of the metal so treated, and he tells me that both contained about 4 to 5 c.c. of occluded gases per grain of iron; in the one case almost wholly hydrogen, and in the other almost wholly CO.

" I have noticed the remarkable difficulty with which gases pass out of molten cast iron under a high vacuum."

Prof. Armstrong then stated: " The idea is growing in Sir Charles Parsons' mind that hydrogen has something to do with the production of graphite. I venture to say that graphite is not a form of carbon, and that there is but one form of carbon, viz., diamond; graphite and the various charcoals are, in my opinion, probably compounds of carbon with a very small proportion of hydrogen."

Now as cast iron contains much hydrogen it is possible that graphite may be precipitated a little before solidification due to the presence of hydrogen.

During the last forty years our scientists have discovered and revealed many wonderful things. Many are familiar with the gas discoveries made during the latter part of the war, but they are not so sensational as the discoveries made by such men as Sir William Ramsey, Professor Soddy and collaborators, commencing the year 1894, which gave the very remarkable information that the air contains, in minute amounts true, in addition to oxygen and nitrogen, six gases, which were named Helium, Neon, Argon, Krypton, Xenon, Niton.

Venting Green Sand, Dry Sand and Loam.

The practice of venting varies somewhat in different parts of the country, the variation being due, in the main, to the quality and availability of sands, as also does the determination of whether to mould in dry sand or green sand. Although such a statement must be modified considerably because the ability of moulders in certain districts and shops to produce castings in green sand which would in the majority of places be made in dry sand is very evident. Again, certain firms demand higher quality castings than others. So that with special castings which must stand a high finish the bias must be in favour of a dry-sand mould.

A correctly made dry-sand mould will produce a high quality casting, both in looks and soundness, than a green-sand mould, and with less risk of waste; also a correctly made loam mould will give better results than either. It does not always follow that the loam or dry sand will be more costly to produce. There are many instances whereby a loam mould or dry-sand mould can be made much more quickly than one in green sand.

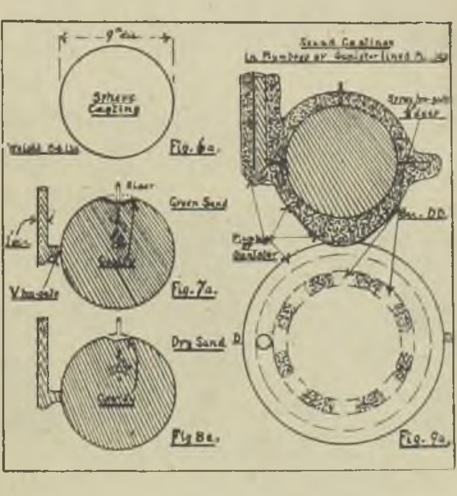
The nature of moulding determines that a dry-sand or loam mould, especially the latter, will be freer venting and with less gases present than green sand. That is the reason that one can expect with a dried mould greater freedom from those embarrassing defects which are disclosed after machining important castings.

The removal of moisture in dry sand and loam creates porosity, as does also the expansion of grains of sand when heated, because they do not quite return to their original position.

Loam when dried is very porous, less artificial venting being needed. Except when building loam around a pattern, only a thin layer is struck up on brickwork. The loam is not compressed by ramming, as is the case with ordinary sands, and for that reason is more open. Cinders are introduced into a loam building when necessary, but sometimes the use of such material is much abused. In many instances it is far better to introduce dry sand and loam waste into cods and between the brickwork. Doubt can exist as to the beneficial use of cinders when loam-moulding certain types of castings, because one cannot always account for the poorly dried moulds when using cinders. The drying of loam is hastened very materially by perforating with the vent wire so that steam can quickly pass out. The holes so formed can be stopped up after drying.

Many more vent holes are made in dry-sand moulds than would apparently be needed just to help drying. When moulding large castings in the floor, and which are to be dried with open fires or patent driers, these holes become still more valuable.

Venting can be materially helped if, when ramming sand in the bottom boxes of large moulds, sand is fed in, after the first ram past the pattern, which is only so damp that it will barely hold together, and finish the last ram with the normal green sand.



Venting in green or in dried moulds is usually more thorough than when working in loam or dry sand. Any neglect may prove disastrous because the gases are generated in greater volumes, the sand is weaker in bond, and the rapidly-expanding gases push off a portion of the face of the sand. If the sand face is not so detached the gas may flow into the metal and cause, if not distinct blowholes, porosity. Unequal distribution of moisture in green sand may prove fatal to the casting. Gases may pass through correctly-mixed facing sand to encounter wet places in the backing sand,

and then return again to find lodgment in the metal or blow off the surface of the mould.

The quantity of gas given off by cores and certain portions of the mould is much greater than in a similar amount of sand forming part of the mould generally, and proves very exacting on the vents. In the mould, the gas which has been liberated and expanded by the heat of the metal, is cooled somewhat when passing through the back sand, but with cores the heating up is more rapid and intense, and gases continue to generate and expand, and the core, if of comparatively small area, may be heated up to the temperature of the metal just before setting.

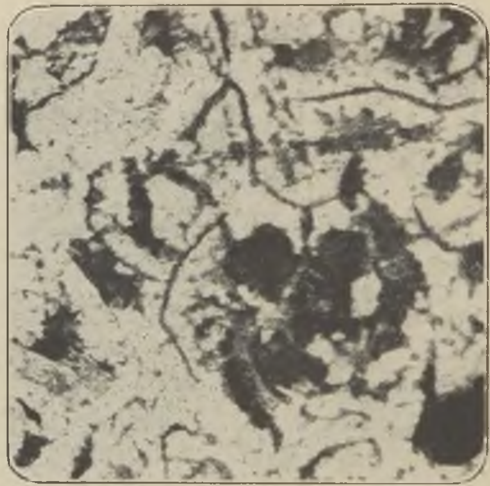


FIG. 7.—CAST IN GANISTER. × 250 DIAS.

The average voids formed around the sand grains is stated to be about 40 per cent. of the bulk. This means that the air in the pores of the sand is also expanded, but much of it begins early to pass out through the vents. Later reactions take place between the oxygen in the sand void and oxygen liberated from the iron oxide in the sand with gases from decomposition of the carbonaceous materials. The burning out of such materials makes the sand more porous.

Vents as large as practicable should be provided to allow the gases to pass out quickly instead of blowing out through the skin of the core into the mould. The smoothing of the surface of the sand and application of refractory wash or powder helps to close up the surface pores and prevent this happening.

Moulders and coremakers often pay scant attention to vents. They will place cinders in various parts of the core or mould and leave them unconnected and isolated without separate exits for gas. Vent pipes and holes in cores, although ample in the first place, are very often seriously reduced in area when the moulder is providing a passage for the core vent through the mould.

Venting Green Sand, Dry Sand and Loam.

Small thin cores are vented by forming a simple passage through the centre. Medium-sized cores may be ventilated by a main passage augmented by holes made with the vent wire either outward from the passage or by thrusting the vent wire in the direction of the main passage before extracting the main vent rod. Large cores are vented by cinders and holes formed by the vent wire and connected to large open vents through the prints. The gas from loam cores pass from the face to the straw wrapping, and then through perforations in the core barrel. Other loam cores are vented in the same manner as with ordinary sand. Wax wire vents are also used in all grades of sand to advantage except oil-sand. The venting in oil-sand cores is very often neglected, both coremaker and moulder trust too much to the excellent free-venting nature of this type of core. Founders cannot do without vents even with oil-sand cores.

Above are only very general statements; special cases call for much ingenuity on the part of the workman.

The moulder should use as small a quantity of water as possible. The large foundries with which the author is connected have provided many amusing instances of the inability of some moulders to understand, even in a small way, what happens when too much moisture and gas is present in the mould. It is the practice in these shops when making green-sand moulds to use a mixture made by boiling linseed meal in water for the purpose of damping, where necessary, portions of the mould, instead of just water, the object being that this mixture prevents scabbing. This solution, when used instead of water alone for the purpose of repairing a mould, or to stiffen a weak upstanding piece of sand, does reduce a little the tendency to scab, but the idea had so gained prominence that they called the solution a non-scab mixture, and consequently certain moulders would sometimes be caught washing over the whole of the face of a mould with the mix. It was certainly ridiculous, as was proved in many instances where castings exhibited signs of vein marks, blowholes and scab, which were traced to the abuse of this non-scab mixture. This custom was not easily broken down.

Birmingham (Bunter) red sand is the best all-round sand that the author has encountered. It possesses good bond and is very porous. Many castings can be made in green sand which in Lancashire, when using Runcorn (Bunter) sand, would be made in dry sand. Runcorn sand is very free venting but weak in bond, and consequently for heavy work and dry sand much milling of the sand takes place; also for green-sand work. In the Newcastle and London district, Erith (yellow) and similar sands are chiefly used, and much drying is practised because the sand is close and contains much water in combination.

Oxide of iron constitutes the red and yellow colouring matter of sand. The red oxide contains little or no water in combination; yellow may contain up to 20 per cent. of its weight, which is driven off when heated.

This would explain to some extent why the practice varies. Although possessing much more bond than red sand, yellow is not so successful for green-sand work.

From a group of drawings, which the author showed in a previous communication,* illustrating certain sections commonly experienced with defects which are usually explained as liquid shrinkage

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* Relative Values of Feeders or Denseners in Grey Iron and Malleable Iron, Figs. 20 to 40, "F.T.J.," Vol. XXIX, pages 30-31.

holes or cavities, it is suggested that they are, with grey iron, in every case gas defects.

Fig. 26A describes a die casting about 8 cwts. Cast in the ordinary way in a loam or sand mould, porosity occurs as shown in the section AA. To remedy this defect, denseners were introduced leaving 1 in. of sand dividing them. After machining hair cracks were disclosed opposite the places which corresponded with the sand between the denseners. This further complication was overcome when denseners were continued over the whole surface.

Surely no one would describe the defects as shrinkage porosity, especially in the position shown. Surely they are gas porosity. Fig. 1 shows a number of sections of castings which exhibit gas cavity and porosity.

Experiments to Eliminate Cavities and Porosity.

Some time ago the author carried out a number of experiments on block castings designed to give the maximum of gas or liquid shrinkage cavity with a view to discovering the cause and the best way to eliminate the defects found.

These experiments have been described and illustrated in a previous communication to the Institute, and reference should be made to it, as the experiments to be described are but supplementary thereto.*

Fig. 1A illustrates the design of the next experimental casting chosen, which weighed 72 lbs.

Fig. 2A shows cross section of the first casting made in the ordinary way without feeding, only a small relief riser being provided on the boss. As would be expected, considerable cavity was disclosed.

The next sketch, Fig. 3A, depicts the cavity which formed, again when made in a green-sand mould and poured through a very thin gate, $\frac{1}{16}$ in. deep, completely encircling the 12-in. dia. plate which surrounds the boss. It will be noted that the cavity is not so great. It was not poured slowly, because the inlet gate, although thin, was equal to an area of 2.36 sq. in. The greater soundness could be attributed partly to the sieving of

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* See "Foundry Trade Journal," issue January 10, 1924.

the metal when passing through the very thin runner.

Fig. 4A shows the amount of cavity resulting from a dry-sand mould, but is less than the one cast in green sand.

Fig. 5A describes the next two castings, which were poured in ganister and plumbago moulds respectively. Absolute soundness was obtained.

The next test was made on a 9-in. dia. sphere casting weighing about 84 lbs., particulars of which are given in Fig. 6A. Considerable cavity was disclosed when poured, as described in Fig. 7A. Fig. 8A shows slightly less cavity when poured in dry sand, and Fig. 9A gives particulars of the next two castings made which were poured into thoroughly dried ganister and plumbago moulds respectively. The castings again were absolutely free from defects.

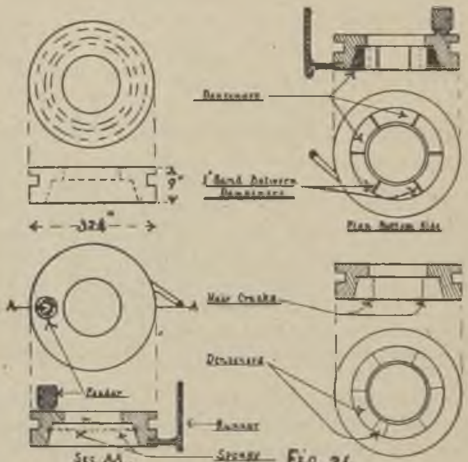

Fig. 26

Fig. 2 shows on the right the broken section of the casting made in a green sand mould, and the one cast in dry sand is shown on the left. These castings were dealt with when describing Fig. 3A and Fig. 4A. Fig. 3 shows sections poured in ganister (right), and plumbago (left), which were definitely free from cavity as previously stated.

Broken sections of the sphere castings are shown in Figs. 4 and 5. Fig. 4 shows on the right the one poured in green sand, on the left the one cast in dry sand. Fig. 5 shows on the left the one cast in ganister and on the right the one poured in plumbago. Again it shows perfectly sound castings.

TABLE I.—*Tests of a Cast Iron Cast under various conditions.*

Analysis.	%	Mould material.	Tensile Tons sq. in.	Transverse 3′ by 2″ by 1″	Deflection.
Total carbon ..	3.11	Green sand	10	25.2	0.37
Graph. carbon ..	2.86				
Comb. carbon ..	0.25	Dry sand	10	24.8	0.38
Silicon ..	3.20				
Phosphorus ..	1.38	Plumbago	9.6	24	0.39
Manganese ..	3.36				
Sulphur ..	0.09	Ganister	10.2	25.4	0.38
Total impurities	8.14				

A comparatively poor metal was used to obtain the worst results. Physical and chemical tests were obtained of the metal poured into the experimental castings and are set out in Table I.

Four transverse and four tensile bars were made in green sand, dry sand, plumbago and ganister moulds respectively. The four transverse bars were poured together in one box and the tensile bars again together in another box. This insured that the bars should be poured with exactly the same metal and at the same temperature. Ample space was allowed between each bar when moulding. The moulds were poured at atmospheric temperature.

Photomicrographs were obtained of, as near as possible, the centre of the four transverse test bars. Photomicrograph (Fig. 6) refers to a casting made in green sand. Its ground mass is of the pearlitic type; the graphite is not relatively well developed, whilst the phosphide eutectic is not very prominent. Fig. 7 was cast in a ganister mould. The pearlite is well developed, and the graphite plates are also well developed.

If some of the common defects found in ordinary and important castings are examined, whether poured in iron low or high in those elements or impurities which constitute cast iron, much will be learnt from the experiments described in this paper. With a progressive reduction of mould gases soundness increases proportionately.

This is the author's case, and until it is explained to him how it is possible for him to secure castings free from defects other than has been previously outlined, he will continue to hold the views outlined.

In conclusion he wishes to acknowledge indebtedness to Mr. A. Horn, the malleable iron-foundry foreman, for assistance rendered in the preparation of a section of this Paper.

Lancashire Branch.

THE MAKING OF THIN SECTION PATTERNS.

By T. W. Markland (Member).

Making Pattern First in Plaster of Paris.

For thin work a primary pattern is made in plaster of paris. For this purpose a piece of sheet zinc is formed into a strickle the design of the pattern required, the first one representing the shape of the back of the pattern. The second strickle, of course, will be larger, in proportion to the thickness of the castings required. These strickles are then screwed to a strong piece of wood for reinforcing. Then a board is procured (Fig. 1) and the strickle made to slide along the edge of the board to keep it in the same position all the time of using. Plaster of paris is then mixed with water to a suitable consistency and placed on the board to the required height. The

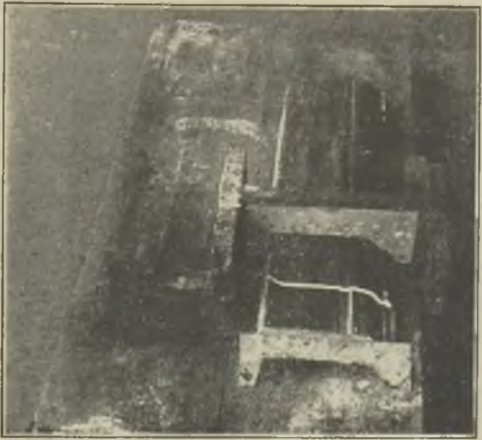

Fig. 1.

first strickle is now brought into action whilst the plaster is soft, being drawn along the board, leaving the required design in plaster for the pattern. This is allowed to harden and dry. The surface is varnished with shellac, and allowed to dry. Afterwards it is covered with a thin coating of tallow.

