Mr. R. O. Patterson (President).

Mr. R. O. Patterson, the President of the Institute of British Foundrymen, was born in 1876. He was educated in Newcastle-on-Tyne and on the Continent. Mr. Patterson has travelled extensively. His first long trip was to the United States in 1898. His next tour was to Australia, and his third excursion was as a soldier to take part in the Boer War. He again visited the States in 1919 to take part in the American Foundrymen's Association Congress. In 1920 Mr. Patterson was elected president of the Newcastle Branch, and the following year junior vice-president of the parent body. He is well known in northern business circles, being a director and works manager of Messrs. Smith, Patterson Company, Limited, of Blaydon-on-Tyne, who are manufacturers of grey-iron and non-ferrous castings, and are general sanitary engineers.

PROCEEDINGS
OF THE . .
INSTITUTE OF
BRITISH FOUNDRYMEN.

1923-1924.

Containing the Report of the Twenty-first Annual Conference, held at Newcastle, June 4th, 5th and 6th, 1924; and also Papers and Discussions presented at Branch Meetings held during the Session 1923-1924.

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

LONDON: Printed by
"THE FOUNDRY TRADE JOURNAL,"
Bessemer House, Adelphi, W.C.2.

A

THE INSTITUTE OF BRITISH FOUNDRYMEN.

OFFICERS 1924—1925.

PRESIDENT :

R. O. Patterson, Pioneer Works, Blaydon-on-Tyne.

VICE-PRESIDENTS :

J. Cameron, Cameron & Robertson, Ltd., Kirkintilloch, N.B.
V. C. Faulkner, 5, Duke Street, Adelphi, London, W.C.2.

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., Ravens Cragg, Wortley, Sheffield. 1910-1911.
C. Jones. (Deceased 1923.) 1912.
S. A. Gimson, 20, Glebe Street, Leicester.
W. Mayer. (Deceased 1923.) 1915.
J. Ellis, 6, Eckstein Road, Clapham Junction, London, S.W.11 1916-1917.
T. H. Firth, Brightside Foundry and Engineering Co., Ltd., Sheffield. 1918.
John Little, M.I.Mech.E., 20, St, Anne'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.

General Council :

*A. R. Bartlett, 1, Lower Park Road, Belvedere, London, S.E.
†W. F. Cheesewright, Col., D.S.O., 5, Duke Street, Adelphi, London, W.C.2.
*W. T. Evans, Mount Pleasant, Sunny Hill, Normanton, Derby.
†H. Field, 12, Bayswater Road, Handsworth, Birmingham.
*A. Firth, Prior Bank, Cherry Tree Road, Sheffield.
†W. J. Flavell, Carter's Green Passage, West Bromwich.
†E. E. G. Grimwood, 6, Balmoral Terrace, Glebelands Road, Ashton-on-Mersey.
*J. Haigh, 9, Bradford Road, Wakefield.
†J. Hogg, 365, Manchester Road, Burnley.
†J. R. Hyde, 27, Hastings Road, Millhouses, Sheffield.
†L. Jackson, Engr.-Lt.-Comm., 2, Richmond Avenue, Park Lane, Sheffield.
†J. B. Johnson, 27, Ball Fields, Tipton, Staffs.

†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.
*H. Pemberton, 15, Wolfa Street, Derby.
†J. M. Primrose, 47, Baird Street, Camelon, Falkirk.
†J. S. Glen Primrose, Richard Johnson & Nephew, Ltd., Metallurgical Laboratory, Bradford Iron Works, Manchester.
G. E. Roberts, Rosedale, Earlsdon Avenue, Coventry.
*J. G. Robinson, 17, Gibraltar Road, Halifax.
*J. Shaw, 39, Montgomery Road, Sheffield.
†R. J. Shaw, 41, Dorset Road, South Ealing, W.5.
†W. H. Sherburn, Rotherwood, Stockton Heath, Warrington.
†J. N. Simm, 61, Marine Drive, Monkseaton.
†Jas. Smith, Harton Lea, Harton, South Shields.
†T. A. Spiers, "Belah," Marston Road, Leicester.
†H. Winterton, "Moorlands," Milngavie, Dumbartonshire.
†D. H. Wood, 7, Augusta Road, Moseley, Birmingham.
†H. J. Young, c/o. North-Eastern Marine Eng. Co., Ltd., Wallsend-on-Tyne.

* Elected at Annual Conference. † Branch Delegates.

BRANCH PRESIDENTS AND SECRETARIES.

(Ex-officio on General Council).

BIRMINGHAM.

Thos. Vickers, 14, New Street, Birmingham.
H. J. Roe, 33, Herbert Road, Bearwood, Birmingham.

EAST MIDLANDS.

S. H. Russell, Bath Lane, Leicester.
H. Bunting, 17, Marcus Street, Derby.

LANCASHIRE.

R. A. Miles, 46, Dean Lane, Newton Heath, Manchester.
T. Makemson, 21, Beresford Road, Gorse Hill, Stretford Manchester.

BURNLEY SECTION OF LANCASHIRE.