More plaster is mixed and laid on to the present dry and varnished portion. Then the second strickle is drawn along the board, and leaves behind it only the plaster that gives a pattern of the required thickness. After hardening, the top portion may be lifted off, leaving the plaster pattern required (Fig. 2). From this a "tin" or iron pattern is prepared. For the "tin" pattern an alloy made up of three of lead to one of tin is used. The tin sections (Fig. 3) are made in lengths convenient for moulding purposes, and are soldered together and then mitred to form the working pattern. The pattern is placed upon a board in such a way that the moulder, when ramming up the bottom box containing the pattern, will not in any way alter the shape. The tin alloy is used because thin section castings are very troublesome on account of the camber needed for straightening, and the tin alloy allows the

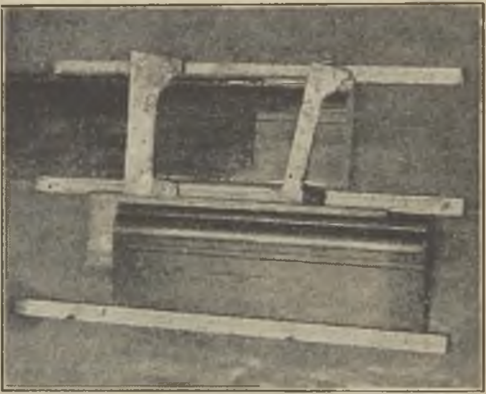

FIG. 2.

pattern-maker to introduce the correct camber (Fig. 4).

Other advantages of tin-alloy patterns are that they can be chased up quite smoothly, thus ensuring a smooth iron pattern, and that they can either be cut down to smaller dimensions or increased in size by soldering a piece to the original pattern.

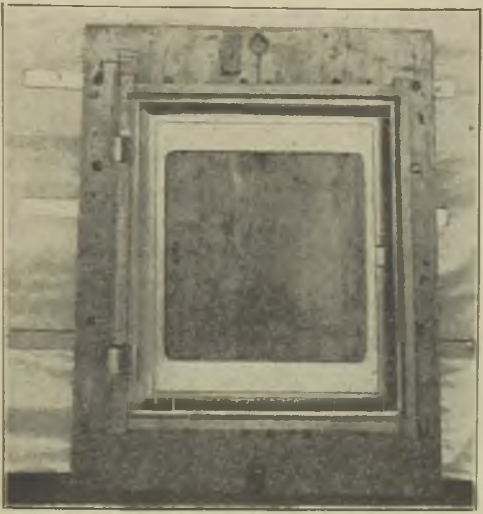

Fig. 3.

Reversing Thin Section Patterns.

Fig. 5 shows the pattern for a model of a liver. This was first made by a sculptor and received in the form of plaster of paris. This plaster pattern is 1 in. thick, flat on the back side, and the liver pattern on the front, but for use in the foundry it has to be 3/16 in. thick. The moulding box used for this purpose is planed on the edges of the top and bottom part so as to give a close and exact fitting of the moulding box. A turning-over board, which must be level and out of twist, is required. The plaster pattern is placed on the board and set between small pieces of wood so that the pattern can be placed exactly in the same position every time, as shown in Fig. 6. The bottom box is then placed over the pattern on the board, and at each corner of the box pieces of wood are screwed on to the board to prevent the box from getting out of position, thus enabling the operator to replace the box in the same position each time required.

A thickness piece is inserted between the box and the board of the necessary thickness of the casting. The plaster being 1 in. thick, pieces 1 3/16 in. thick are placed under the box edge. Sand is sieved on to the pattern, and the box filled with sand in the usual way, but the sand must be rammed hard so as to get a hard surface near the pattern. After clamping the box and board together, they are turned over on to a definitely level bed, but before removing the board the box is twisted about from right to left to ensure that it is quite solid on the sand floor. Then all clamps are removed, and the box is lifted off the board.

FIG. 4.

All the sand is levelled to the edge of the box and the plaster pattern, making sure there are no soft places. After smoothing with a trowel, the plaster pattern is withdrawn (Fig. 7). Using fine parting sand or foundry parting, the mould is dusted through a fine bag on to the joint. The top box is then placed on to the bottom part and the down gate fixed in position. After sieving on the facing sand, the box is filled up to the required height with black sand; when the box has been rammed up, the top is cleaned and the down gate removed. The top box, which will now have an impression of the bottom part of the mould, is removed and placed on one side, the mould being finished in the usual way.

FIG. 5.

After removing all the sand from the bottom box, the turning-over board is placed in position as in the first process (Fig. 6), placing the pattern on the board between the templates. The bottom box is put on the board exactly in the same position as before, but instead of placing 1 3/16-in. thickness pieces under the box edge, 1-in. thickness pieces are used, thus giving a casting 3/16 in. thick.

Facing sand having been sieved on and the mould filled up with black sand, the box is rammed up in the usual way. All loose sand is scraped off, the box and board are clamped together, and turned over on to a level bed, twisting the box about as in the previous case. The excess sand is removed down to the level of the box edge, and the joint is smoothed. Then the plaster pattern is withdrawn in the ordinary way. This gives a front and back impression (Fig. 8), and the gates can be cut and the mould finished off. The top box is replaced on to the bottom, and when cast it will give a casting 3/16 in. thick.

Making a Plate Pattern.

For this purpose a box sufficiently large to make a joint round the plate frame is used, and spaced to make the gates. The top and bottom boxes must have planed edges so as to give a close and level jointing. Well fitting box pins are essential. They must be straight, so as to give no twist in the box.

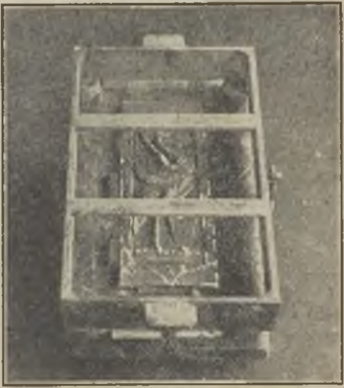

FIG. 6.

The top box is placed on the floor with the planed edges uppermost. The box is rammed up with black sand, levelled with the box edge, thus ensuring a level surface, or, alternatively, turning-over board must be used.

The pattern to be plated is placed in position, using the frame as a guide. Any projection which may be on the pattern must not come in contact with the box bars. This, unfortunately, has happened, and plates have had to be remade.

Once the pattern is in position the facing sand is sieved on the bottom box, then placed on, and the mould is rammed up in the usual way. All loose sand having been scraped off level with bottom of the box, the job is well vented all over the bottom part.

Then a level bed is made on the sand floor, the box is well clamped together, and turned over on to it. The clamps are removed and the top box or board lifted off. Then the joint of the mould round the edge of the pattern can be commenced. This is probably the most important part of the job.

Fig. 7.

In making the joint, care must be exercised that where the frame has to lie on the mould, it must be perfectly level and out of twist, otherwise trouble may arise when the pattern filers have to do their part of the work. Having made a good joint and ascertained that the plate frame fits exactly, the sand is smoothed with a trowel, brushed and covered with parting sand.

Facing sand and black sand are sieved over the pattern and joint to such a thickness that when the top box is placed on, the bars of the box will press into the sand and prevent any soft places under the bars.

The empty top box is returned, ascertaining that all the down gates are in position. It then remains to fill up with black sand, to ram up in the usual way, to scrape off all sand level with the bars, to clean round all gates and risers, to vent well, and finally to lift off the top box.

Fig. 8.

Fig. 9.

Before removing the pattern in the bottom box the frame which has formed the plate (Fig. 9) is placed firmly on the joint of the mould in its correct position.

The joint is made all round the frame to its frame thickness. As the sand is now $\frac{3}{8}$ in. higher than the box edge, there is a danger that when the job is cast the metal may burst out at the sides. To prevent this, thin pieces of sheet iron $1\frac{1}{2}$ in. deep are inserted round the inside of the box and allowed to stand up just the thickness of the plate-frame.

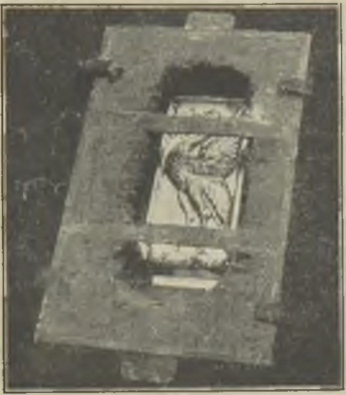

FIG. 10.

When the joint has been made all round the frame and to the box edge, ascertaining by means of a straight edge all is level, the top box is replaced. The box is then rammed all round where the plate frame is to ensure a close joint. After removing the top box, all gates and risers are cut to the plate. The risers serve the dual purpose of carrying away any dirt that might be flowing about and alleviating the strain. Additionally, all gates to the pattern lying in the bottom box must be cut. The frame is then withdrawn and chipping pieces inserted in the mould just where the plate rests on the edges of the moulding box. These chipping-pieces are to facilitate the chipping of the plate into the box by the pattern filer. Then the pattern is withdrawn and finished with as little tooling as possible.

The mould is dusted over with good plumbago, and the pattern is then replaced in the mould to make firm the plumbago and give the mould a smooth surface after the pattern is withdrawn; no tools are used, which promotes a perfect mould.

Before replacing the top box on to the bottom box $\frac{3}{8}$-in. pieces are placed on the corners of the box, so that when the boxes are brought together and clamped up there is no fear of the plate being thick and thin. Before finally closing the mould a hot plate is held over the bottom part of the mould to give it a little skin-drying; this is to give the delicate projections a better chance of withstanding the action of the molten metal when flowing over them. This part-drying is done just before the time for casting; the mould is then closed, the box clamped together and cast at once.

FIG. 11.

The temperature of the molten iron should be at the heat which will run the finest parts of the mould sharp. After casting some little time is allowed to elapse, after which the box is turned up on its side whilst remaining clamped together (Fig. 10). Then that part of the pattern plate which has the thickest portion on it is made bare by removing all sand with a scraper, and leaving all other portions of the plate covered with sand. All is left till the following morning to cool (Fig. 11). For this particular job eleven minutes is allowed from casting to baring.

A Few Hints on Camber.

In making a standard pattern and a working pattern, and a casting from the working pattern, it should be done by the same moulder, and as far as possible when the job is cast the metal should be of the same heat every time, or different results will be given.

When a pattern has been plated and it is ready to be put into service every moulder will not give the same results, because no man rams with the same pressure, and therefore more or less camber is needed.

The runners on thin section castings make a great difference respecting camber. A mantel leg run on the sides causes the leg to camber sideways. To overcome this, the standard pattern is run on one side and the plate casting on the opposite side, thus ensuring a straight leg.

THE INSTITUTE OF BRITISH FOUNDRYMEN.

LIST OF MEMBERS.

September, 1926.

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.
W.R. of Y.—West Riding of Yorkshire Branch.
W. & M.—Wales and Monmouth Branch.
S.—Sheffield Branch.
Sc.—Scottish Branch.

—General or unattached to a Branch.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1926.	Ackroyd, A. H., White Cottage, Park Road, Timperley.
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.	1918.	Allan, J. M., Cyclops Works, Sheffield.
B.	1906.	Allbut, J. E. H., "Woodcote," Bourne Street, Dudley, Staffs.
S.	1906.	Allen & Company, Edgar (Subscribing Firm), Imperial Steel Works, Sheffield.
E.M.	1924.	Allin, G. E., 21, Dairy House Road, Derby.
Sc.	1920.	Andrew, J. H., D.Sc., Royal Technical College, Glasgow.
Lncs.	1919.	Andrew, J. W., 964, Oldham Road, Thornham, Royton, Oldham.
N.	1925.	Appleyard, K. C., Birtley Springs House, Birtley, Co. Durham.
B.	1925.	Ardern, W. J. A., 23, St. Michaels Hill, Handsworth, Birmingham.

B'nch.	Year of Election.	MEMBERS.
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.
N.	1920.	Arrowsmith, J. K., 4, Dean Road, South Shields.
Lncs.	1924.	Arstall, J., "Kenmarlean," Back, Bowe, Hyde, Cheshire.
L.	1925.	Ashwell, E. C., "Kenwyn," Stafford Road, Waddon, Croydon.
B.	1924.	Aston, A., "Holly Bank," Sedgley Road, West Tipton, Staffs.
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.
N.	1918.	Aynsley, W. B., 62, Bath Lane, Newcastle-on-Tyne.
L.	1925.	Bagshawe, A. W. G., Kingsbury, Dunstable.
B.	1920.	Ball, F. A., c/o Ball Bros., Stratford-on-Avon.
Sc.	1923.	Ballantyne, H. D., 91, Drumover Drive, Parkhead, Glasgow.
M.	1926.	Barbour, A. R., Bon Lea House, Thornaby-on-Tees.
L.	1923.	Bargellesi, G., Casella Postale, 458, Milano.
B.	1922.	Barnsley, W. G., The Limes, Church Road, Netherton, nr. Dudley.
L.	1911.	Bartlett, A. R., 1, Lower Park Road, Belvedere, S.E.
L.	1923.	Bartram, J., 369, Grove Green Road, Leytonstone, E.11.
M.	1926.	Bashford, T. E., "Hillingdon," South Road, Norton-on-Tees.
E.M.	1921.	Bates, W. R., United Steel Companies, Limited, Irthlingboro' Iron Works, Wellingboro'.
—	1926.	Baxter, J. P., Morro Velho, E.F.C., Raposos Minas, Brazil, S. America.

B'nch.	Year of Election.	MEMBERS.
W. & M.	1922.	Bayley, J. P., "Ty-gwyn," Clytha Park, Newport, Mon.
L.	1920.	Beech, A. S., 97, Queen Victoria Street, London, E.C.
Sc.	1910.	Bell, W., 1, George Street, Airdrie.
—	1922.	Bell, Wm. Dixon, 72, Radstock Road, Itchen, Southampton.
L.	1919.	Benbow, M., "Ombersley," Carrington Road, Dartford, Kent.
Lncs.	1925.	Bennett, A., 112, Old Road, Flowery Field, Hyde, Cheshire.
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., 6, Cocklington Terrace, Hull Road, York.
Lncs.	1922.	Bentley, L. A., Wood End, Bromley Cross, Bolton.
B.	1924.	Bethell, R. P., 51, Sutton Road, Walsall, Staffs.
B.	1925.	Bettinson, C. L., Hall Green, Birmingham.
E.M.	1915.	Bigg, C. W., Someries, Darley Lane, Allestree, nr. Derby.
S.	1918.	Biggin, Frank, Rye Lodge, Ashland Road, Sheffield.
S.	1921.	Birchall, T., Latebrook House, Goldenhill, Stoke-on-Trent.
B.	1920.	Birkett, W., 11, Raleigh Road, Coventry.
N.	1921.	Birtley Iron Company (Subscribing Firm), Birtley, Co. Durham.
B.	1922.	Blackburn, W. A., "Wynsty," Lichfield Road, Rushall, Staffs.
—	1919.	Blair, A., 7, Derryvolgie Avenue, Belfast.
B.	1912.	Boote, E. M., 11, Lydgate Road, Coventry.
L.	1912.	Booth, C. C., Mildmay Works, Burnham-on-Crouch.

B'nch.	Year of Election.	MEMBERS.
E.M.	1919.	Booth, J. H., Fletton Spring House, Peterborough.
L.	1920.	Booth, P. M., 4, Erchingham 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.
S.	1921.	Breakey, J. E., Abbeydale Hall, Dore, nr. Sheffield.
L.	1926.	Brendle, T. F., Burma Railway Qtrs., Insein, Lower Burma.
Lncs.	1914.	Bridge, W., 199, Drake Street, Rochdale, Lancs.
S.	1922.	Brightside Foundry Engineering Co., Ltd. (Subscribing Firm), Wicker Works, 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., 12, Gladstone Road, Sheffield.
Lncs.	1924.	Bruce, A., "Rose Bank," Swanpool Lane, Aughton, Ormskirk, Lancs.
B.	1926.	Buchanan, G., "The Whim," Wilkinson Avenue, Bradley, Bilston.
—	1922.	Bull, R. A., 541, Diversey Parkway, Chicago, Ill., U.S.A.
L.	1924.	Bullers, W. J., 77, Coleraine Road, Blackheath, S.E.3.
Lncs.	1924.	Bullock, T. W., "Shirley," Warrington Road, Rainhill, Liverpool.
E.M.	1910.	Bunting, H., 17, Marcus Street, Derby.
E.M.	1905.	Burder, K. M., "Clavering," Ashby, Road, Loughboro'.

B'nch.	Year of Election.	MEMBERS.
B.	1922.	Burn, A. J. H., 34, Old Road, Llanelly, S. Wales.
W.R. of Y.	1922.	Burnley, H.,Norcroft Foundry, Lister Hills, Bradford, Yorks.
S.	1923.	Butler, J., 63, Deepdale Road, Rotherham.
Lncs.	1926.	Button, L. J., 294, Nantwich Road, Crewe.
—	1909.	Caddick, A. J., 83, Borough Road, Middlesbrough.
Lncs.	1926.	Cadman, E., 69, Manchester Road, Fairfield, Manchester.
Sc.	1917.	Cameron, J. (Cameron & Roberton, Linited), 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.	1911.	Campion, A. (Honorary Life), 3, Strathview Gardens, Bearsden, Glasgow.
S.	1923.	Cantrill, W. H.,249,Chatsworth Road, Chesterfield.
N.	1912.	Carmichael, J. D. (Life), 10, Sydenham Terrace, South Shields.
N.	1912.	Carmichael, J. D., Jun. (Life), 9, Belgrave Gardens, Harton, South Shields.
S.	1918.	Carnegie, W., Firs Hill House, Pitsmoor, Sheffield.
L.	1919.	Carpenter, H. C. H., Prof. (Hon.), 30, Murray Road, Wimbledon, S.W.19.
S.	1921.	Castle, Geo. Cryil, 141, Rustlings Road, Endcliffe, Sheffield.
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., 5, Duke Street, Adelphi, W.C.2.
L.	1925.	Chell, E., A.M.I.Mech.E., 68, Ferndene Road, London, S.E.24.

B'nch.	Year of Election.	MEMBERS.
—	1923.	Clamer, G. H., 129. So. Berkeley Square, Atlantic City, N.Y.
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.
M.	1926.	Clark, W. H., 90, Marton Burn Road, Middlesbrough.
L.	1917.	Cleaver, C., 10, Ringcroft Street, Holloway, N.1.
W. & M.	1917.	Clement, W. E., Morfa Foundry, New Dock, Llanelly.
L.	1913.	Coan, R., Aluminium Foundry, Goswell Road, E.C.
Sc.	1917.	Cockburn, N., 48, Murrayfield, Gardens, Edinburgh.
L.	1925.	Cockram, G. F., 54, Murray Road, Ipswich.
L.	1926.	Coggan, H. F., Saville Court, 49, Saville Park Road, Halifax.
N.	1926.	Colls, F. C., "Ashcroft," St. Mark's Avenue, Harrogate, York.
L.	1922.	Coll, J., Comandancia General de Ingenieros, Sevilla, Spain.
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.
N.	1921.	Cooke, W. W., 40, Sefton Avenue, Heaton, Newcastle-on-Tyne.
Lncs.	1911.	Cooper, C. D., Dolphin Foundry, Chapel Street, Ancoats, Manchester.
N.	1921.	Cooper, J. H., 5, Trinity Road, Darlington.

B'nch.	Year of Election.	MEMBERS.
L.	1919.	Corby, S. F. (R. B. Doulton, Ltd.), Lambeth Sanitary Engineering Works, Albert Embankment, London, S.E.1.
S.	1924.	Cottle, E. Hy., 58, Mount Street, Lincoln.
Lncs.	1924.	Cowlishaw, S. D., 7, Temple Street, Basford, Stoke-on-Trent.
L.	1925.	Cowper, L., 159, Eversleigh Road, Lavender Hill, S.W.11.
E.M.	1914.	Cox, J. E. (The Rutland Foundry Company, Limited), Ilkeston.
B.	1919.	Craig, A., Earlsdon House, Earlsdon, Coventry.
Lncs.	1924.	Craig, A., 20, Mottram Road, Stalybridge.
B.	1922.	Cramb, F. M., 5, Triangle Villas, Oldfield Park, Bath.
L.	1920.	Creek, W., 2, Eleanor Road, Stratford, E.
L.	1911.	Creighton, T. R., The Foundry, Stepney Causeway, E.
W.R. of Y.	1922.	Croft, Frank, 52, Pollard Lane, Bradford.
B.	1920.	Cross, John 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.
B.	1921.	Danks, A., "Northfield," Hucclecote, Gloucester.
N.	1925.	Darlington Railway Plant and Foundry Co., Ltd. (Subscribing Firm), Bank Top, Darlington.
—	1926.	Darnis, I. S., Rampas de Uribitarte 2–1, Bilbao, Spain.
Lncs.	1926.	Davenport, J., Myrtle Bank, Grimsargh, Preston.

B'nch.	Year of Election.	MEMBERS.
—	1919.	Davies, P. N., 29, Brunswick Road, Brunswick, Melbourne, Victoria, Australia.
L.	1923.	Dawes, C. E., 26, Keston Road, West Green, N.15.
Lncs.	1924.	Dawson, S. E., 8, Lynton Park Road, Cheadle, Hulme, Cheshire.
S.	1916.	Dawson, W. J., Hadfields, Ltd,, Newhall Road, Sheffield.
Lncs.	1924.	Deakin, F., 14, Belfield Road, Reddish, Stockport.
—	1925.	Dean, J. P., c/o Hoare & Co. (Engineers), Ltd., P.O. Box 22, Colombo, Ceylon.
M.	1919.	Deas, P., 4, Blenheim Terrace, Coatham, Redcar.
L.	1925.	Delport, V., 2–3, Caxton House, S.W.1.
B.	1924.	Denham, H., "Birchwood," Walsall Road, Aldridge, Staffs.
S.	1917.	Desch. C. H., Ph.D., D.Sc., F.I.C., The University, Sheffield.
L.	1926.	Dews, H. C. (Dewrance & Co.), 165, Great Dover Street, S.E.1.
B.	1921.	Dicken, Charles, H., 2, Ash Street, Daisy Bank, Bilston.
S.	1924.	Didden, F. G. J., Broad Elms Lane, 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.
S.	1921.	Duckenfield, W., 47, Dunkeld Road, Ecclesall, Sheffield.
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'nch	Year of Election.	MEMBERS.
B.	1922.	Edwards, A., "Dunbar," Old Bath Road, Cheltenham.
N.	1921.	Eldred, E. J., 8, Ford Street, Gateshead-on-Tyne.
L.	1909.	Elliot, A., Ingate Ironworks, Beccles.
L.	1904.	Ellis, J., 20, Lambourn 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., Lime Road, Falkirk.
L.	1919.	Estep, H. Cole, The Penton Publishing Co., Penton Building, Cleveland, Ohio, U.S.A.
L.	1926.	Evans, S., 60, Brian Road, Norbury, S.W.16.
E.M.	1918.	Evans, W. T., Mount Pleasant, Sunny Hill, Normanton.
S.	1920.	Fairholme, F. C., Churchdale Hall, nr. Bakewell, Derbyshire.
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.	1914.	Field, H., "Glenora," Richmond Avenue, Wolverhampton.
B.	1904.	Finch, F. W. (Honorary), 52, Denmark Road, Gloucester.
S.	1914.	Firth, A., junr., 50, Clarendon Road, Sheffield.
S.	1914.	Firth, F. W., "Storth Oaks," Ranmoor, Sheffield.
M.	1926.	Fisher, F. E., 2, Albert Terrace, Haverton Hill, Middlesbrough.
—	1907.	Flagg, S. G. (Honorary), 1,407, Morris Buildings, Philadelphia, Penn., U.S.A.

B'nch.	Year of Election.	MEMBERS.
B.	1923.	Flavel, P., Bushbury Lodge, Leamington.
B.	1922.	Fletcher, J. 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.
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., 147, Foleshill Road, Coventry.
W.R. of Y.	1925.	Frame, J. Y., 19, Sherburn Street, Hull.
L.	1920.	Frank, A. C., "Rozel," Knatchbull Road, Harlesden, N.W.
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 Cleuch, Pencisely Road, Cardiff.
N.	1912.	Gallon, M. E., c/o Younger & Gallon, Atlas Foundry, Dunston-on-Tyne.
N.	1921.	Gardiner, E. T., Hoppyland House, Albert Hill, Bishop Auckland.
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.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1922.	Garner & Sons, Limited (Subscribing Firm), Victoria Street, Openshaw, Manchester.
Lncs.	1922.	Garnett, N., Bury New Road, Kersal, Manchester.
Lncs.	1919.	Gartside, F., 18, George Street, Chadderton, Lancs.
L.	1922.	Gibbs, A. F., 55, Gordon Road, Wanstead, E.11.
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.
B.	1920.	Glover, S., Rookery Farm, Keresley, nr. Coventry.
S.	1905.	Goodwin, J. T., Red House, Old Whittington, Chesterfield.
N.	1922.	Gordon-Luhrs, Henry, 52, Moorside, Fenham, Newcastle-on-Tyne.
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., 113, Albert Avenue, Sedgley Park, Prestwich, Manchester.
L.	1926.	Grange, R., 40, Allcroft Road, Queen's Crescent, London, N.W.5.
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.

B'nch	Year of Election.	MEMBERS.
L.	1926.	Gray, T. H., Eastcote Lodge, Richmond Road, New Barnet.
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.
S.	1910.	Hadfield, Sir R. A. (Hon.), Hadfields, Limited, Hecla Works, Sheffield.
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., 31, Robin Hood Road, Brentwood, Essex.
N.	1922.	Hamilton, C. J., 30, Malvern Street, Newcastle-on-Tyne.
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.
S.	1925.	Hardwick, H., Cemetery Road, Dronfield, nr. Sheffield.
L.	1921.	Harford, A. E., Capt., 85, Sumatra Road, West Hampstead, N.W.6.
B.	1910.	Harley, A., Ashlea, Stoke Park, Coventry.
B.	1925.	Harper, W. E., Enville Road, Kinver, Staffs.
L.	1918.	Harris, A. J. A. (Capt.), 41, High Road, Balby, Doncaster, Yorks.

B'nch.	Year of Election.	MEMBERS.
M.	1926.	Harrod, H., 15, Egglestone Terrace, Stockton-on-Tees.
Lncs.	1918.	Hartley, Wm. Alexr., Stonebridge Foundry Company, Limited, Colne.
—	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.
Lncs.	1925.	Heatley, J., 146, Redlam, Blackburn.
Lncs.	1918.	Helm, R. W., c/o Francis Helm, Ltd.. Victoria Foundry, Padiham, Lancs.
—	1926.	Henderson, P.C., M.P., The Right Hon. Arthur (Honorary), 33, Eccleston Square, London, S.W.1.
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. J., 23, Muriel Street, Rochdale.
Sc.	1917.	Hetherington, R., 105, West George Street, Glasgow.
B.	1926.	Hicatt, H. J., South Bank, Brierley Hill, Staffs.
L.	1926.	Hider, G. E., Lauriston Villas, 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.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1914.	Hodgson, A., 14, Park Range, Victoria Park, Manchester.
N.	1922.	Hodgson, G. W., 2, Beechwood Terrace, Sunderland.
Lncs.	1912.	Hogg, J., 321, Manchester Road, Burnley, Lancs.
B.	1924.	Homer, W. A., "Douville," Lechfield, Rushall, Staffs.
N.	1919.	Holmes, C. W. H., M.Met., c/o Birtley Iron Co., Birtley, Co. Durham.
Sc.	1914.	Hood, John McLay (Life), 54, Maxwell Drive, Pollokshields, Glasgow.
Lncs.	1919.	Horrocks, B., 1, Jersey Street, Ashton-under-Lyne.
L.	1920.	Housby, I., 369, Norwich Road, Ipswich.
Lncs.	1922.	Howard & Bullough, Ltd. (Subscribing Firm), Accrington, Lancs.
L.	1924.	Hunt, N. H., 15, Wantz Road, Maldon, Essex.
L.	1920.	Hunt, R. J., "Greenhills," Earls Colne, Essex.
N.	1920.	Hunter, Hy., 1, Manor Terrace, Tynemouth.
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.
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.
S.	1922.	Hyde, Robert & Son, Ltd. (Subscribing Firm), Abbeydale Foundry, Woodseats, Sheffield.
Sc.	1925.	Hyman, H., Ph.D., 55, Dixon Avenue, Crosshill, Glasgow.

B'nch.	Year of Election.	MEMBERS.
S.	1915.	Jackson, L., 2, Richmond Avenue, Park Lane, Sheffield.
L.	1925.	Jadoul, J. E., 28, Daisy Bank Road, Longsight, Manchester.
L.	1925.	James, A. W., 1, Broomhill Road, Ipswich.
L.	1911.	Jarmy, J. R., "Ajaccio," Abbey Road, Leiston, Suffolk.
W. & M.	1924.	Jenkins, T., 51, Tydvil Street, Barry.
S.	1917.	Jenkinson, S. D., Cromwell House, Wincobank, Sheffield.
L.	1904.	Jewson, H., 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.
Lncs.	1922.	Jones, G. A., 54, Fox Street, Edgeley, Stockport.
B.	1925.	Jones, O. P., 25, Rathbone Road, Bearwood, Birmingham.
S.	1921.	Kayser, J. F., 30, Oakhill Road, Nether Edge, Sheffield.
Lncs.	1925.	Kelly, A. F., 31, Windbourne Road, St. Michaels, Liverpool, S.
L.	1917.	Kelly, Jas., 74, Rotherfield Street, N.1.
Lncs.	1922.	Kent, C. W., 16, Beech Grove, Withington, Manchester.
Lncs.	1919.	Kenyon, H. W., Lime Mount, Whalley Road, Accrington.
Lncs.	1910.	Kenyon, M. S., Waterloo, Whalley Road, Accrington.
Lncs.	1904.	Kenyon, R. W.. Entwistle & Kenyon, Limited, Accrington.
Lncs.	1907.	Key, A. L., 271, Reddish Road, S. Reddish, Stockport.
Sc.	1914.	King, D., Keppock Ironworks, Possil Park, Glasgow.

B'nch	Year of Election.	MEMBERS.
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.
M.	1926.	Kinnell & Co., Ltd., Chas. P. (Subscribing Firm), Vulcan Iron Works, Thornaby-on-Tees.
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, J. Stone & Co., Limited, Deptford, S.E.14.
Sc.	1907.	Landale, D. (Life), 36, Great King Street, Edinburgh.
B.	1919.	Lane, F. H. N., 46, Holyhead Road, Coventry.
—	1922.	Lane, H. M., 333, State Street, Detroit, Michigan, U.S.A.
W. & M.	1925.	Lawrence, Edward, 39, Pen-y-dre, Rhiwbina, nr. Cardiff.
L.	1921.	Lawrence, Geo. D., Donnington, Bushwood, Leytonstone, E.11.
Lncs.	1918.	Layfield, R. P., 42, Marsden Road, Burnley.
B.	1909.	Lee, Howl & Company, Engineers, Tipton.
S.	1920.	Leetch, S., 126, Pitt Street, Rotherham.
—	1922.	Lennox, D. Wm., The High House, Ladye's Hill, Kenilworth.
—	1922.	Leonard, J. (Hon.), 51, Quai du Canal, Herstal, Belgium.
Lncs.	1922.	Lewis, A. H., 6, Coverdale Avenue, Heaton, Bolton.
W. & M.	1924.	Lewis, B. E., 6, Ty Gwyn Road, Pontypridd.
W.R. of Y.	1922.	Liardet, A. A., Leyland Motors, Ltd., Leyland, Lancs.
N.	1920.	Lillie, G., "Bloomfield," Strathmore Road, Rowlands Gill, Durham.

B'nch.	Year of Election.	MEMBERS.
S.	1913.	Little, J., 20, St. Ann's Square, Manchester.
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.
S.	1904.	Longmuir, P., D.Met., 2, Queens Road, Sheffield.
Lncs.	1913.	Longworth, T. P., Moorside, Horrocks Fold, Bolton.
W.R. of Y.	1910.	Love, A., 232, Gladstone Street, Bradford, Yorks.
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.	1922.	Macaulay, J. M., B.Sc., A.M.I.M.E., 52, Abbey Drive, Gordon Hill, Glasgow.
Lncs.	1924.	MacKay, M., 191, Edmund Street, Rochdale.
Sc.	1914.	MacKenzie, Alex. D., 35, Braid Road, Edinburgh.
Sc.	1910.	Mackenzie, L. P., 5, Polwarth Terrace, Balcarres Street, Edinburgh.
N.	1923.	Mackley, J. R., "Meadowcroft," Stocksfield-on-Tyne.
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.
B.	1924.	Marks, A., F.I.C., A.M.I.Mech.E., A.R.S.M., 78, Himley Road, Dudley, Worcs.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1922.	Marsden & Son, J. (Subscribing Firm),188,Regent Road,Liverpool.
S.	1922.	Marshall, J., "The Willows," Barrow Hill, Chesterfield.
L.	1922.	Martin, M. J., 200, Park Road, Crouch End, N.
L.	1924.	Mason, W. C., Richardson & Cruddas, Byculla Iron Works, Bombay, India.
S.	1915.	Mather, T., 149, Carholme Road, Lincoln.
N.	1912.	Mathews, W., 4, Burnside, Willington Quay-on-Tyne.
L.	1923.	Maybrey, H. J., B.A., D.I.C., 22a, Gloucester Road, South Kensington, S.W.7.
Sc.	1925.	McArthur, J., "Hawthorn," Shields Road, Motherwell.
W. & M.	1922.	McClelland, J. J., "Druslyn," Bishops Road, Whitchurch, Glam.
L.	1922.	McConnell, S. J., 44, Blythe Vale, Catford, S.E.6.
N.	1922.	McCrory, C., 5, Station Road, Wallsend-on-Tyne.
N.	1924.	McDonald, J., The Villa, Willington Quay-on-Tyne.
Sc.	1919.	McFedries, T., 17, Kirktonholm Street, Kilmarnock.
S.	1916.	McGrah, F. E., "Rosegarth," Woodfield Avenue, Penn, Wolverhampton.
L.	1919.	McIntosh, A. E., Engineers' Club, Coventry Street, London, W.
Sc.	1922.	McKinnon, Gavin, 1477, Dumbarton Road, Scotstoun, Glasgow.
Sc.	1923.	McKinty, J., 229, 82nd Street, Brooklyn, N.Y., U.S.A.
Lncs.	1921.	McLachlan, Jas., 2, Broadoaks Road, Washway Road, Sale, nr. Manchester.
—	1922.	McLain, D. (Hon.), 710, Goldsmith's Buildings, Milwaukee, Wis., U.S.A.
Lncs.	1923.	McLean, C. G., 14, Jemmett Street, Preston.