G. Barnes, 16, Tremallan Street, Accrington.
J. Pell, 100, Rose Grove Lane, Burnley.

LONDON:

V. C. Faulkner, Bessemer House, 5, Duke Street, Adelphi, London, W.C.2.
H. G. Sommerfield, Charterhouse Chambers, Charterhouse Square, London, E.C.1.

NEWCASTLE-ON-TYNE.

J. W. Frier, 5, Northumberland Villas, Wallsend-on-Tyne.
C. Gresty, 93, Queen's Road, Monkseaton, Northumberland.

SCOTTISH.

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

SCOTTISH-FALKIRK SECTION.

G. Walker, 21, Napier Place, Bainsford, Falkirk, N.B.
J. E. Gibson, "Armont," Falkirk, N.B.

SHEFFIELD.

Cecil H. Desch, Ph.D., D.Sc., The University, St. George's Square, Sheffield.
R. Village, Albion Foundry, Whittington Moor, nr. Chesterfield.

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.
A. Love, 232, Gladstone Street, Bradford.

Hon. Treasurer :

F. W. Finch, 52, Denmark Road, Gloucester.

General Secretary :

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

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Institute of British Foundrymen

ANNUAL CONFERENCE
HELD AT
NEWCASTLE-ON-TYNE.

June 4, 5 and 6, 1924.

The twenty-first Annual Convention of the Institute of British Foundrymen was held in Newcastle-on-Tyne from Wednesday, June 4, till Friday, June 6.

The business of the Convention opened on Wednesday, June 4, in the Lecture Theatre of the Literary and Philosophical Society, Westgate Road. Mr. Oliver Stubbs, the retiring President, presided, and there were a large number of members and visitors present.

Civic Reception.

The members and visitors were welcomed by Dr. R. W. Simpson (the Deputy Lord Mayor of Newcastle-on-Tyne), the Right Hon. Lord Joicey, J.P. (President of the Newcastle and Gateshead Incorporated Chamber of Commerce), and Sir Theodore Morison (Principal of Armstrong College and Vice-Chancellor of the University of Durham).

Dr. Simpson apologised for the absence of the Lord Mayor, who was absent in London on a very important engagement. The industry with which the Lord Mayor was associated (the building industry) was passing through a very difficult time, and on that day there was a very critical meeting in London—critical not only from the industrial, but the national, point of view—and he had considered it his duty to attend. Dr. Simpson hoped the members of the Institute would accept that explanation, and the Lord Mayor's regret at the same time.

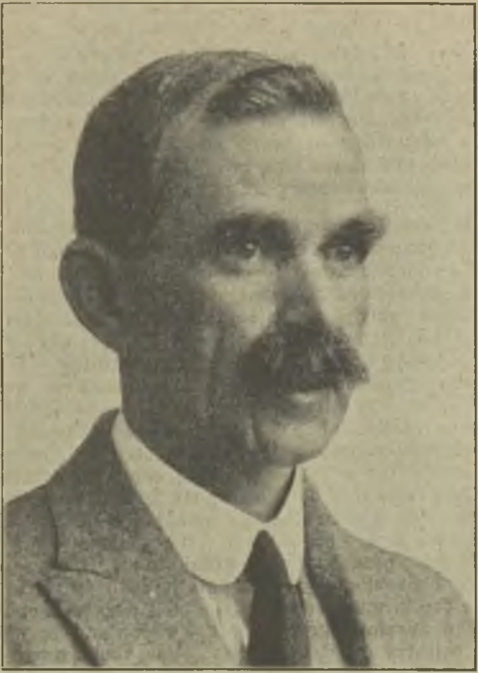
Dr. Simpson, continuing, said he was very glad that it had fallen to his lot to welcome such an important Institute. He understood that this was its twenty-first year, and he took it as a very happy incident that he happened to be the Deputy Lord Mayor, and had the task of welcoming the Institute on the occasion of its majority. He hoped it would have a very successful future. He understood that it existed for the linking up of science and industry, and he could imagine no happier object for any body than to carry out that very high ideal. At the present time, in this country, we are suffering a good deal from want of sympathy and want of co-operation between the scientific worker and the manual worker, and he could see that if the ideal of the Institute was carried out enthusiastically we should begin to get to the end of a good deal of our industrial unrest, which, at the present moment, is such an affliction.

The Industries of the Newcastle District.

Speaking of the industries of Newcastle, he pointed out that the factories and works which would be visited by the members in the course of their stay in Newcastle were the pride of the North of England. The Newcastle people were very delighted to think that the turbine, a great engineering proposition, was invented and perfected on the Tyne as was also the locomotive; so that two of the most outstanding engineering triumphs in the whole world were originated in the Tyne Valley. On behalf of the Lord Mayor, the Corporation and the citizens of Newcastle, he wished the members a very profitable and enjoyable sojourn in Newcastle, and hoped that the meeting would benefit both the Institute itself and the nation, through the efforts of the Institute.

Tyneside's Notable Engineers.

The Rt. Hon. Lord Joicey said that as the representative of the Chamber of Commerce, he was very glad indeed to have the honour of receiving so distinguished a body as was represented by the Institute, which was doing splendid work. Although the Institute had only been in existence twenty-one years it had already made its mark in



Mr. John Cameron (Senior Vice-President).