B'nch.	Year of Election.	MEMBERS.
N.	1918.	McPherson, T., M.B.E., 21, Percy Park Road, Tynemouth.
Sc.	1918.	McTurk, J. B., Dorrator Iron Company, Falkirk.
Lncs.	1917.	Meadowcroft, Wm. H., 10, Hambledon View, Habergham, Burnley.
Lncs.	1919.	Medcalf, W., 265, Manchester Road, Burnley, Lancs.
S.	1922.	Melmoth, F. A., "The Chalet," Ivy Park Road, Sandygate, Sheffield.
L.	1920.	Melville, A. C., F.I.C.
Lncs.	1912.	Milburn, J., Hawkshead Engineering Works, Workington.
—	1919.	Miles, F. W.
S.	1921.	Miles, R. (Major), Chapeltown, nr. Sheffield.
Lncs.	1916.	Miles, Rd. A., 46, Dean Lane, Newton Heath, Manchester.
Lncs.	1918.	Mills, Hilton, 9, Stocks, Alkrington, Middleton, Lancs.
—	1924.	Mills, R. C., 90, Kelsey Street, Waterbury, Conn., U.S.A.
—	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.
—	1910.	Moldenke, Dr. R. (Hon. Member), Watchung, New York.
L.	1925.	Moore, A. H., Standard Brass Foundry, Benoni, S. Africa.
E.M.	1914.	Moore, H. H., Holmwood, Leicester Road, Loughborough.
L.	1926.	Moorwood, H. S., Onslow House, Sheffield.
N.	1912.	Morris, A., Pallion Foundry, Sunderland.
B.	1925.	Morris, D., Queen's Road, Tipton, Staffs.
L.	1925.	Mundey, A. H., 14, Wrottesley Road, Woolwich, S.E.18.
B.	1926.	Murray, J. V., 80, Manor House Road, Wednesbury.

B'nch.	Year of Election.	MEMBERS.
S.	1925.	Nelson, C., 93, Hawksley Avenue, Hillsbro', Sheffield.
S.	1918.	Newell, Ernest, M.I.Mech.E., The Thorne, Misterton, *via* Doncaster.
N.	1912.	Newton, J. W., Flora House, Cobden Street, Darlington.
Lncs.	1920.	Newton, Sam, Linotype & Machinery Ltd., Altrincham.
L.	1924.	Nikaido, Y. (Lieut.-Com.), Hiro Naval Works, Kure, Japan.
N.	1913.	Noble, H., "The Cedars," Low Fell, Co. Durham.
Lncs.	1924.	Noor, Mohamed S., 1, Zaki Pacha Buildings, Gheit El Edda, Abdin, Cairo, Egypt.
L.	1913.	Norman, A. J., 43, Dunvegan Road, Eltham, S.E.
S.	1923.	North, The Hon., J. M. W., "Lindenhurst," Chesterfield.
N.	1921.	North-Eastern Marine Engineering Company Ltd. (Subscribing Firm), Wallsend-on-Tyne.
Lncs.	1918.	Oakden, E., A.M.I.C.E., Further Hey, Woodley, nr. Stockport.
B.	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., "Lomond," 66, Westmoreland Road, Bromley, Kent.
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.

Bnc'h.	Year of Election.	MEMBERS.
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., 22, Clay Pits Lane, Pellon, Halifax.
E.M.	1905.	Parker, W. B., 1, 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.
N.	1912.	Patterson, R. O., Thorneyholme, Wylam-on-Tyne.
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., Central House, 75, New Street, Birmingham.
E.M.	1913.	Pearson, N. G. (Lieut-Col.), Beeston Foundry Company, Limited, Beeston, Notts.
E.M.	1914.	Pegg, S. J., Alexander Street, Leicester.
Lncs.	1909.	Pell, J., 17, Mersey Street, Rosegrove, Burnley, Lancs.
Lncs.	1922.	Pellatt, D. L., 43, Hawthorn Road, Deane, Bolton.
M.	1926.	Pennington, D. G., Lea Close, Middleton St. George, Co. Durham.
E.M.	1918.	Perkins, J. E. S., "Hillmorton," The Park, Peterborough.

B'nch	Year of Election.	MEMBERS.
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.
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.
W.R. of Y.	1922.	Poole, W. H., Kings Grove, Villa Road, Bingley, Bradford.
S.	1923.	Porter, H. W., c/o F. Haseldine, Broadwood, Beeston, Notts.
B.	1919.	Pott, L. C., The Hardware Mfg. Co., Highbury Lane, Cheltenham.
E.M.	1924.	Potter, W. C., "Kenwalyn," Sykefield Avenue, Leicester.
S.	1908.	Prestwich, W. C., Charnwood, Cecil Road, Dronfield, Sheffield.
Sc.	1920.	Primrose, James M., Mansion House Road, Falkirk.
B.	1924.	Pritchard, P., "Eastcote," St. Agnes Road, Moseley, Birmingham.
E.M.	1904.	Pulsford, F. C., "Kenmore," Sandown Road, Leicester.
—	1922.	Ramas, E. (Honorary), 2, Rue de Constantinople Place de l'Europe, Paris.
N.	1912.	Rang, H. A. J., 2, St. Nicholas Buildings, Newcastle-on-Tyne.

B'nch	Year of Election.	MEMBERS.
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.
B.	1909.	Reason, H. L., M.I.Mech.E., M.I.M., 29, Hallewell Road, Edgbaston, Birmingham.
Sc.	1920.	Rennie, A., "Kilnside," Falkirk.
Lncs.	1919.	Rhead, E. L., Prof. (Honorary), College of Technology, Manchester.
S.	1923.	Rhydderch, A., 165, Shirebrook Road, Sheffield.
W. & M.	1925.	Richards, C. E., 53, Merches Gardens, Grange, Cardiff.
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.
B.	1923.	Roberts, E., 39, Radford Lane, 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., Garrison Chambers, Falkirk.
Sc.	1911.	Robertson, R., Etna Ironworks, Falkirk.
W.R. of Y.	1908.	Robinson, J. G., 17, Gibraltar Road, Halifax.
Lncs.	1912.	Roe, S., 6, Grantham Street, Oldham.
—	1909.	Ronceray, E. (Hon.), 3, Rue Paul Carle, Choisy-le-Roi, Seine, Paris, France.
—	1925.	Ropsy, P. A., 27, Rue Dodoens, Antwerp, Belgium.
—	1923.	Roxburgh, W., 271, Clifton Road, Rugby.

B'nch.	Year of Election.	MEMBERS.
S.	1918.	Russell, F., c/o General Refractories Company, Limited, Kelham Island, Sheffield.
E.M.	1924.	Russell, P. A., 88, Dulverton Road, Leicester.
E.M.	1906.	Russell, S. H., Bath Lane, Leicester.
N.	1915.	Sanderson, F. (Lawson, Walton & Company, Ltd.), 2, St. Nicholas Buildings, Newcastle-on-Tyne.
S.	1921.	Sandford, J., 46, Clifford Road, Sheffield.
N.	1915.	Saunders, J., Borough Road Foundry, Sunderland.
B.	1921.	Scampton, Chas., South Avenue, Stoke Park, Coventry.
B.	1910.	Sexton, A. Humbolt (Hon. Life), 6, Clarendon Road, St. Helier, Jersey, C.I.
L.	1922.	Shannon, H., 112, Madrid Road, Barnes, S.W.
Sc.	1920.	Sharpe, Daniel, 100, Wellington St., Glasgow.
S.	1906.	Shaw, J., 39, Montgomery Road, Sheffield.
L.	1907.	Shaw, R. J., 41, Dorset Road, South Ealing, W.5.
M.	1922.	Shaw, W. (Subscribing Firm), Wellington Cast Steel Foundry, Middlesbrough.
S.	1908.	Sheepbridge C. & I. Company, Limited (Subscribing Firm), Sheepbridge Works, Chesterfield.
B.	1922.	Shenai, S. D., East Road, T.D. Temple, Cochin, E. India.
Lncs.	1907.	Sherburn, H. (Life), c/o Richmond Gas Stove and Meter Company, Limited, Grappenhall Works, Warrington.
Lncs.	1905.	Sherburn, W. H. (Life), Rotherwood, Stockton Heath, Warrington.
L.	1913.	Shillitoe, H., "Westwood," Potter's Bar, N.

B'nch.	Year of Election.	MEMBERS.
N.	1920.	Shipley, H. J., 49, Theresa Street, Blaydon-on-Tyne.
W.R. of Y.	1922.	Shoesmith, N., 8, Noster Hill, Beeston, Leeds.
Lncs.	1907.	Simkiss, J., Abington House, Hyde Road, Gorton, Manchester.
N.	1913.	Simm, J. N., 61, Marine Avenue, Monkseaton.
Lncs.	1924.	Simpson, H., 99, Peel Street, Rochdale.
S.	1926.	Singleton, T., 2, Warwick Street, Sheffield.
Sc.	1926.	Skinner, F. J., Lockend House, Maryhill, Glasgow.
W.R. of Y.	1921.	Slingsby, W., Highfield Villa, Keighley.
L.	1925.	Small, F. G., "Meliden," Burdon Lane, Cheam.
N.	1921.	Smalley, O., Park Villa, Thrybergh, Rotherham.
S.	1922.	Smith, A., "Oakroyd," Dodworth Road, Barnsley.
S.	1922.	Smith, A. Qualter, 118, Dodworth Road, Barnsley.
B.	1925.	Smith, B. W., 104, Sutton Road, Erdington, Birmingham.
N.	1908.	Smith, E., Belle Vue, Harton, South Shields.
S.	1921.	Smith, Fredk., Devonshire Villas, Barrow Hill, nr. Chesterfield.
E.M.	1921.	Smith, George, Cavendish Place, Beeston, Notts.
N.	1905.	Smith, J., "Harton Lea," Harton, South Shields.
M.	1926.	Smith, J. D., 19, Shaftesbury Street, Stockton-on-Tees.
N.	1917.	Smith, J. E., 7, Lily Avenue, Jesmond, Newcastle.
M.	1926.	Smith, J. L., "Holmesdale," Billingham, nr. Stockton-on-Tees.
W.R. of Y.	1922.	Smith, J. W., 96, Beech Grove, Clayton Road, Bradford.

B'nch.	Year of Election.	MEMBERS.
N.	1922.	Smith Patterson & Company, Limited (Subscribing Firm), Pioneer Works, Blaydon-on-Tyne.
N.	1913.	Smith, R. H., 16, Dulverton Avenue, South Shields.
N.	1919.	Smith, S. E., Woodside, Rowlands Gill, Newcastle-on-Tyne.
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.
S.	1925.	Spafford, Arnold V., Imperial Works, Brown Street, Sheffield.
E.M.	1914.	Spiers, T. A., "Belah," Marston Road, Leicester.
—	1921.	Standard Motor Company, Limited (Subscribing Firm), Canley, Coventry.
Lncs.	1922.	Staveley Coal & Iron Company (Subscribing Firm), Staveley Works, nr. Chesterfield.
—	1910.	Stead, J. E. (Hon. member).
Sc.	1920.	Steven, A. W., Lauriston Ironworks, Falkirk.
E.M.	1914.	Stevenson, E., "Charnwood," Albert Avenue, Carlton Hill, Nottingham.
N.	1912.	Stobie, V., Oakfield, Ryton-on-Tyne.
L.	1912.	Stone, J., 106, Harlaxton Road, Grantham.
—	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, O. (Hon. Life), (J. Stubbs, Limited), Openshaw, Manchester.
Lncs.	1919.	Stubbs, R. W., 209, Dickenson Road, Longsight, Manchester.

B'nch.	Year of Election.	MEMBERS.
W.R. of Y.	1922.	Summerscales, W. H. G., Rockfield, Keighley.
W.R. of Y.	1919.	Summersgill, H., Stanacre Foundry, Wapping Road, Bradford.
Lncs.	1926.	Sutherst, R., 8, Raven Street, Bury.
—	1926.	Swaine, G., 50, Lower Circular Road, Calcutta.
S.	1918.	Swift, L. J., "The Farm," Hunter's Lane, Handsworth, Sheffield.
S.	1908.	Swinden, T., D.Met., 26, Oakhill Road, Nether Edge, Sheffield.
W.R. of Y.	1912.	Sykes, J. W., Birdacre House, Gomersall, Leeds.
B.	1925.	Tarrant, W. J., Eiffeldale, Longfleet, Poole, Dorset.
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.
N.	1923.	Thomson, A., Percy House, Percy Park Road, Tynemouth.
W.R. of Y.	1922.	Thornton, W. G., 1,081, Grangefield Avenue, Thornbury, Bradford.
L.	1924.	Thornycroft and Co., Ltd., John I. (Subscribing Firm) (T.Donaldson), Iron Foundry, Woolston Works, Southampton.
M.	1926.	Thorpe, S. P., 14, Park Terrace, Stockton-on-Tees.
L.	1925.	Tibbenham, L. J., The Limes, Stowmarket.
M.	1926.	Todd, H., 26, Rockliffe Road, Linthorpe, Middlesbrough.

B'nch.	Year of Election.	MEMBERS.
—	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.
M.	1924.	Toy, S. V., The Ridge, Saltburn-by-the-Sea.
L.	1922.	Tremayne, Chas., 26, Eversley Road, Charlton, S.E.7.
Sc.	1922.	Tullis, D. R., 10, Eglinton Drive, Kelvinside, Glasgow.
L.	1926.	Turner, A. C., 10, Holmdene Avenue, Dulwich, S.E.24.
B.	1910.	Turner, Prof. T. (Hon. Member), The University, 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., 406, Rotton Park Road, Birmingham.
S.	1916.	Underwood, G. H., Pye Bridge House, Pye Bridge, Alfreton, Derbyshire.
Sc.	1913.	Ure, G. A., Bonnybridge, Scotland.
—	1922.	Varlet, J. (Hon.), Esperance Longdoz Works, Liège, Belgium.
S.	1924.	Varma, J. P., 44, Grange 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.
Lncs.	1924.	Wainwright, T. G., The Mount, 195, Huddersfield Road, Stalybridge.
S.	1907.	Walker, E., Effingham Mills, Rotherham.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1924.	Walker, J. S. A., Major, Walker Bros., Ltd., Wigan.
M.	1926.	Walker, T., 22, Vansittart Terrace, Redcar, Yorks.
S.	1918.	Walker, T. R., 42, Firth Park Crescent, Sheffield.
N.	1921.	Wallsend Slipway & Engineering Co., Ltd. (Subscribing Firm), Wallsend-on-Tyne.
—	1922.	Walters, A. F. (H. I. Dixon & Company, Limited), The Omiar Founding Eng. Company, Limited, Love Lane, Mazagon, Bombay, India.
S.	1908.	Ward, A. J. (T. W. Ward, Limited), Albion Works, Saville Street, Sheffield.
S.	1914.	Ward, J. C., Oak Park, Manchester Road, Sheffield.
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., 3, Springdale Avenue, Huddersfield.
B.	1917.	Webb, B., 531, Stourbridge Road, Scott Green, Dudley.
L.	1925.	Webster, F. K., 6, Halesworth Road, Lewisham, London, S.E.13.
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., 16, Leonard Place, Bingley, Yorks.
S.	1910.	Wells, G. E. (Edgar Allen & Co., Limited), Imperial Steel Works, Sheffield.
S.	1914.	Wells, J. A. E., Moorlands, Ringinglow Road, Sheffield.
Lncs.	1926.	West, Walter, 12, The Crescent, Leyland, Lancs.

B'nch.	Year of Election.	MEMBERS.
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.
Sc.	1919.	Williams, H., c/o J. Cochrane, Ltd., Barrhead.
W. & M.	1924.	Williams, R. G., 179, Crogan Hill, Barry Dock.
W. & M.	1916.	Williams, W., Alexandra Brass Foundry, East Dock, Cardiff.
N.	1913.	Willott, F. J., 17, Park Road, Clydach-on-Tawe, Swansea Valley.
S.	1926.	Wilson, C., 93, Hawkesley Avenue, Sheffield.
M.	1912.	Wilson, F. P., "Parkhurst," Middlesbrough.
N.	1922.	Wilson, R. R., "Canonbury," Rowlands Gill, nr. Newcastle-on-Tyne.
Sc.	1906.	Winterton, H., "Moorlands," Milngavie, Dumbartonshire.
W.R. of Y.	1912.	Wise, S. W., 110, Pullan Avenue, Eccleshill, Bradford, Yorks.
B.	1925.	Wiseman, Alfred, Ltd. (Subscribing Firm), Glover Street, Birmingham.
B.	1919.	Wood, D. Howard (Capt.), 7, Augusta Road, Moseley, Birmingham.
N.	1922.	Wood, E., B.Sc., "Overtoun," 20, Beverley Road, Monkseaton.

B'nch.	Year of Election.	MEMBERS.
B.	1909.	Wood, E. J. (Patent Axlebox and Foundry Company, Limited), Wednesfield Foundry, Wolverhampton.
Lncs.		Woodcock, A., 163, Hartington Street, Moss Side, Manchester.
B.	1923.	Woodvine, G. R., "The Firs," Bowbridge, Shrewsbury.
B.	1914.	Wright, E. N. (Life), Oxford Lodge, Penn Fields, Wolverhampton.
Sc.	1919.	Wyllie, W., 66, Titchfield Street, Kilmarnock, Ayr.
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., "Abbotsford," 28, Cole Park Road, Twickenham, Middlesex.

ASSOCIATE MEMBERS.

B'nch.	Year of Election.	
M.	1926.	Adcock, F. H., 7, Beech Grove, Middlesbrough.
Sc.	1919.	Affleck, J., 21, Overdale Avenue, Langside, Glasgow.
B.	1915.	Aldridge, S., 91, Dale Street, Walsall,
B.	1925.	Allen, Wm., Chuckery Foundry, Walsall, Staffs.
Sc.	1926.	Anderson, J. Y., 33, Alice Street, Paisley.
Lncs.	1907.	Andrew, F., 120, Gas Street, Failsworth, Manchester.
Lncs.	1925.	Anson, A., 60, South Royd Street, Tottington, Bury.
L.	1925.	Armishaw, W. J., 44, Cannon View, Letchworth, Herts.
M.	1926.	Armstrong, G., 23, Chipchase Street, Middlesbrough.
L.	1925.	Armstrong, L. R., 39, Lessinden Mansions, N.W.5.
Sc.	1920.	Arnott, J., A.I.C., G. & J. Weir, Ltd., Cathcart, Glasgow.
B.	1919.	Ashmore, H., 26, Ellys Road, Coventry.
Lncs.	1916.	Ashton, F., 24, Isherwood Street, Heywood, Lancs.
Lncs.	1918.	Ashton, L., 59, Seymour Street, Radcliffe, Lancs.
Lncs.	1923.	Astall D., 380, Oldham Road, Limehurst, Ashton-under-Lyne.
L.	1905.	Aston, D. A., 36, Bastwick Street, St. Luke's, London, E.C.
Lncs.	1922.	Atkinson, Albert, 1, Guy Street, Padiham, Burnley.
S.	1920.	Atkinson, A. A., 24, Wath Road, Nether Edge, Sheffield.
S.	1916.	Atkinson, F., "Woodlands," Richmond Road, Handsworth, Sheffield.
N.	1925.	Atkinson, G., 10, Queen's Drive, Whitley Bay.
E.M.	1923.	Austin, J. T., 24, Danvers Road, Leicester.
S.	1920.	Avill, Wm., 44, Albion Road, Rotherham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
B.	1918.	Baker, W., 24, Church Hill Road, Stockwell End, Tettenhall, Wolverhampton.
N.	1925.	Balderston, R. A., 21, Wentworth Place, Newcastle-on-Tyne.
M.	1926.	Barclay, D., 45, Edward Street, Stockton-on-Tees.
S.	1922.	Barker, A. G., 28, Victoria Road, Balby, Doncaster.
B.	1919.	Barker, S. B., 34, Darby Road, Coalbrookdale, Salop.
S.	1924.	Barker, W., 136, Nidd Road, Attercliffe, Sheffield.
N.	1922.	Barkes, R. P., 23, Thomas Street, E.E. Sunderland.
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.
Lncs.	1924.	Barrett, S., 150, Chorley New Road, Horwich, nr. Bolton.
E.M.	1916.	Barringer, E. A., 80, Lambert Road, Narborough Road, Leicester.
L.	1911.	Batch, J., 60, Robertson Street, Queen Street, Battersea, S.W.
B.	1920.	Bates, J. E., 79, Ransome Road, Coventry.
E.M.	1921.	Bates, Thos. Wm., 25, Marcus Street, Derby.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1904.	Bather, H. K. (Chamberlain & Hill), Chuckery Foundry, Walsall.
S.	1920.	Batty, F., 52, Hampton Road, Pitsmoor, Sheffield.
E.M.	1926.	Baxter, J., 4, Pittar Street, Derby.
L.	1921.	Baxter, Percy L., 131, Ampthill Avenue, Benoni, Transvaal, S. Africa.
—	1911.	Bayles, R. (Douglas & Grant, Limited), Raith Engineering Works, Dunneedaw, Rangoon, Burma.
N.	1923.	Bean, A. S., Beresford Park, Sunderland.
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., 131, Upper Dale Road, Derby.
Lncs.	1925.	Becker, M. L., 15, Upper Lloyd Street, Manchester.
S.	1920.	Beeley, W. H., Clarence Lane Works, off Eccleshall Road, Sheffield.
B.	1924.	Beeny, H. H., 57, Bramble Street, Coventry.
Sc.	1917.	Bell, J., 60, St. Enoch Square, Glasgow.
N.	1925.	Bell, J., 65, Park Avenue, Whitley Bay, Northumberland.
L.	1923.	Bell, John, B.Sc., Admiralty Research Laboratory, Teddington, Middlesex.
Sc.	1910.	Bell, T., 2, Bellfield Street, Barrhead, Glasgow.
S.	1918.	Bennett, A. M., 12, Brandon Grove, Newton Park, Leeds.
W.R. of Y.	1912.	Berry, F., 125, Watkinson Road, Illingworth, Halifax.
Lncs.	1917.	Berry, R. I., 31, Bury Road, Bamford, Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1926.	Bettinson, J. S., Cole Bank, Hall Green, Birmingham.
Sc.	1920.	Binnie, Alex., 15, Cochrane Buildings, Pleasance Square, Falkirk.
N .	1919.	Binns, A. E., 534, Shields Road, Newcastle-on-Tyne.
B.	1916.	Birch, H., Inglewood, Chester Road, Streetley, Birmingham.
B.	1922.	Bird, J. B., Plas-Newydd, Streetley, nr. Birmingham.
Sc.	1919.	Black, A., 10, Prince Edward Street, Crosshill, Glasgow.
E.M.	1921.	Blackham, E. L., 44, May Street, Derby.
E.M.	1920.	Blackwell, Wm., 36, Arthur Street, Loughborough.
Sc.	1910.	Blackwood, R., "Kenilworth," Johnstone, Glasgow.
L.	1920.	Blackwood, R. W., "Rothesay," The Avenue, Erith.
E.M.	1919.	Blades C., The Vines, Wanlip Road, Syston, Leicester.
W.R. of Y.	1926.	Blair, J. W., 13, Milton Street, Hull Road, York.
W.R. of Y.	1922.	Blakey, Wm., 15, Kirkburn Place, St. Margaret's Road, Bradford.
N.	1920.	Blenkinsop, S. D., Hillcroft, High Fell, Gateshead-on-Tyne.
E.M.	1924.	Bloor, F. A., "Inglemere," Stenson Road, Derby.
N.	1919.	Blythe, J. D., 81, Northumberland Terrace, Willington-on-Tyne.
B.	1925.	Bode, C., 14, Farm Road, Sparkbrook, Birmingham.
S.	1915.	Booker, H. H., 153, Albert Road, Heeley, Sheffield.
W.R. of Y.	1922.	Booth, G. E., 80, Institute Road, Eccleshill, Bradford, Yorks.
Lncs.	1924.	Booth, S., 31, Birchenlea Road, Hollinwood, nr. Oldham.
N.	1915.	Borthwick, T., Crookhall House, Leadgate, Co. Durham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1920.	Bound, W. H., Wh. Ex. A.M.I. Mech.E., 12, Dufton Road, Linthorpe, Middlesbrough.
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, Littlemore Crescent, Newbold, Chesterfield.
S.	1916.	Bradley, H., "Cotswald," Bocking Lane, Woodseats, Sheffield.
N.	1918.	Bradley, J. H., 7, Crawley Road, Wallsend-on-Tyne.
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.	1921.	Brassington, H., 16, East Street, Hollinwood Park, Stockport.
Lncs.	1923.	Brereton, C. F., c/o Mrs. Oldham, 25, Manchester Road, Chorlton-cum-Hardy, Manchester.
Lncs.	1917.	Brierley, A., 21, Milnrow Road; Rochdale.
Lncs.	1923.	Brockbank, A. H., 3, Hawkens Street, Old Trafford, Manchester.
L.	1917.	Brookfield, D., 285, Camden Road, Holloway, N.7.
Lncs.	1925.	Broughton, H., 5, New York, 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., 95, Derbyshire Lane, Stretford, Manchester.
Lncs.	1917.	Brown, J., 298, Milnrow Road, Rochdale.
S.	1909.	Brown, T. W., 9, Coupe Road, Burngreave, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1914.	Bruce, A., 52, Ashley Terrace, Edinburgh.
Sc.	1926.	Bruce, W. T., 52, Ashley Terrace, Edinburgh.
N.	1920.	Buckham, G. H.. "Harewood," Grange Road, Newcastle-on-Tyne.
L.	1926.	Buckingham, F. A. T., 114, Richmond Road, Gillingham, Kent.
Lncs.	1915.	Bulcock, A., 397, Gorton Road, Reddish, Stockport.
W.R. of Y.	1922.	Bullock, Herbert.
B.	1925.	Bullows, W. D., Stillaig, Streetley, Warwickshire.
N.	1920.	Burcham, J., 35, Alverthorpe Street, South Shields.
S.	1924.	Burkinshaw, J. W., 13, Laverack Street, Handsworth, Sheffield.
N.	1925.	Burn, R. D., B.Sc., A.I.C., "Oslo," Irwin Avenue, Wallsend-on-Tyne.
L.	1922.	Burningham, E. F., 1, Cambridge Road, Sidcup, Kent.
Sc.	1917.	Burns, J. K., 77, Sandy Road, Renfrew.
N.	1925.	Burrell, J., 2, Bede Crescent, Willington-on-Tyne.
W.R. of Y.	1921.	Butterfield, P., 10, Eastfield Place, Sutton-in-Craven, Keighley, Yorks,
Lncs.	1923.	Butterworth, A. W., 214, Frederick Street, Werneth, Oldham.
Lncs.	1919.	Butterworth, J., 40, Clement's Royds Street, Rochdale.
W.R. of Y.	1921.	Butterworth, John, 19, Neville Street, Clare Mount, Halifax.
Lncs.	1920.	Buxten, J., 68, Luke Lane, Hurst, Ashton-u.-Lyne.
Lncs.	1926.	Cairns, F., 59, Blodwell Street, Seedley, Manchester.
B.	1924.	Callaghan, G. M., 193, Douglas Road, Acocks Green, Birmingham.
S.	1920.	Cameron, N., Cavendish Villas, Devonshire Road, Totley Rise, Nr. Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
Lncs.	1925.	Carr, H., 7, Lord Street, Stalybridge.
L.	1921.	Carrell, Hy. Alfred, 6J, Peabody Buildings, Farringdon Road, E.C.
W.R. of Y.	1908.	Carrick, R., 14, Avondale Mount, Shipley, Yorks.
Lncs.	1914.	Carter, E., 59, Chief Street, Oldham.
W.R. of Y.	1923.	Carver, W., 112, Valley Road, Pudsey, near Leeds.
Lncs.	1920.	Castle, S., 68, Uxbridge Street, Ashton-under-Lyne.
W.R. of Y.	1922.	Causer, L. W., 79, Fitzroy Road, Barkerend Road, Bradford.
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.
S.	1911.	Chope, H. F., 38, Church Street, Sheffield.
N.	1920.	Clark, J. W., 133, St. Thomas' Terrace, Blaydon-on-Tyne.
L.	1923.	Clark, W., 9, Jubilee Road, Basingstoke.
E.M.	1919.	Clarke, A. S., Leicester Road, Loughborough.
N.	1912.	Clarke, J., Droston, Tayport, Fife.
N.	1920.	Clements, H. F., 14, Roseberry Crescent, Jesmond, Newcastle-on-Tyne.
Sc.	1922.	Cleverley, A.M., B.Sc., 45, Kennard Street, Falkirk, Scotland.
Lncs.	1922.	Cleworth, Alf., 25, Walnut Street, Bolton.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1921.	Coleman, J. I., West Dene, Brooklyn Road, Wilpshire, Blackburn.
W. & M.	1926.	Coles, F. L., 15, Moon Street, Adamstown, Cardiff.
S.	1920.	Coles, W. H., 2, Gordon Avenue. Woodseats, Sheffield.
B.	1919.	Colgrave, W., 13, Windsor Street, Coventry.
S.	1916.	Collins, B. L., Folds Crescent, Abbey Lane, Sheffield.
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.
Lncs.	1926.	Cooke, T., 15, Finchley Road, Hale, Cheshire.
S.	1914.	Cooper, J. F., 176, Attercliffe Road, Sheffield.
L.	1925.	Cooper, M. J., 48, Empress Avenue, Woodford Green, Essex.
B.	1915.	Cooper, W., 123, Wyley Road, Coventry.
N.	1919.	Corbett, W. A., "Dinguardi," Bungalow 19, High Farm Estate, Wallsend-on-Tyne.
S.	1914.	Coupe, B., 317, Bellhouse Road, Shiregreen, Sheffield.
Sc.	1919.	Cree, A.,383, Cathcart Road, Glasgow.
L.	1910.	Cree, F. J., Fair View, Huntley Grove, Peterborough.
E.M.	1926.	Creese, H. J., 46, Kensington Street, Leicester.
Lncs.	1910.	Critchley, F., 631, St. Helens Road, Bolton.
S.	1912.	Critchley, T., 52, Limpsfield Road, Brightside, Sheffield.
B.	1906.	Curnow, M. H., 41, Cemetery Lane, West Bromwich.
Sc.	1926.	Currie, J., 1, Sutherland Crescent, Bathgate.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1907.	Dalrymple, D., 20, Beeches Road, West Bromwich.
S.	1920.	Darby, A., 5, Dobbin Hill, Greystones, Sheffield.
S	1909.	Darley, F., 187, Burngreave Road, Pitsmoor, Sheffield.
S.	1915.	Darley, G. F., Cawwood & Co., Ltd., Westgate Foundry, Rotherham.
E.M.	1923.	Darrington, L. G., 27, Kingston Avenue, Hallam Fields, Ilkeston.
Sc.	1922.	Davidson, W. B., 18, Hayswell Road, Arbroath.
W. & M.	1924.	Davies, E. H., 224, Cardiff Road, Aberaman.
B.	1925.	Davis, A., 3/247, Gt. Russell Street, Birmingham.
L.	1916.	Davis, E. J., 11, Beclair Street, Belfast.
Lncs.	1923.	Davis, J., 50, Old Road, Dukinfield, Cheshire.
L.	1914.	Davis, W. H., 8, Pye Street, Portsmouth.
N.	1920.	Dawson, A. L. B., 5, Lesbury Road, Heaton, Newcastle-on-Tyne.
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., 6, Victoria Terrace, Hopwood Lane, Halifax.
L.	1909.	Derry, L. B., 3, Preston Road, Yeovil, Somerset.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1924.	De Ville, J. C., 16, Co-operative Street, Derby.
B.	1925.	Dexter, B. J., 80, New Rowley Street, Walsall.
S.	1915.	Dickinson, J., 49, Yarboro' Road, Lincoln.
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., 16, Botanical Road, Sheffield.
B.	1909.	Dobson, C., "Fairview," Hillside Road, Higher Tranmere, Birkenhead.
L.	1916.	Dobson, J., 25, Pix Road, Letchworth.
B.	1909.	Dobson, J. G., 6, Daniels Road, Ideal Village, Bordesley Green, Birmingham.
N.	1924.	Dodds, J., 64, Scotswood Road, South Benwell, Newcastle-on-Tyne.
Lncs.	1921.	Dolphin, J. H., 201, Eskrick Street, Halliwell, Bolton.
W. & M.	1924.	Domville, S., 301, Railway Street, Cardiff.
Sc.	1919.	Donaldson, J. W., 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.
Lncs.	1921.	Dunkerley, James, 10, Old Hall Drive, Gorton, Manchester.
S.	1925.	Dunstan, C., 10, Addison Road, Firth Park, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1913.	Eastwood, J. H., 83, Princess Street, Castleton, nr. Manchester.
L.	1912.	Eccott, A. E., The Elms, 68, Smithies Road, Plumstead, S.E.
N.	1923.	Eckford, J. W., 34, Tynedale Avenue, Monkseaton.
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.
N.	1920.	Elliott, J. V., 17, Oxford Avenue, South Shields.
E.M.	1909.	Ellson, J., Manor View, Ripley, Derby.
B.	1922.	Elston, Alfred, 62, Craven Street, Coventry.
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.	1920.	Everett, A., 28, Maycock Road, Coventry.
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.
Lncs.	1923.	Fellows, F., 21, Bright Street, Gorton, Manchester.
L.	1924.	Fenn, J. H., 25, Francemary Street, Brockley, S.E.4.
Sc.	1912.	Ferlie, T., Steel and Iron Founder, Auchtermuchty, Fifeshire.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1922.	Firm, P., 39, Parsonage Road, Laisterdyke, Bradford.
L.	1926.	Fish, F. W., 166, Glebe Street, Letchworth, Herts.
Lncs.	1917.	Fitzpatrick, A., 198, Rochdale Old Road, Bury, Lancs.
N.	1922.	Flack, E. W., 3. Falshaw Street, Washington Station, Co. Durham.
B.	1918.	Flavell, W. J., Carter's Green Passage, West Bromwich.
Lncs.	1923.	Flint, W. H., 225, Peel Green Road, Patricroft, Manchester.
Lncs.	1919.	Flitcroft, E., School Hill Ironworks, Bolton.
E.M.	1925.	Food, F. H., 108, Upper Conduit Street, Leicester.
N.	1912.	Ford, H., 14, Oakwellgate Chare, Gateshead-on-Tyne.
W.R. of Y.	1922.	Forrest, H., 43, Beaumont Road, Manningham, Bradford.
W.R. of Y.	1924.	Foster, H., 10, Highfield Place, Bramley, Leeds.
L.	1912.	Fowler, T. E., 72, Station Road, New Southgate, N.11.
B.	1909.	Fraser, A., 1, Bridge Street, Chilvers Coton, Nuneaton.
Lncs.	1924.	Frith, W., 8, Buckley Street, Ashton New Road, Clayton, Manchester.
N.	1920.	Futers, R. Wm., 107, Sandwich Road, South Shields.
E.M.	1925.	Gale, B., 15, Ridgway Street, Nottingham.
B.	1910.	Gale, W., 36, Salisbury Road, West Bromwich.
Sc.	1904.	Galt, J., Henry & Galt, Sneddon Foundry, Paisley.
L.	1925.	Gaskin, A., 20, Heath Way, North Heath, Erith.
B.	1920.	Gaunt, J. W., 101, Beeches Road, West Bromwich.
Lncs.	1923.	Gilpin, W., "Sunnyside," Birch Grove, Rusholme, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1924.	Gilson, A. J., 15, Marcus Street, Derby.
M.	1926.	Gleave, J., 1, Victoria Street, Haverton Hill, Middlesbrough.
Lncs.	1922.	Gledhill, F., 205, East View, Bradford Road, Brighouse, Yorks.
B.	1917.	Glynn, T. A., 67, Green Lane, Handsworth, Birmingham.
W.R. of Y.	1922.	Goff, R. M., 78, Lower Rushton Road, Thornbury, Bradford.
Lncs.	1924.	Goodwin, G. W., 11, Wycliffe Road, Urmston, Manchester.
E.M.	1919.	Goodwin, T., Braeside Street, New Bedford, Derby.
N.	1922.	Gospel, W., Gutta Percha Co., c/o The Staffordshire Stainless Iron Co., Ltd., Baldwin Street, Bilston, Staffs.
B.	1923.	Goss, W., Ivy Cottage, King William Street, Coventry.
B.	1919.	Gourd, C. D., 25, Shaftesbury Road, Earlsdon, Coventry.
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., 5, West Bars, Chesterfield.
S.	1919.	Greaves, J. B., 121, Upperthorpe, Sheffield.
S.	1924.	Green, A., 31, Broom Grove, Rotherham.
Lncs.	1924.	Green, A. E., 66, Wolseley Road, Preston.
S.	1917.	Green, F. N., Brook House, Ecclesfield, Sheffield.
S.	1914.	Green, P., 54, Rolleston Road, Firth Park, Sheffield.
Lncs.	1920.	Greenhalgh, W., 86, Crosby Road, Bolton.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
M.	1926.	Greenwell, O., 12, Angle Street, Grove Hill, Middlesbrough.
Lncs.	1924.	Greenwood, T., 1, Schofield Street, Todmorden.
L.	1918.	Gregory, E., 16, Mansfield Road, Beech Hill, Luton.
M.	1926.	Griffiths, A. G., 2, Tilbury Grove, King's Heath, Birmingham.
E.M.	1924.	Griffiths, S., c/o 88, Havelock Road, Derby.
M.	1926.	Griffiths, W., 15, Temple Street, Middlesbrough.
Lncs.	1925.	Grieve, J. E., 24, Tindall Street, Reddish, Stockport.
Lncs.	1919.	Grimwood, E. E. G., 129, Glebelands Road, Ashton-on-Mersey.
Lncs.	1921.	Grundy, H. V., Pentrick, Campbell Road, Brooklands, Cheshire.
L.	1920.	Gurney, S. J., 24, Burns Road, Battersea, S.W.
M.	1926.	Hackworth, J., 52, Byelands Street, Middlesbrough.
S.	1921.	Hagon, Wm., 35, Southgrove Road, Ecclesall, Sheffield.
Sc.	1920.	Haig, J., 7, Victoria Road, Larbert, N.B.
Sc.	1920.	Haig, T., 23, Livingston Terrace, Larbert.
S.	1909.	Hall, E. D., 31, Broomgrove Road, Sheffield.
L.	1921.	Hall, Geo., 125, Burton Road, Brixton, S.W.9.
N.	1914.	Hall, J. J., Clyde Vale, Rowlands Gill, Co. Durham.
E.M.	1925.	Hallamore, J. C., Oak Farm, Burton Road, Littleover, nr. Derby.
Sc.	1925.	Hamil, W., 50, Woodhead Avenue, Kirkintilloch.
B.	1924.	Hammond, G. A., 13, Anderson Road, Tipton, Staffs.
L.	1921.	Hammond, L., 27, North Way, North Heath, Erith.
E.M.	1925.	Hancock, D., 43, Drewry Lane, Derby.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
Lncs.	1926.	Hargraves, R. C., 114, Chapel Street, Levenshulme, Manchester.
Lncs.	1919.	Hargraves, R. R., (Grandridge and Mansergh, Ltd.), Wheathill Street, Salford, Manchester.
Lncs.	1911.	Harper, H., 28, Alexandra Street, Castleton, nr. Manchester.
L.	1925.	Harrington, W. T., 21, Vernon Road, Stratford, London, E.15.
Lncs.	1922.	Harris, F., 18, Holland Street, Padiham, Lancs.
M.	1926.	Harrison, A. G., 11, Bevan Terrace, Norton Road, Stockton-on-Tees.
S.	1923.	Harrison, John, 10, St. Helens Street, Chesterfield.
B.	1919.	Harrison, J. A., 7, Edmund Road, Coventry.
Sc.	1916.	Harrower, J. (Bo'ness Iron Company), Bo'ness, Scotland.
Lncs.	1924.	Hartley, R., 15, Oxford Road, Bootle, Liverpool.
Sc.	1914.	Hartley, R. F., London Road Foundry, Edinburgh.
L.	1922.	Harwood, John P., 112, Nithdale Road, Plumstead, S.E.
M.	1926.	Harvey, D., 4, Rydal Road, Stockton-on-Tees.
E.M.	1925.	Hawley, T. H., 53, Willow Brook Road, Leicester.
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,