Mr. John Cameron is managing director of Messrs Cameron & Roberton, Limited, of Kirkintilloch, near Glasgow, and also a director of the Eastern Light Casting Company, Limited, of Bengal, India. He is the elder son of the late Mr. John Cameron, and became the sole proprietor of this firm in 1890, and remained so until the concern became a private limited company in 1899. Mr. Cameron joined the Institute of British Foundrymen in 1917, and the following year represented the Scottish Branch on the General Council. That his services were appreciated was shown by the fact that he was elected a member of the council in 1921. He is also a member of the Council of the British Cast Iron Research Association. Mr. Cameron has made a study of semi-steel, and has read Papers on this subject at Glasgow, Falkirk, Sheffield, and before the 1922 Birmingham Convention.

the industries it represented. He had been told that the educational portion of the Institute's work was having a very good effect upon the various industries and upon the young men who were likely to carry them on in the years to come. Depend upon it, he said, in these days it was absolutely necessary, if we were to hold our own, to take advantage of every means in our power to develop our industries in order to compete with those in every other part of the world.

He realised that in the future this country would have to face such competition as it had never had to face before. Many of those whom we had been accustomed to supply with our various manufactured goods were beginning to manufacture them for themselves, and many of them were even supplanting the industries of this country. When it was considered what that competition would mean, he was sure the members of the Institute would realise the importance of bringing all those who represented the industry to the very highest point of efficiency that could be attained. As had been said by the Deputy Lord Mayor, Newcastle was practically the birthplace of the locomotive, and, indeed, of the development of railways, because those great men, George and Robert Stephenson, who had had so much to do with the locomotive, were the men who took charge of the development of the railways, and to whom the country owed so much. Then there was Lord Armstrong, who, of course, had built our great ships, and was such an inventor with regard to ordnance. Following him, there was Sir Charles Parsons, the inventor of the turbine, to whom the country owes so much. Long may he remain with us to carry on his splendid work. There were many more such names that he could mention which would show, at all events, that the North of England has contributed as much as any other part of the country to the great developments of industry of which we were so proud. The Chamber of Commerce represented all the various industries. It was not limited to the City of Newcastle, but extended over the whole of the district—Tyneside, the Wear, Northumberland and Durham—and these industries had found it to their advantage to become connected with the Chamber of Com-

Photo] [*Elliott & Fry*

Mr. V. C. Faulkner (Junior Vice-President).

Mr. V. C. Faulkner was trained under Professor J. O. Arnold at Sheffield University. He was a pioneer of the electric arc furnace, and has travelled extensively in Western Europe in this connection. Some three-and-a-half years ago he was appointed Editor of the "Foundry Trade Journal." He joined the Institute in 1908, and has read several Papers on electric steel manufacture. In 1921 he was appointed secretary of the London Branch, and was elected President in 1923, an office he still holds.

merce. The Chamber of Commerce, which he represented, was one of the oldest and, he believed, was proved to be one of the most influential in the country, and in these days, with Governments who are so keen and so apt to interfere with our various industries, it was necessary that our industries should have these organisations in order to see that the legislation which Governments were passing was not likely to be such as to injure these industries. Finally, on behalf of the Chamber of Commerce, he extended to the Institute the heartiest welcome to Newcastle, and hoped that their visits to various works would be useful to the members.

Sir Theodore Morison also offered a very hearty welcome in the name of the University of Durham, and, in especial, of Armstrong College. He hoped that the members of the Institute would find time to look at the laboratories at Armstrong College, and assured them of a most hearty welcome to the Scientific Departments of the College. It was a matter of regret that their visit happened to coincide with one of the rather gloomy portions of the academic year, *i.e.*, they were now holding the annual examinations, and he feared that neither examiners nor examinees would be able to give the members the whole-hearted attention which they would have been glad to give if they had come in more fortunate times. The University and the Institute had a great deal in common, because both were working upon the same problem, or rather, on different ends of the same problem. The University was engaged in the elaboration and investigation of general principles of science, whilst the Institute was engaged upon the practical application of these principles, and he had felt very strongly that neither side could achieve very much without the other. It was necessary that there should be a body of independent investigators who were pursuing true science for its own sake without regard to its practical or commercial application, but, at the same time, he assured the members of the Institute, as a member of the University, that it was of considerable benefit to those who were following pure science to have continually brought before them those practical problems and difficulties with which the members of the Institute were in daily contact. The two things could not work efficiently unless brought into wholesome co-operation, and it was on these grounds that he felt he had some claim to extend to the Institute a very hearty welcome on behalf of the University.

Presentation of the "Oliver Stubbs" Gold Medal.

The President then asked the Deputy Lord Mayor to present the "Oliver Stubbs" Gold Medal to Mr. John Shaw, of Sheffield. It would be agreed that the decision to present the Medal to Mr. Shaw was a good one. Everybody appreciated very much the work that Mr. Shaw had done for so many years, and more particularly during the last 18 months, in connection with test bars. As Sir Theodore Morison had said, there was a great necessity for co-operation between the practical and the scientific side, because one without the other was of no use. The Institute were doing their best to carry this work along, and they thought they could claim that, as a result of their work, they had been of immense benefit to the industry, and particularly to the employers, because they had been able to supply the employers with very well trained men to manage the foundry side of the engineering industry—better trained than ever before.

The Deputy Lord Mayor, in presenting the Medal, referred to it as the equivalent of the "Nobel Prize." It was given to the man who, during the session, had done, in the opinion of the Executive, the most outstanding work for the good of the Institute, the members, and the industry. That encouraged and recompensed research, which was very badly recognised in this country, and looked upon with the greatest suspicion by the Government and by the "Powers that Be" generally, and the presentation of the Medal was one more proof of the up-to-dateness and the good sense of the Institute. He congratulated Mr. Shaw upon winning the Medal.

The Medal was then presented to Mr. Shaw, amid loud applause from the members.

Mr. Shaw, in acknowledgment, said he appreciated the presentation of the Medal, not merely for its intrinsic value, but for the good feeling and esteem of the members, which it betokened. What little he had been able to do he had done purely and simply for the trade—a trade which was not understood, he was afraid, by University people, but one which would come into its own, for Diesel engine work could not go unless the metal used was improved.

Presentation of Illuminated Address to Mr Reason.

The Deputy Lord Mayor then presented to Mr. H. L. Reason (President of the Institute, 1922-23) an Illuminated Address, which it is the custom to present to retiring Presidents. In doing so, he said that one of the most valuable things in this world was regard for one's fellow-men, and the good opinion of the men one had been working with, and one of the most delightful things a man could treasure was a tangible expression of that good will. He congratulated Mr. Reason upon having been President of such a distinguished body, and upon having this very tangible emblem of the good will of the members.

The Address was presented amid applause.

Mr. H. L. Reason, expressing his appreciation, said he had been connected with the Institute for many years. Whatever he had done had always been a work of pleasure, and he numbered some of his best friends among the members of the Institute. A presentation of this sort served to remind one, particularly in the evening of one's years, that one had done something in one's humble way for the benefit of the industry, to which they were all so proud to belong.

The President, in proposing a vote of thanks to the Deputy Lord Mayor, Lord Joicey and Sir Theodore Morison for having given the members of the Institute such a splendid welcome, said they all appreciated it very much indeed, and were very pleased to think that the poor sand rat was beginning to be acknowledged as a very necessary "evil"—as some people might say—in the engineering industry.

The vote of thanks was accorded with acclamation.

The Deputy Lord Mayor, replying on behalf of himself, Lord Joicey and Sir Theodore Morison, said the measure of their thanks would be judged by the amount of the enjoyment of the members whilst in Newcastle. If the members of the Institute enjoyed themselves as well as it was hoped they would, the people of Newcastle would all be very pleased indeed.

THE ANNUAL GENERAL MEETING.

The 21st annual general meeting was then held.

The minutes of the last annual general meeting having been read, confirmed and signed,

The President proposed that the annual report of the General Council for the Session 1923-24 be adopted.

Annual Report and Balance Sheet.

The General Council have pleasure in presenting to the Members their Report of the progress and work of the Institute during the past Session 1923-24.

Four General Council Meetings have been held during the Session at Manchester, York, Manchester and London respectively. Representatives of the Branches from all parts of the country have attended the Meetings, and there has been an average attendance of thirty.

The respective Branches have the following members attached :—

	Members.	Associate Members.	Associates.	Total.
Birmingham	56 (54)	85 (88)	14 (17)	155 (159)
Coventry	29 (32)	41 (50)	4 (8)	74 (90)
East Midlands ..	32 (31)	46 (65)	7 (9)	85 (106)
Lancashire	99 (96)	174 (161)	6 (4)	279 (261)
London	80 (88)	64 (70)	11 (9)	155 (167)
Newcastle	84 (87)	100 (105)	67 (66)	251 (258)
Scottish	65 (70)	150 (153)	21 (17)	236 (240)
Sheffield	86 (93)	89 (100)	12 (13)	187 (206)
West Riding of Yorks.	36 (34)	46 (44)		82 (78)
Wales and Mon.	16	11		27
General	21 (31)	4 (13)		25 (44)
	604 (516)	810 (850)	142 (143)	1556 (1609)

The figures in brackets are for the session 1922-1923.

The total number of Members on the Roll of the Institute on April 30, 1924, was 1556. The Council regret to have to report that 12 deaths have taken place during the year, one of these being late Past-President, Mr. Chas. Jones, of Cardiff, who filled the position of President in 1912, and took considerable interest in the work of the Institute.

Annual Conference 1924.—This will be held on June 4, 5 and 6, on the premises of the Literary and Philosophical Society, Newcastle, by the kind permission of the authorities.

"Oliver Stubbs" Gold Medal.—The second medal was awarded to Mr. W. H. Sherburn, of the Lancashire Branch, the award being made on the ground of his paper entitled "Evolution of the British Foundryman," and for meritorious services rendered to the Institute from its inception as well as for the example and precepts given to the Members of the Institute and industry in general.