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1922.	Hayward, Wm., Fairhaven, Pastures Road, Stapleford, nr. Nottingham.
N.	1922.	Heap, G. H., 269, Bensham Road, Gateshead-on-Tyne.
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.
L.	1910.	Henderson, G. B., 23, College Road, Woolston, Southampton.
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., 427, Stockport Road, Lower Bredbury, Stockport.
E.M.	1920.	Hey, James Wm., 43, Howe Street, Derby.
L.	1922.	Hibbert, J., 138, Burlington Road, Thornton Heath, Croydon.
L.	1925.	Hickenbottom, W. J., 50, Waterloo Road, Dunstable.
Lncs.	1925.	Higgins, J. D., 19, Lynton Avenue, Marland, Rochdale.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1922.	Hird, W., The Corner, Harden, Bingley, Yorks.
B.	1913.	Holberry, F., Hedley Terrace, Llanelly, S. Wales.
B.	1918.	Holder, F. W., 131, Eagle Street, Coventry.
E.M.	1926.	Holland, G., Costock, nr. Loughborough.
S.	1920.	Holland, G. A., Paten & Co., Church Lane, Norwich.
Lncs.	1922.	Holland, W., 1151, Chester Road, Stretford, Manchester.
B.	1917.	Hollinshead, A. E., 68, King's Road, Sedgley, Dudley.
E.M.	1925.	Holloran, J., 162, Brook Street, Derby.
Lncs.	1924.	Holt, A., 41, Carmen Street, Ardwick, Manchester.
B.	1917.	Homer, W. C.. 51, Lodge Road. West Bromwich.
B.	1924.	Hopkins, O. W., 225, Holyhead Road, Handsworth, Birmingham.
Lncs.	1925.	Hopwood, A., 154, Chestergate, Stockport.
L.	1921.	Hotchkis, J. D., 29, Romberg Road, London, S.W.17.
B.	1922.	Houghton, J., 15, Mayfield Road, Coventry.
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., "Brinteg," Ponallta Road, Ystrad, Glam.
W.R. of Y.	1917.	Hoy, R. E., 33, Brunswick Avenue, Beverley Road, Hull.
N.	1923.	Hudson, F., 28, Curtis Road, Fenham, Newcastle-on-Tyne.
B.	1924.	Hulse, J. C., 8, Cecil Street, Walsall, Staffs.
S.	1925.	Hunt, A., 18, Hollingwood Common, Barrow Hill, nr. Chesterfield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.C.	1926.	Hunter, J. M., 77, Prestwick Road, Ayr.
Sc.	1923.	Hunter, R. L., Newlands House, Polmont, Stirlingshire.
Lncs.	1914.	Hurst, S., 1 Saint Andrews Street, Radcliffe, Lancs.
L.	1922.	Husselbury, E., 147, Marlborough Road, Bedford.
L.	1924.	Hutchings, T. C., 10, Lopen Road, Silver Street, Edmonton, London, N.18.
B.	1925.	Hyde, Sidney, 25, Inhedge, Gornal, nr. Dudley.
Lncs.	1917.	Inskip, A., 992, Ashton Old Road, Openshaw, Manchester.
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.	1917.	Jackson, H. G., 1, Brierley Street, Stalybridge, Lancs.
Lncs.	1921.	Jackson, J., 25, Clarance Street, Burnley.
Lncs.	1920.	Jacques, J. W., 9, Stanton Street, Clayton, Manchester.
Lncs.	1923.	Jacques, T., The Cottage, Hill Top, Romiley, nr. Stockport.
B.	1909.	Jacques, W., 131, Wyley Road, Coventry.
B.	1914.	James, W., 96, Grove Lane, Handsworth, Birmingham.
L.	1925.	Jarvis, B., 30, Princes Street, Dunstable, Beds.
N.	1919.	Jay, H. C., 97, Cardigan Terrace, Heaton, Newcastle-on-Tyne.
N.	1921.	Jobes, G. B., 18, South Street, Gateshead-on-Tyne.
B.	1919.	Johnson, J. B., 27, Ball Fields, Tipton.
M.	1926.	Johnson, L., 45, Lanehouse Road, Thornaby-on-Tees.
N.	1925.	Johnson, N., 17, Chester Road, Sunderland, Co. Durham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1924.	Johnston, W. L., 49, Gough Road, Coseley, nr. Bilston, Staffs.
Lncs.	1916.	Jones, J. H., "Elleray," Temple Drive, Swinton, Manchester.
Lncs.	1919.	Jowett, H., 53, Turf Hill Road, Rochdale.
B.	1919.	Judd, G. H., 8, Ludlow Road, Coventry.
Lncs.	1924.	Kay, A., 24, Wilson Street, Gorse Hill, Stretford, Manchester.
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.
B.	1921.	Kemp, J. A., 1, Fairfax Street, Coventry.
Sc.	1912.	Kennedy, J., "Dunard," Howieshill, Cambuslang.
N.	1921.	Kent, Geo. A., 5, High West Street, Gateshead on Tyne.
E.M.	1918.	Kerfoot, John, 23, Cumberland Road, Loughborough.
Sc.	1914.	Kerr, W., 101, Ardgowan Street, Glasgow.
Lncs.	1925.	Kershaw, J., 31, Birkdale Street, Cheetham Hill, Manchester.
N.	1925.	Kirby, A. D., 6, Falshaw Street, Washington Station.
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.
B.	1919.	Klyver, F. D., 45, Farman Road, Coventry.
S.	1908.	Knowles, J. (c/o. Walkers), Manchester Road, Stocksbridge, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1922.	Laidlow, Wm., 9, Griffin Road, Plumstead, S.E.
Lncs.	1923.	Laing, J., 75, Victoria Road, Bedford.
Sc.	1922.	Lang, Wm., 5, Third Terrace, Radnor Park, Clydebank.
Sc.	1907.	Lawrie, Alex., 40, Glebe Road, Kilmarnock.
Sc.	1919.	Lawrie, R. D., 23, Fleming Street, Riccarton, Kilmarnock.
S.	1920.	Laycock, E., 160, Malton Street, Pitsmoor, Sheffield.
Lncs.	1917.	Leach, R., 53, Tower View, Lord Street, Stalybridge.
Lncs.	1914.	Leaf, J. W., District Bank House, Castleton, nr. Rochdale.
E.M.	1925.	Lee, H., 20, Moss Street, Derby.
N.	1913.	Lee, J., 38, Point Pleasant Terrace, Wallsend-on-Tyne.
S.	1925.	Levesley, Wm., 32, Westbourne Road, Broomhill, Sheffield.
S.	1920.	Lewin, H., Gov. Inspector of Castings, Kulti, E.I. Rly., India.
B.	1919.	Lewis, D. (John Harper & Company, Limited), Albion Works, Willenhall, Staffs.
B.	1925.	Lewis, E. J., 61, Church Vale, West Bromwich.
B.	1910.	Lewis, G., Strathmore, Paget Road, Wolverhampton.
W.R. of Y.	1926.	Liddemore, A. E., 2, Cliffe Terrace, Ingrow, Keighley.
Sc.	1925.	Liddle, R., 117, Dalmeny Street, Oatlands, Glasgow.
E.M.	1923.	Limbert, H., 15B, Factory Street, Loughborough.
Lncs.	1925.	Lineker, A. W., Ruddington House, Beaconsfield, C.P., South Africa.
B.	1919.	Linnett, A. T., 4, Earlsdon Avenue, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1919.	Lisby, T., 7, Meanley Road, Manor Park, E.
N.	1919.	Little, J. E. O., 83, Rothwell Road, Gosforth, Newcastle-on-Tyne.
Sc.	1910.	Littlejohn, A., 11, Esmond Street, Yorkhill, Glasgow.
L.	1922.	Littleton, W. H., 29a, Wabeck Road, Anerley, S.E.20.
N.	1916.	Loader, W. S., 282, Stanhope Road, South Shields.
Lncs.	1925.	Lockett, E., 38, Jackson Street, Gorton, Manchester.
Lncs.	1921.	Longden, Ed., 158, Manley Road, Manley Park, Manchester.
Sc.	1922.	Longden, J., 11, Drumny Road, Clydebank.
W.R. of Y.	1922.	Lowe, E., 35, Foster Road, Ingrow, Keighley, Yorks.
Lncs.	1919.	Luby, W., 10, East Avenue, Burnage, Manchester.
Sc.	1923.	Lumley, R., Garden Row, Bonnybridge.
Lncs.	1910.	Lupton & Sons, H. E., Scaithcliffe Works, Accrington.
S.	1913.	Macdonald, W. A., 219, Ringinglow Road, Ecclesall, Sheffield.
Sc.	1917.	MacDougall, Miss E., 22, Clarendon Street, St. George's Cross, Glasgow.
B.	1908.	Mace, C., 64, Port Street, Manchester.
Sc.	1910.	Macfarlane, J., 51, Kings Park Avenue, Cathcart, Glasgow.
Sc.	1910.	Mackay, G., 103, Glasgow Road, Paisley.
S.	1916.	Mackley, A., 151, Malton Street, Sheffield.
Lncs.	1922.	Maclachlan, J. R., 7, Newall Mount, Otley, Yorks.
—	1925.	Mahindra, J. C., 6 and 7, Clive Street, Calcutta, India.
Lncs.	1921.	Mallett, E., 1152, Chorley Old Road, Bolton.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1924.	March, T., 25, Clifford Street, Blaydon-on-Tyne.
B.	1909.	Marks, J., 73, Crosswells Road, Langley, Birmingham.
Lncs.	1923.	Marlow, E., 53, Flixton Road, Urmston, Manchester.
Sc.	1910.	Marshall, G., "Fereneze," Russell Street, Burnbank, Lanarkshire.
L.	1922.	Marshall, H. C., 29, Westward Road, S. Chingford, E.4.
Sc.	1912.	Marshall, W. G., "Kyleakin," Larkhall, Scotland.
Lncs.	1925.	Marsland, J., 205, Manchester Road, Droylesden, Manchester.
—	1924.	Marson, A., 2, Lindsey Street, Frodingham, Scunthorpe, Lincs.
Lncs.	1913.	Marsland, T., 401, Manchester Road, Droylesden, Manchester.
W.R. of Y.	1922.	Martin, F., 67, Nowell Terrace, Harehills Lane, Leeds.
B.	1925.	Massey, J. S., 50, New Street, 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.
N.	1919.	McBride, T. B., 3, Kingsley Avenue, Whitley Bay.
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.
Lncs.	1924.	McDermott, J. P., 118, Briersill Avenue, Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1924.	McDonald, D. M., 45, Stenson Road, Derby.
Sc.	1913.	McDonald, W. F., 5, Hutchinson Place, Cambuslang.
Sc.	1911.	McEachen, J., Regent Street, Kirkintilloch.
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.
Lncs.	1923.	McKenzie, Wm., c/o J. Hodgkinson, Ltd., Ford Lane Works, Pendleton, Manchester.
Sc.	1922.	McKinnon, J. C., Leaside Cottage, Cogan Street, Barrhead.
Sc.	1910.	McLachlan, W., 5, Dawson Terrace, Carron, Falkirk.
N.	1922.	McLaughlin, P., 70, John Street, Blaydon-on-Tyne.
W. & M.	1925.	McLean, J., "Donella," 12, Dinas Street, Grange, Cardiff.
Sc.	1915.	McNab, J., Bells Wynd, Falkirk.
Sc.	1910.	McPhie, H., 40, Philip Street, Falkirk.
Sc.	1925.	McNiven, Alex, 13, Dawson Street, Falkirk.
B.	1910.	McQueen, D., 6, Anchorage Road, Erdington, Birmingham.
Sc.	1926.	McWhirter, A., 114, Corlett Street, Tollcross, Glasgow.
Lncs.	1925.	Meadowcroft, H., 14, Worcester Street, Rochdale.
Sc.	1914.	Mearns, A., 54, Nairn Street, Glasgow.
Lncs.	1926.	Mellors, W., 166, West Street, Oldham.
M.	1926.	Menzies, A., 9, Cadogan Street, Middlesbrough.
Lncs.	1926.	Merigold, J. J., 67, Swans Lane, Bolton.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1921.	Meston, J. M., Priory House, Priory Street, Coventry.
S.	1913.	Millar, A., 90, Bawtry Road, Tinsley, Sheffield.
B.	1921.	Miller, G. A., 68, St. Margaret's Road, Coventry.
S.	1918.	Milner, H., 163, Cross Hill, Ecclesfield, nr. Sheffield.
W.R. of Y.	1923.	Milner, J. W., 29, Welbeck Street, Sandal, Wakefield.
W.R. of Y.	1923.	Mitchell, G. W., Stafford Cottage, S. Westhorpe Road, Wakefield.
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.
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.
N.	1919.	Molineux, W. J., Newcastle-on-Tyne.
E.M.	1921.	Moodie, Colin, 169, Station Road, Beeston, Notts.
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.
—	1920.	Morgan, B. S., B.Sc., A.I.C., 42, Park Road, Rugby.
B.	1926.	Morgan, E. S., 22, Clipton Road, Aluin Park, Birmingham.
W. & M.	1922.	Morgan, W., Bryn Derwen, Bryn Terrace, Porth, Glam., So. Wales.
B.	1922.	Morris, H. J., New Shop, Heath Road, Swan Lane, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1924.	Morris, T. R., 3, Albert Street, Masboro', Rotherham.
Lncs.	1925.	Morris, W., 16, Bird Street, Preston.
N.	1924.	Mudie, T., 34, Beech Grove, Monkseaton.
N.	1913.	Murray, J., 5, Elmwood Avenue, Willington-Quay-on-Tyne.
S.	1914.	Naylor, A., 239, Abbeyfield Road, Pitsmoor, Sheffield.
Lncs.	1915.	Naylor, F., 26, Nowell Crescent, Harehills Lane, Leeds.
B.	1926.	Neath, F. K., 16, Sarehole Road, Hall Green, Birmingham.
Lncs.	1925.	Needham, G. A., 11, Newbridge Lane, Stockport.
E.M.	1926.	Needham, J., 5, Rupert Street, Nottingham.
W.R. of Y.	1925.	Neild, G., 3, Baden Terrace, Hough End, Bramley, Leeds.
N.	1914.	Nekervis, J., 14, Broughton Road, South Shields.
Lncs.	1920.	Newport, F., 1428, Ashton Old Road, Higher Openshaw, Manchester.
W.R. of Y.	1926.	Nichol, W. E., 19, College Road, Crosland Moor, Huddersfield.
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, Hillend Road, Lambhill, Glasgow.
Lncs.	1920.	Noble, A., 42, Central Road, Gorton, Manchester.
Lncs.	1925.	Noble, H., 53, Rock Street, Gee Cross, Hyde, Cheshire.
Lncs.	1924.	Noble, J., 53, Reddish Lane, Gorton, Manchester.
B.	1924.	Northcott, L., The Den, Halesowen, Birmingham.
S.	1921.	Offiler, G., 9, Ward Place, Highfields, Sheffield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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, N.B.
S.	1924.	O'Shea, D. B., Vickers, Ltd., Broadway House, Westminster, S.W.
E.M.	1922.	Ottewell, H., The Mead, Swanwick, Alfreton, Derby.
B.	1922.	Owen, A. C., 33, Park Street, Madeley, Salop.
Lncs.	1924.	Owen, W., 33, Granville Road, Gorton, Manchester.
S.	1914.	Oxley, C., c/o Oxley Bros., Ltd., Mowbray Street, Sheffield.
B.	1924.	Palmer, A., 14, Marsh Hill, Stockland Green, Birmingham.
Lncs.	1923.	Palmer, T., 5, Marmaduke Street, Oldham.
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.	1918.	Parsons, A., 32, Cordley Street, West Bromwich.
Sc.	1914.	Patrick, A., 65, Mungalhead Road, Falkirk.
B.	1925.	Patrick, J., 5, St. Margarets Street, Canterbury, Victoria, Australia.
L.	1925.	Payton, T. G., 33, King Street, Dunstable, Beds.
N.	1925.	Pearson, C. E., 2, Pearl Street, Saltburn-by-Sea.
E.M.	1906.	Pemberton, H., 15, Wolfa Street, Derby.
Lncs.	1919.	Perkins, F. S., 55, Slaney Street, Newcastle-under-Lyme, Staffs.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1914.	Pevitt, Hy., 75, Orford Street (Central), Warrington.
Lncs.	1922.	Phillips. A., 38, Gorse Crescent, Stretford, Manchester.
B.	1919.	Phipps, H., 93, Raglan Street, Coventry.
B.	1918.	Picken, J., Lilac Cottage, Doseley, Dawley, Salop.
L.	1920.	Pierce, G. C., 11, Athelney Street, Bellingham, S.E.
S.	1926.	Pollard, C. D., 7, Causton Road, Pitsmoor, Sheffield.
Lncs.	1918.	Potts, W., 1, Far Lane, Hyde Road, Gorton, Manchester.
W.R. of Y.	1922.	Poulter, H., 4, Beech Grove, Undercliffe, Bradford, Yorks.
Lncs.	1922.	Prescott, J., 3, Louisa Street, Bolton, Lancs.
Lncs.	1922.	Priestley, Jos., 258, Waterloo Street, Bolton, Lancs
Lncs.	1922.	Priestley, Thos., 185, Kay Street, Bolton, Lancs.
L.	1912.	Primrose, H. S. (Campbell & Gifford), 17, Victoria Street, S.W.1.
Lncs.	1912.	Primrose, J. S. Glen, 17, Salisbury Road, Chorlton-cum-Hardy, Manchester.
B.	1909.	Pugh, C. B., Ramsey House, Bescot, Walsall.
S.	1917.	Pugsley, T. M., c/o Post Office, 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., c/o Mrs. Bourne, 115, Northcroft Road, W. Ealing, W.13
Sc.	1904.	Rankin, R. L. (Sharp & Company), Lennox Foundry, Alexandria, Scotland.
L.	1920.	Rasbridge, W. J., 160, Evelyn Street, Deptford, S.E.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1910.	Rawlinson, W., "Fairhaven," Portland Road. Ellesmere Park, Eccles, Manchester.
L.	1917.	Reaman, H., 13, Adelaide Road, Brockley, S.E.4.
S.	1907.	Redmayne, L., Little London Road, Sheffield.
N.	1921.	Reece, D., 24, Forster Street, Gateshead-on-Tyne.
E.M.	1916.	Reffin, J. J., 79, Barclay Street, Fosse Road South, Leicester.
Lncs.	1907.	Reynolds, W., 13, Park View Terrace, Oldham.
W.R. of Y.	1922.	Rhodes, W., 1, Vernon Place, Undercliffe, Bradford, Yorks.
S.	1922.	Rhodes, Wm., Beech Holme, Ecclesfield, nr. Sheffield.
L.	1925.	Richards, W. S., 68, Beatrice Avenue, Keyham Barton, Devonport.
W. & M.	1924.	Richardson, R. J., Llanblethian House, nr. Cowbridge.
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.	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.
S.	1912.	Roberts, G. E., 149, Sharrow Vale Road, Sheffield.
N.	1921.	Robertson, H.. 13, Leamington Street, 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.
N.	1917.	Robinson, J. H., 22, Park Parade, Whitley Bay.
W.R. of Y.	1922.	Robinson, W. G., 5, Keswick Street, Laisterdyke, Bradford, Yorks.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1919.	Robson, F., 44, Stannington Place, Heaton, Newcastle-on-Tyne.
S.	1913.	Rodgers, F., Brightside Foundry & Engineering Co., Ltd., Wicker, Sheffield.
S.	1913.	Rodgers, J. R. R., 362, Firth Park Road, Sheffield.
Sc.	1924.	Rodgers, P., Jubilee Place, Bonnybridge.
B.	1917.	Roe, H. J., 84, Church Road, Moseley. Birmingham.
E.M.	1913.	Roe, J., Globe Foundry, Stores Road, Derby.
B.	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., 1, Rathbone Place, Middle Hill, Nottingham.
W.R. of Y.	1922.	Rowntree, F., 28, Campbell Street, Bowling Back Lane, Bradford, Yorks.
M.	1926.	Rutherford, C., "Inglefield," Eaglescliffe, S.O.
N.	1925.	Rutledge, W. B., 61, North View, Heaton, Newcastle-on-Tyne.
Lncs.	1924.	Ryding, F., 52, Barnsley Road, Wigan, Lancs.
L.	1913.	Samson, A, 18, Martin Road, Ipswich.
L.	1923.	Sanders, H. H., 21, Etherley Road, Harringay, N.15.
S.	1921.	Sanders, Horace L., 72, Murray Road, Eccleshall, Sheffield.
B.	1905.	Sands, J., 27, Victoria Street, West Bromwich.
M.	1926.	Sault, A., 10, Pine Street, Norton-on-Tees.
N.	1923.	Savage, R., 5, Winchester Terrace, Hendon, Sunderland.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1922.	Sayers, H., 239, Goodman Terrace, Hunslet, Leeds.
Lncs.	1924.	Scholes, W. H., 15, Hope Park Road, Bent Hill, Prestwich, Manchester.
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., 11, Croft Street, Failsworth, Manchester.
S.	1921.	Senior, George, 305, Upperthorpe Street, 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.
Lncs.	1922.	Shaw, S., 35, Frog Lane, Wigan, Lancs.
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,” Beech Lanes, Birmingham.
B.	1920.	Shorthouse, W. H., 60, Edward Street, West Bromwich.
W. & M.	1925.	Silverwood, H. Wm., 320, Newport Road, Cardiff.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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., 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.
Lncs.	1925.	Smith, F., 85, Greenbank Road, Rochdale.
B.	1919.	Smith, F. G., 15, Cherry Street, Coventry.
S.	1913.	Smith, J., Abney House, Gleadless Road, Sheffield.
Sc.	1921.	Smith, J., 6, Kennard Street, Falkirk.
Sc.	1914.	Smith, J. M., 64, Lennox Avenue, Scotstoun, Glasgow.
B.	1917.	Smith, S., 240, Bromford Lane, West Bromwich.
Lncs.	1909.	Smith, S. G., 86, Barton Road, Stretford, Manchester.
Lncs.	1924.	Smith, W., 358, Halifax Road, Todmorden.
E.M.	1925.	Smith, W. F., Fireman's Houses, Colombo St., Derby.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1924.	Smith, Wm., 50, Shetcliffe Lane, Tong Street, Bradford, Yorks.
Sc.	1924.	Sneddon, F. M., 28, Forest Street, Mile End, Glasgow.
S.	1924.	Somerfield, H., 146, Sandygate Road, Sheffield.
L.	1904.	Sperring, B. F., 244, Lake Road, Portsmouth.
Sc.	1920.	Spittal, J., 80, Norham Street, Shawlands, Glasgow.
Lncs.	1926.	Stacey, C. W., 5, Harcourt Street, Gorse Hill, Stretford, Manchester.
Sc.	1918.	Stark, W. C., 37, Summertown Road, Govan.
B.	1917.	Starr, F. G. S., 128, Selwyn Road, Rotton Park, Birmingham.
Lncs.	1917.	Stead, H., 1st 36, Cheetham Hill Road, Stalybridge.
S.	1914.	Steggles, A. L., 240, Bellhome Road, Sheffield.
B.	1914.	Stephen, S. W. B., The Woodlands, Beech Lanes, Birmingham.
W. & M.	1924.	Stephens, C. W., Efail Isaf, nr. Pontypridd, Mon.
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.
L.	1915.	Stone, E. G., 20, Cautley Avenue, Clapham Common, S.W.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
N.	1922.	Tait, A. H., Armagh House, Wallsend-on-Tyne.
S.	1913.	Tait, E., Brightside Foundry & Engineering Company, Limited, Sheffield.
Lncs.	1922.	Tate, C. M., Brook Royd, Todmorden Road, Burnley.
—	1906.	Taylor, A. (Fielding & Platt, Limited), Atlas Ironworks, Gloucester.
B.	1925.	Taylor, A., The Willows, Gipsy Lane, Willenhall.
B.	1925.	Taylor, E. R., 148, South Road, Handsworth, Birmingham.
W. & M.	1905.	Taylor, F. (Taylor & Sons, Limited), Britonferry, South Wales.
B.	1926.	Taylor, F., "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.
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.
Lncs.	1922.	Thatcher, E. H., "Trostrey," Wraxall, Somerset.
N.	1924.	Thom, J., 11, Moorland Crescent, Walker, Newcastle-on-Tyne.
L.	1909.	Thomas, E., 41, Kingshill Road, Swindon.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1922.	Thompson, E., Thryburg Street, Leeds Road, Bradford.
L.	1926.	Thompson, J. S., 21, Erith Road, Belvedere, Kent.
Sc.	1925.	Thomson, D. B., 149, Great Hamilton Street, Glasgow East.
S.	1923.	Thornton, A. E., 34, Hampton Road, Pitsmoor, Sheffield.
Lncs.	1911.	Timmins, A. E., 133, Roose Road, Barrow-in-Furness.
Lncs.	1924.	Timperley, T., 30, Ventnor Road, Heaton Moor, Stockport.
Sc.	1925.	Tonagh, Chas., 70, Stevenson Street, Calton, Glasgow.
Lncs.	1919.	Toplis, H., Hans Renold, Limited, Burnage Works, Didsbury, Manchester.
Lncs.	1914.	Topping, G., 17, Bebbington Street, Clayton, Manchester.
L.	1925.	Torode, G. F., 537, Oxford Road, Reading.
B.	1909.	Toy, J. H., 374, Bearwood Road, Smethwick, Staffs.
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.
S.	1918.	Turner, W., 90, Edgedale Road, Sheffield.
B.	1923.	Twigger, T. R., Post Office, Bubbenhall, nr. Kenilworth.
L.	1925.	Underwood, W. G., 9, Sears Street, New Church Road, Camberwell, S.E.5.
Sc.	1920.	Ure, R., Stenhouse House, Carron, Falkirk.
E.M.	1921.	Vaughan, Benj. H., 25, Holmes Street, Derby.
B.	1917.	Vaughan, G. A., 15, Green Street, West Bromwich.
Lncs.	1921.	Vernon, G. W., 11, Ashfield Road, Burnley.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1914.	Wainford, E. H., High Row, Gainford, Darlington.
Lncs.	1925.	Walker, A., 117, Robert Street, Newton Heath, Manchester.
S.	1921.	Walker, Alex. W., 129, Honeysuckle Road, Shiregreen, Sheffield.
L.	1911.	Walker, C. F., 42, Windsor Street, Wolverton, Bucks.
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, John, 130, Wallace Street, Falkirk.
Sc.	1920.	Walker, Wm., Gowanlea Cottages, Anderson Street, Bonnybridge, Falkirk.
Lncs.	1915.	Walwork, R. N., Western Road, Wilmslow, Cheshire.
E.M.	1924.	Ward, J. C., 56, Danvers Road, Leicester.
B.	1919.	Wareham, H., 37, Broadway, Coventry.
L.	1919.	Wares, F. J., 216, Cromwell Road, Peterborough.
E.M.	1925.	Warner Amos, 252, Thomas Road, Derby.
S.	1911.	Wasteney, J., Vulcan Foundry, Eckington, nr. Chesterfield.
—	1914.	Watson, R., Saxilley House, 49, York Street, Rugby.
Sc.	1919.	Watt, R., Etna Ironworks, Falkirk.
Sc.	1920.	Waugh, Wm., 21, Dundas Crescent, Laurieston. Falkirk
N.	1921.	Weathers, J. H., 76, Stanton Street, Newcastle-on-Tyne.
B.	1923.	Webb, A. W. J., 1, Sidney Street, Gloucester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1921.	Webb, Ernest Alfred, 109, Warwick Street, Leicester.
S.	1909.	Webster, C., 34, Milton Road, Rotherham.
B.	1922.	Webster, H. E., 46, Dovey Road, Moseley, Birmingham.
B.	1926.	Webster, W., 74, Horseley Road, Tipton, Staffs.
W.R. of Y.	1922.	West, W., 32, Oakfield Road, Manningham, Bradford.
B.	1911.	Westwood, J. H., 163, St. Paul's Road, Smethwick, Staffs.
W.R. of Y.	1913.	Whitaker, E., 145, St. Enoch Road, Wibsey, Bradford.
M.	1926.	Whitehead, A., "Avondale," St. Lukes Avenue, Thornaby-on-Tees.
L.	1911.	Whiting, A., Brynbella, Pembroke Road, Erith, Kent.
L.	1924.	Whiting, A. F., 56, Battle Road, Erith, Kent.
Lncs.	1922.	Whittle, Harry, 94, Bridgefield Street, Radcliffe, Manchester.
B.	1919.	Whitworth, E., 274, Munition Cottages, Holbrook's Lane, Coventry.
S.	1925.	Wild, A. J., Midland Brass Foundry, Attercliffe, Sheffield.
E.M.	1926.	Wild, H., 14, Albert Promenade, Loughborough, Leicestershire.
M.	1926.	Wilkes, R., 39, Pearl Street, Haverton Hill, Middlesbrough.
M.	1910.	Wilkinson, T., Stockton Street, Middlesbrough.
S.	1919.	Williams, A., 31, Burngreave Bank, Sheffield.
B.	1919.	Williams, A. Morgan-, 43, Queen's Road, Coventry.
—	1923.	Williams, B. E., "Aldersey," Crick Road, Hillmorton, Rugby.
Lncs.	1925.	Williams, O., 36, Sark Road, Stoneycroft, Liverpool.
B.	1923.	Williams, R., 166, Cross Road, Foleshill, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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., Elm Villa, Mildmay Road, Burnham-on-Crouch.
W.R. of Y.	1923.	Wilson, H. T., 34a, Commercial Street, Thornes Lane, Wakefield.
Lncs.	1904.	Wilson, W. R., 15, Sackville Street, Liverpool.
E.M.	1921.	Winfield, F., "Ambleside," Osmaston Park Road, Derby.
S.	1924.	Winterton, H. T., Wm. Cummings & Co., Whittington Mills, Nr. Chesterfield.
B.	1924.	Wiseman, A. A., 7, Danks Street, Tividale, Tipton.
Lncs.	1912.	Wolstenholme, J., 111, Carlton Terrace, Bury, and Bolton Road, Radcliffe, Manchester.
B.	1922.	Wood, A., 30, Toll End Road, Toll End, Tipton, Staffs.
S.	1926.	Wood, E. A., 30, Dixon Street, Rotherham.
E.M.	1921.	Wood, James H., 18, Alcester Road, Sheffield.
W.R. of Y.	1922.	Wood, John, 6, Hudswell Street, Sandal, Wakefield.
M.	1926.	Woolley, H. E., 5, Albion Terrace, Saltburn-by-Sea.
W.R. of Y.	1914.	Worcester, A. S., 162, Victoria Road, Lockwood, Huddersfield.
Lncs.	1917.	Worrall, J. N., 77, Ansdell Road, Turf Hill, Rochdale.
W. & M.	1926.	Wren, J., 30, Cambria Street, Griffithstown, W. Newport, Mon.
Lncs.	1925.	Wright, H. G., 78, Lloyd Street, Heaton Norris, Stockport.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W.R. of Y.	1923.	Wright, L. L., 168, Oxford Road, Gomersall, near Leeds.
Sc.	1913.	Wright, W., Burnbank Foundry, Falkirk.
Lncs.	1924.	Wylie, J. F., 206, Stockport Road, Bredbury, Stockport.
Lncs.	1925.	Yates, J., 37, King Edwards Avenue, North Shore, Blackpool.
Lncs.	1924.	Yeoman, Robert, 18, Lord Street, 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.
N.	1923.	Allcock, H., 164, H. S. Edwards Street, South Shields.
B.	1925.	Andrews, E., 214, Highfield Road, Saltley, Birmingham.
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.
N.	1921.	Bentham, J. W., 9, Cumberland Street, Gateshead-on-Tyne.
N.	1924.	Betham, W. S., 9, South Frederick Street, South Shields.
N.	1913.	Bewley, J. E. T., 13, Woodland Terrace, Leadgate, Co. Durham.