General Council.—The Members who retire in accordance with the Rules are Messrs. A. R. Bartlett, H. Pemberton, J. Shaw and H. Sherburn. Messrs. Bartlett, Pemberton and Shaw offer themselves for re-election. As six were elected at the last Conference only four will require to be elected at the Newcastle Conference to complete the ten Members as provided for in the Bye-Laws.

Standardisation of Test Bars.—The Tentative Specification has been issued and submitted for the consideration of the varied Technical Societies. No definite steps have been taken to place the matter before the B.E.S.A. because it is desirous that agreement shall be arrived at with the Special Committee set up by the B.C.I.R.A. Owing to certain circumstances this Committee has not completed its work, but there is a promise that a joint meeting will be held, probably before this report is published. A number of large firms have tried the various size bars in practice and are unanimous that, if test bars are specified, the new specification will give more information than any one sized bar.

International Tests.—A strong Committee has been set up to consider this matter. A member has been appointed from each of the Countries represented at the Paris Convention in September last. Mons. Portevan was elected Chairman, and Mons. Ronceray, Honorary Secretary. So far Mr. Shaw has not called the I.B.F. Committee together to consider this question, as it will be better to settle the question of the British Specification first. That will, of course, guide the Committee in their deliberations on the International Bar.

Diplomas.—Since the last Conference a new Diploma Award has been prepared, and these have been awarded to the following for papers read at

Meetings:—J. E. Bates, Coventry; C. Bickerton, Burnley; T. Brown, Sheffield; W. T. Evans, Derby; G. H. Judd, Coventry; J. Masters, Burnley; D. McQueen, Glasgow; J. D. Nicholson, Newcastle; W. Rawlinson, Lancashire; F. R. Rowe, Manchester; O. Smalley, Newcastle; O. Smalley, for paper read at Sheffield; John Watson, formerly of Sheffield; and C. Webster, Sheffield.

CERTIFICATES.—During the past Session a form of Certificate of Membership has been prepared and adopted. It was decided by the General Council that a Certificate should be given to all Members and Associate Members of the Institute whose subscriptions were paid up for the year 1923.

BRITISH CAST IRON RESEARCH ASSOCIATION.—In the last Conference Programme it was announced that Dr. Percy Longmuir had been appointed Director of Research, but he was compelled to resign at the end of his first year on account of ill-health. Mr. Thos. Vickers, who had acted as Secretary of the Association from its conception, has also resigned, and the Council has appointed Mr. J. G. Pearce to fill the offices of Director and Secretary. The Association has the benefit of the services of Mr. J. E. Fletcher as Consultant.

The acute depression in the Foundry trade has prevented the Association hitherto from entering on an ambitious research programme. There are now very distinct signs of improvement, and an active research programme is proceeding.

AMERICAN FOUNDRYMEN'S ASSOCIATION. — The Members generally are aware that in August last year we received a delegation from the American Foundrymen's Association, and that they were entertained in London, Sheffield, Manchester, Birmingham and Coventry. They afterwards attended the French International Conference in Paris along with a large number of our own Members. We have every reason to believe that the Members of the A.F.A. returned to the States feeling that the goodwill and hospitality shown to them had done much to cement the relationship between the two countries in the foundry trade.

WALES AND MONMOUTH BRANCH.—This new Branch has recently commenced operations with efficient Officers and we have every reason to hope that it will become a most successful Branch.

New Bye-Laws.—These are now in operation, and every Member will receive a copy of the same along with the Conference Booklet.

Statement of Account and Balance Sheet for the year ending December 31, 1923, are given below.

Oliver Stubbs, *President.*

W. G. Hollinworth, *General Secretary.*

BALANCE SHEET.

INCOME & EXPENDITURE ACCOUNT.

Expenditure.

	£	s.	d.	£	s.	d.
Postages				84	8	2
Printing and Stationery, including Printing of Proceedings				585	10	9
Council, Finance and Annual Meeting Expenses				74	3	11
Certificates and Diplomas				45	8	6
Illuminated Address				10	10	0
Branch Expenses:—						
Lancashire	81	7	9			
Birmingham	39	10	10			
Scottish	60	17	2			
Sheffield	69	19	3			
London	85	5	6			
East Midlands	29	4	3			
Newcastle	88	19	10			
Coventry	52	6	11			
West Riding of Yorkshire	34	1	9			
				541	13	3
Audit Fee				6	6	0
Incidental Expenses				24	10	6
Salaries: Secretary and Staff				400	0	0
Rent of Office				65	0	0
Depreciation of Furniture, etc.				6	12	9
Grant to Branches for Entertainment—American Delegation	125	0	0			
Less: Amount refunded	11	0	9			
				113	19	3
				£1,958	3	1

INCOME.

	£	s.	d.
Subscriptions Received	1,677	4	4
Sale of Proceedings, etc.	13	0	3
Interest on War Loan, Cash on Deposit, etc.	28	7	0
Miscellaneous Receipts	0	8	2
Balance—Excess of Expenditure over Income	239	3	4
	£1,958	3	1

BALANCE SHEET, DECEMBER 31st, 1923.

LIABILITIES.

							£	s.	d.
Subscriptions paid in advance							98	13	0
Sundry creditors							314	9	9
The Oliver Stubbs Medal Fund—£342 5 7 Local Loans £3 per cent.									
Stock at cost				£200	0	0			
Interest to date				15	0	4			
				215	0	4			
Less : Cost of Medal, 1923				10	0	0	205	0	4
Surplus at December 31st, 1922				965	7	3			
Less : Transferred to Oliver Stubbs Medal Fund	3	17	0						
Excess of Expenditure over Income for the year ended 31st December, 1923	239	3	4	243	0	4			
							722	6	11
							£1,340	10	0

ASSETS.

	£	s.	d.	£	s	
CASH IN HANDS OF SECRETARIES—						
Lancashire	12	8	3			
Birmingham	39	11	4			
Scottish	19	0	9			
Sheffield	50	3	3			
London	14	12	3			
East Midlands	20	5	4			
West Riding of Yorkshire	9	14	1			
Coventry	5	18	4			
				171	13	7

ASSETS—*continued.*

	£	s.	d.	£	s.	d.
Brought forward				171	13	7
Lloyds Bank, Limited—						
General Account	121	9	1			
Deposit Account	300	0	0	421	9	1
The Oliver Stubbs Medal Fund—						
£342 5 7 Local Loans £3 per cent. Stock at cost	200	0	0			
Balance in hand Lloyds Bank, Ltd.	5	0	4	205	0	4
Investment Account—						
£100 5% National War Bonds						
£350 5% War Loan at Cost				432	10	1
Furniture, Fittings, and Fixtures—						
Per last Account	66	7	8			
Less : Depreciation 10%	6	12	9			
	59	14	11			
Additions Typewriter and Seal	35	2	0	94	16	11
Birmingham Branch—						
Special Advance				15	0	0
				£1,340	10	0

We have prepared and audited the above Balance Sheet with the Books and Vouchers of the Institute and certify same to be in accordance therewith.

J. & A. W. SULLY & CO.,
Chartered Accountants,
AUDITORS.

April 15th, 1924.

The report was adopted.

THE PRESIDENT then proposed the adoption of the balance-sheet for the Session. The Finance Committee and the General Council, he said, had been through it very carefully, and were satisfied that it was a correct one.

No questions were asked, and the balance-sheet was adopted.

The New President.

THE PRESIDENT proposed the election of Mr R. O. Patterson (Senior Vice-President) as President for the Session 1924-25. In Mr. Patterson the Institute had—or would have, he hoped—a President who would be able to take them along on the right track. He had a wide experience of all sides of the foundry industry, and had travelled considerably in this country and abroad. He (Mr. Stubbs) felt fortunate to be able to put before the members the name of Mr. Patterson, and to assure Mr. Patterson of their loyal support during his term of office. One could not wish for a finer body of members than those of the Institute. They had all worked together splendidly, and one was very much better for having moved among them.

Mr. F. J. Cook, in seconding the proposition, endorsed all that Mr. Stubbs had said about Mr. Patterson. Those who knew him intimately knew that he had only one fault, and that was his great modesty. That, however, would not interfere with his carrying out the duties of his high office, and they would all be very proud to have him in the chair.

Mr. Patterson was unanimously elected.

Mr. Stubbs then invested Mr. Patterson with the chain of office, and trusted he would be given health and strength to wear it, and that they would all be better men at the end of his term of office.

Mr. Patterson, who was received with loud applause, expressed his great appreciation of the honour done him. He was just beginning to realise, he said, the magnitude of the office, but he hoped that, with the help of Mr. Stubbs, the Council and the members, the Institute would have another successful year.

The President, referring to the election of Vice-Presidents, expressed regret that Mr. E. H. Broughall had had to withdraw from the position of Senior Vice-President (to which he would have succeeded this year), owing to continual ill-health. The Council therefore had asked Mr. J. Cameron, of Glasgow, to fill that office. Mr. Cameron, in his usual good-natured way, had stepped into the breach, and he (the President) was sure that that would meet with the entire approval of the members, and he proposed that Mr. Cameron be elected Senior Vice-President for the ensuing year.

Mr. John Shaw seconded Mr. Cameron's nomination, and said he had known him for some years, and, as a member of the Test-Bar Committee, Mr. Cameron was most assiduous in his duties. At his own works he had made about 150 tests, and had carried them out to completion, and that would give them some idea of what to expect during Mr. Cameron's term of office.

Mr. Cameron was unanimously elected.

Mr. Cameron, in returning thanks, said how much he had always enjoyed and appreciated the membership of the Institute. After expressing his regret that Mr. Broughall was unable to carry on, he said he felt his own limitations in succeeding such a number of excellent Presidents; however, he would try to do his best.

Mr. T. Makemson then proposed that Mr. V. C. Faulkner, President of the London Branch, be elected Junior Vice-President. Mr. Faulkner's work, he said, was well known, and he had been a member for quite a long time. His work as a practical metallurgist was also well known to all. He had had a most varied experience as a metallurgist and foundryman, both in this country and on the Continent, and was a recognised authority in certain branches of steel works' practice. He had just completed a very successful year of office as President of the Branch; he was responsible probably more than any other man for the success, from the British point of view, of the International Conference in Paris last year.