B'nch.	Year of Election.	ASSOCIATES.
N.	1925.	Blackwell, J., 113, George Street, Willington Quay-on-Tyne.
Sc.	1926.	Blackwood, W. S., 12, Napier Street, Linwood, N.B.
S.	1924.	Blades, H., 37, Petre Street, Pitsmoor, Sheffield.
B.	1922.	Boudry, C., 46, Holly Lane, Smethwick, Birmingham.
N.	1922.	Bowden, F., 5, Holmwood Grove, West Jesmond, Newcastle-on-Tyne.
B.	1914.	Boyne, W., 157, Wood End Road, Erdington, Birmingham.
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., 75, Albert Street, Slough, Bucks.
N.	1923.	Chapman, L. B., Daisy Cottage, Dene Villas, Chester-le-Street, Co. Durham.
N.	1923.	Charlton, F. J., 96, Adelaide Street, South Shields.
Sc.	1926.	Clark, J., 28, King Street, Paisley.
Sc.	1925.	Climie, C., 40, Delburn Street, Parkhead.
S.	1920.	Coates, L., 30, Oakwood Road, Rotherham.
W. & M.	1925.	Coles, H., 101, Woodlands Road, Barry Dock.
Sc.	1924.	Coubrough, W. J., 68, Guthrie Street, Maryhill, Glasgow.
L.	1926.	Cummings, F. C., 3, Waller Road, New Cross, London, S.E.14.
Sc.	1924.	Cummings, J., 27, Hillview Street, Shettleston, Glasgow.
B.	1918.	Currie, E. M., 3, Stockton Road, Coventry.
N.	1924.	Cuthbertson, J., 1, Tower Street, Gateshead-on-Tyne.
N.	1924.	Davidson, T. H., 156, Croydon Road, Newcastle-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
Sc.	1926.	Davis, T., 633, Dumbarton Road, Partick, Glasgow.
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., 34, Downing Street, Handsworth, Birmingham.
B.	1924.	Eardley, H. R. V., 6, White Friars Street, Coventry.
N.	1918.	Eglen, T., 22, Morley Street, Heaton, Newcastle-on-Tyne.
L.	1922.	Ellis, J. P., 20, Lambourn Road, Clapham, S.W.4.
B.	1922.	Elston, A. G. W., 62, Craven Street, Coventry.
B.	1925.	Evans, E. H., 100, Brunswick Road, Handsworth, Birmingham.
N.	1923.	Farrell, T. P., 6, St. Mary's Terrace, Willington Quay.
N.	1917.	Ferguson, J., 62, South Palmerston Street, South Shields.
N.	1923.	Ferrier, J. E., 29, Maple Grove, Cleadon Park, South Shields.
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.
N.	1917.	Francis, J., Straughan House, Felling-on-Tyne.
B.	1924.	Frost, C., 73, Whitmore Road, Small Heath, Birmingham.
N.	1923.	Galbraith, R., 18, Byethorne Street, South Shields.
N.	1923.	Gibson, W., 66, King George Road, Cleadon, South Shields.
N.	1923.	Golder, T., 7, Orange Street, South Shields.
N.	1923.	Gould, M,, 42, Elswick East Terrace, Newcastle-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
Sc.	1924.	Graham, T., 25, William Street, Dumbarton.
L.	1924.	Graves, 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.
B.	1923.	Griffiths, T. J., 35, Sir Thomas White's Road, Coventry.
N.	1925.	Grigor, R., 38, Grey Street, Wallsend-on-Tyne.
B.	1925.	Hadley, E. T., 207, Horsley Heath, Tipton, Staffs.
B.	1909.	Hamilton, G., 18, 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.
N.	1924.	Harvey, J. E. B., 96, Marshall Wallis Road, South Shields.
S.	1921.	Heeley, John Jas., 36, Gertrude Street, Owlerton, Sheffield.
Sc.	1924.	Higgins, N., Portland Rows, Hurlford, Ayrshire.
Sc.	1920.	Hill, T., 9G, Mitchell Street, Airdrie.
Lncs.	1925.	Hindley, W., 13, Charles Street, Farnworth, near Bolton.
W. & M.	1926.	Hird, J., "Woodcot," Upper Cwmbran.
N.	1925.	Hodgkinson, H. D., 10, Sidney Grove, Newcastle.
E.M.	1917.	Holmes, A., 78, Albert Promenade, Loughborough.
N.	1923.	Holmes, A., 20, Earl Street, Jarrow-on-Tyne.
Lncs.	1923.	Hopkins, W., 70, Tootal Drive, Weaste, Manchester.
E.M.	1916.	Hughes, J. O., 27, Evington Road, Leicester.