Mr. Field (Birmingham), in seconding, said it had always been the desire of the officers and Council of the Institute to nominate for this high office a gentleman in whom they had confidence. In putting Mr. Faulkner's name forward, the Council felt that they were fulfilling the conditions which had always been fulfilled before, and he (the speaker) felt that he was only voicing the opinion of the Council when he said that Mr. Faulkner would fill the office with every grace and with every ability.

Mr. Faulkner was unanimously elected.

Mr. Faulkner, in expressing his thanks, said he was deeply conscious of the honour which had been done him. He did not take it so much as a personal honour, but as a recognition of the important character of the work which had recently been carried out by the London Branch. Also, perhaps, it was some recognition of the use of technical journalism to technical societies; when the time came for him to assume the chain of office of the Institute he promised that he would do his best to keep up the traditions of the Institute.

Hon. Treasurer and General Secretary.

Mr. Oliver Stubbs then proposed that Mr. F. W. Finch be re-elected Hon. Treasurer. Mr. Finch was, he believed, the first one to suggest the formation of the Institute of British Foundrymen, and, although he was not able to attend meetings very often, his interest was just as great as ever.

Mr. H. L. Reason seconded, and Mr. Finch was unanimously re-elected.

The President proposed the re-election of Mr. W. G. Hollinworth as Secretary.

This was seconded, and Mr. Hollinworth was unanimously re-elected.

Mr. Hollinworth expressed thanks for his re-election, and assured the members that he would continue to do his best for the Institute.

Members of General Council.

A ballot was taken for the election of five members of Council to fill the vacancies on the Council. The members ultimately elected were Mr. A. R. Bartlett (London), Mr. Wesley Lambert (London), Mr. H. Pemberton (E. Midlands), Mr. G. E. Roberts (Coventry), and Mr. J. Shaw (Sheffield).

Trustees.

The President proposed the re-election of Messrs. R. Buchanan. F. J. Cook, and Mr. Oliver Stubbs as Trustees of the Institute. This was seconded, and carried unanimously

Auditors.

On the motion of the President, seconded by Mr. Stubbs, Messrs. J. and A. W. Sully & Company, chartered accountants, were re-elected Auditors

Mr. H. L. Reason moved that the Secretary be instructed to write to Mr. Broughall expressing sympathy in his illness, and regret that he was unable to carry on as Vice-President. He thought Mr. Broughall would very much appreciate a message from the full Convention. He was almost one of the founders of the Institute, had done yeoman service, and had been looking forward with a good deal of pleasure to occupying the chair as President, and it was only through ill-health that he had had to give up the idea. His illness was very serious.

The President said that that would be done, and he felt sure all of the members felt very much Mr. Broughall's inability to carry on.

Greetings from the United States.

A telegram from Mr. G. H. Clamer was then read as follows:—

R. O. Patterson, Blaydon-on-Tyne.

On behalf American Foundrymen's Association I extend to you personally and to the Institute of British Foundrymen greetings and best wishes for a successful Convention. Kind invitation received; regret cannot be with you.—G. H. Clamer.

The President proposed that a suitable reply be sent to Mr. Clamer, which was agreed to.

Mr Stubbs Elected Honorary Member.

The President then mentioned a matter which had been dealt with at the Council meeting on the previous evening, that some slight recognition should be made of the extraordinary services rendered to the Institute by the Past-President, Mr. Stubbs. Mr. Stubbs had stepped into the breach last year, thereby doing both the Institute generally and the Newcastle Branch in particular a very good turn indeed. The Newcastle Branch was not quite ready to carry on, but Mr. Stubbs stepped into the breach and had filled it admirably. Therefore he proposed that Mr. Stubbs should be made a honorary life member of the Institute. It was the highest honour that it was in their power to give, and he believed it would be agreed it was the least they could do.

Mr. G. E. Roberts, who seconded, endorsed what the President had said. It was common knowledge that Mr. Stubbs had devoted an unprecedented amount of time to fulfilling the high office to which he had been called. He believed Mr. Stubbs had been round to almost every Branch during his period of office. He had given counsel to everyone who had asked for it, and added dignity to the office of representing the Institute at various conferences to which the Institute had been called to send representatives, and he (Mr. Roberts) was certain that the Institute would really be doing the right thing in recognising Mr. Oliver Stubbs' services in the manner suggested.

Mr. James Smith, President of the Newcastle Branch, supported the resolution. He said he had known Mr. Stubbs for a considerable time, and he was delighted to think that at Newcastle they were making him a honorary member of the Institute. It was eighteen years ago since the Institute had held its last Convention in Newcastle, when their dear and respected friend, Mr. Cook, was made President, and he was sure it would be a great pleasure to the Newcastle Branch to know that they had conferred honour upon their old friend, Mr. Stubbs.

The resolution was carried unanimously.

Mr. Oliver Stubbs, in a brief acknowledgment, said how much he appreciated the honour, which he would never forget and would always respect.

Presidential Address.

The President then delivered his presidential address.

Gentlemen,—

It gives me great pleasure to welcome you to the banks of coaly Tyne.

The last Conference held in Newcastle dates back to the very early days of the Institute, and great strides have been made since that day. Great as the progress has been, however, there is an immense field in front of us which requires our attention at the earliest possible moment.