B'nch.	Year of Election.	ASSOCIATES.
M.	1926.	Jameson, J. R., 9, Olive Street, Hartlepool.
N.	1923.	Jennings, P., 23, Cullercoats Street, Welbeck Road, Newcastle-on-Tyne.
B.	1919.	Johnson, J. B., junr., Slater Street, Great Bridge, Tipton.
N.	1925.	Jones, J., 21, Cooper Street, Sunderland Road, Gateshead-on-Tyne.
L.	1924.	Jones, T. H., 40, Glengall Road, Cubitt Town, E.14.
Sc.	1922.	Jones, W. C., Blair Terrace, Hurlford, Ayrshire.
N.	1922.	Kelly, F. J., 1545, Walker Road, Newcastle-on-Tyne.
Sc.	1924.	Laughland, H., 15, Burnside Street, Kilmarnock.
N.	1925.	Laven, J., 140, Richardson Street, Wallsend-on-Tyne.
N.	1923.	Lewins, W., 90, H. S. Edwards Street, South Shields.
N.	1922.	Liddell, L., 7, Tyne View, Lemington-on-Tyne.
N.	1920.	Lindsay, A. W., 16, Phillipson Street, Willington Quay-on-Tyne.
N.	1924.	Lowes, W., 1, Baden Street, Chester-le-Street.
Lncs.	1914.	Lucas, G. E., 36, Langford Street, Leek, Staffs.
Sc.	1924.	MacNab, R., 13, Walker Street, Paisley.
Sc.	1925.	Magee, J., 11, Douglas Street, Paisley.
Sc.	1924.	Martin, A. L., 31, George Street, City, Glasgow.
M.	1926.	Martin, J. H., 7, South View, Cargo Fleet, Middlesbrough.
B.	1924.	Mason, J. L., 11, Kentish Road, Handsworth, Birmingham.

B'nch.	Year of Election.	ASSOCIATES.
L.	1925.	Mata, C. H., 51, Grosvenor Road, Canonbury, N.5.
L.	1911.	Mather, D. G., "Westoe," Queen's Road, Ashford, Kent.
B.	1913.	Mather, F., "Doris," Deykin Avenue, Witton, Birmingham.
N.	1923.	Matthews, G. W., 4, Burnside, Rosehill, Willington-Quay-on-Tyne.
Sc.	1926.	McAllister, W. C., 144, Drumoyne Road, S.O., Govan, Glasgow.
N.	1924.	McDonald, C. R., The Villa, Willington-Quay-on-Tyne.
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.	1913.	McLeish, R., 7, Buchanan Terrace, Paisley.
Sc.	1926.	McPhee, J. McA., 70, High Street, Paisley.
N.	1926.	McQuillan, J., 1 Lodge Terrace, Wallsend-on-Tyne.
Lncs.	1923.	Meadowcroft, H., 10, Hambledon View, Habergham, Burnley.
Sc.	1924.	Meikle, A. S., 207, Kent Road, Glasgow.
B.	1925.	Meredith, C., 4, Thomas Street, Smethwick, Birmingham.
N.	1922.	Miller, J. G., 79, Clarence Street, Newcastle-on-Tyne.
B.	1918.	Morgan, W. G., 51, Palmerston Road, Earlsdon, Coventry.
N.	1925.	Morland, R. H., 106, Clifford Street, Byker, Newcastle-on-Tyne.
N.	1914.	Murray, J., 13, Dean Road, South Shields.
N.	1925.	Nesbit, G. L., 4, Coben Avenue, Mexborough.

B'nch.	Year of Election.	ASSOCIATES.
N.	1925.	Nesbitt, I., 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.	1917.	Oliver, J., 74, King Edward Street, Gateshead-on-Tyne.
N.	1925.	Osborne, G. F., 39, Franklin Street, Sunderland.
N.	1922.	Paterson, J. W., 108, Corbridge Street, Byker, Newcastle-on-Tyne.
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., 2, Tweed Street, Hebburn-on-Tyne.
N.	1922.	Pittuck, M. D. (Miss), 4, Catherine Terrace, Whitley Bay.
Lncs.	1926.	Pollard, Wm., 7, Powell Street, Burnley, Lancs.
W.R. of Y.	1926.	Poole, F. T. L., 85, Starr Hill, Wyke, Bradford.
E.M.	1916.	Radford, H. P., 151, Barclay Street, Fosse Road South, Leicester.
N.	1917.	Rang, E. J., 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.	1923.	Reid, J. N. (junr.), Elmbank, Larbert.
Sc.	1923.	Riddell, J., 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.

B'nch.	Year of Election.	ASSOCIATES.
N.	1923.	Rollin, C. N., Keys House, Gilesgate, Durham.
N.	1926.	Rowley, J. S., 51, South Terrace, Wallsend-on-Tyne.
N.	1925.	Ruff, J., 88, Richardson Street, Wallsend-on-Tyne.
N.	1923.	Sams, W. B., 6, North Terrace, Wallsend-on-Tyne.
M.	1926.	Saunders, A., 34, Queens Road, North Ormesby, Middlesbrough.
N.	1925.	Scott, R. J., 5, Dene Avenue, High Farm Estate, Wallsend-on-Tyne.
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. .
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.
Sc.	1924.	Stevenson, A. H., 6, Kennedy Street, Kilmarnock.
N.	1923.	Stobbs, T., 199, Stanhope Road, South Shields.
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.
Lncs.	1926.	Tate, W. G., Brook Royd, Todmorden Road, Burnley.

B'nch.	Year of Election.	ASSOCIATES.
M.	1926.	Taylor, D., 35, Langby Avenue, Thornaby-on-Tees.
N.	1926.	Thompson, J. T., 42, Monk Street, Gateshead-on-Tyne.
N.	1923.	Towns, E., 50, Whitehead Street, South Shields.
N.	1921.	Tunnah, R. C., 22, Ripon Gardens, Jesmond, Newcastle-on-Tyne.
Sc.	1924.	Turnbull, J., Primrose Cottage, Bonnybridge.
N.	1921.	Turnbull, R. G., S.S. "Cairnross," Edinburgh Docks, Leith.
S.	1922.	Tyler, G. H., 86, Pickmere Road, Crookes, Sheffield.
N.	1922.	Van-der-Ben, C. R., 169, Dunsmuir Grove, Gateshead-on-Tyne.
M.	1926.	Vause, W., 33, Hannah Street, Thornaby-on-Tees.
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.	1926.	Whitehouse, T., 4, Carlton Road, Smethwick, Staffs.
M.	1926.	Whitfield, C. S., 131, Victoria Road, Middlesbrough.
S.	1920.	Wordsworth, W. A., 11, Coverdale Road, Millhouses, Sheffield.
N.	1925.	Worley, E. R., 2, Primrose Hill, Low Fell, Gateshead-on-Tyne.
Sc.	1926.	Young, H., 4, Glasgow Road, Paisley.

Members changing their address are requested to notify the same immediately to the General or Branch Secretary of the District.

NAME INDEX.

SUBJECT INDEX.