The years which have passed since the close of the great war have, with one or two exceptions, been exceptionally difficult for the general foundry trade of the country. The post-war unrest, expressing itself in strikes and restrictions of output, has been one of the main factors in the destruction of our trade. The position to-day, whilst still most uncertain, is no doubt considerably better, and I am glad to say that prospects at the moment are more cheering, but the natural volume of trade is still very short. How can we as an Institute help matters along? What is firstly required to my mind is that the selling price of castings be materially lowered. This can only be done to-day by either lower wages or increased output. The first, I think we are all agreed, is out of the question; in fact, most of us will say that wages to-day are too low, and we would much rather like to see a rise, were such a thing economically possible.

The second method is one that takes some thinking over, and can only be approached from the view of giving better facilities in our foundries so that men can give greater output with less or certainly no more effort.

Great progress has been made in several directions, and it behoves us to study all new processes and, wherever possible, apply them in our own plants. There are a few developments which I should like to mention here as being worthy of our consideration.

Centrifugal Castings.

Take the question of centrifugal castings. This operation has been extensively developed, particularly in certain pipe foundries, and would appear to be making great headway, making stronger and lighter pipes than is possible by the old methods, and thereby lowering the cost to the consumer. Developments are also proceeding with centrifugal castings for engineering purposes. There are great possibilities in this direction, for if we can turn out a lighter and stronger casting so much the better for the engineer.

Melting Iron and Riddling Sand.

Then there are foundrymen at work experimenting with oil-fired furnaces in order to cut out the cupola, with a view of improving the quality of their molten metal, to suit high-class castings such as motor cylinders, which particularly require an iron low in total carbon.

Wonderful progress has been made, I am led to understand, by certain Midland aluminium firms in the production of die-castings. Castings as large as six-cylinder crank-cases are successfully made in dies, which surely must constitute a record. Then, again, what about our cupolas? Do we make enough of our engineering knowledge and apply same to save handling of material? I have attempted recently, in a small way, more or less mechanically to charge a pair of cupolas, and whilst not for a moment holding this arrangement out to be a perfect one, great savings have been made. My trouble was, however, that the whole installation had to be made in our own works. The only help received was from the illustrations in the technical press. Now in this direction is there not an opening in this country for a good foundry engineer? One who could act as a consultant, such as our American friends have in plenty. I visited the United States in 1919, and amongst many other things I was greatly taken by the gyratory riddles seen there in nearly every foundry. On my return I bought three of these, and can safely say that my expenses for the trip were more than made out of these riddles within 12 months. They are one of the greatest money-savers in a foundry, and yet the local agent tells me that he has the greatest difficulty in selling any of them up here on the North-East Coast. Now this should not be. We must wake up and take advantage of every mechanical appliance we can lay hold of.

The Sand Question.

The sand question is also one worthy of consideration. I am not satisfied that we get the fullest possible life out of our sands, but research is being made in this direction and should bear valuable fruit in time. The handling and preparation of sand is one that presents many interesting points to the foundryman, and large economies should be made by a proper application of good engineering practice in this connection.

The test-bar question has been very thoroughly ventilated during the past twelve months, and has proved to be a bigger proposition than was generally thought at the beginning. A vast amount of work has been done by the international committees, but nothing definite has been settled, and it would appear that a lot of ground has to be covered before finality is reached. I should imagine that perhaps this is a question which must be approached scientifically and without any regard to individual preferences.

Classification of Pig-Iron.

Has the time not arrived to make a move in the direction of the classification of pig-iron by analysis? This is a most important question and is long overdue. I know that certain pig-iron makers have the greatest reluctance to do anything in this matter; on the other hand, there are others who seem to want to do their best to help along the movement. The best way in which we can help is to encourage those who act sympathetically in the movement and buy our pig-iron from them whenever possible. With all the metallurgical knowledge we have at our disposal in these days, it seems ridiculous to have to buy our pig-iron by fracture alone, and I am quite sure that if each one of us moves persistently in this direction the producers will come into line in due time. The same remarks apply equally to our coke supplies. These for a very long time have been anything but satisfactory, and I am sure that we are now quite strong enough to insist upon our requirements being filled.

With regard to these last two items of pig-iron and coke, we might, I think, take a leaf out of the book of our American cousins, who have got both questions settled on very commonsense lines

Co-operative Research.

Now to help us along these sort of lines we have our own Institute, the British Cast Iron Research Association, and our various trade associations. These, whilst working on independent lines for the common good, ought, I think, to be brought into closer fusion. The Institute for the individual, the other two for the firms.

We all know what the Institute has done—and still does—for each of us, but are we making the best use of the research association?

After a vast amount of work this Association has issued from its teething stage and is now in full swing and doing valuable work for the industry. It provides expert technical advice, and reports on any difficulty or trouble experienced by its members in their everyday practice.

The reports provided cover a very wide range, including pig-iron, sands, fuels, moulding practice, cupola practice, designing of castings, production of semi-steel, malleable castings, and the mixtures and methods required for special irons for various purposes.

An excellent library is at the disposal of the members, and the Quarterly Bulletin provides a means of communication between the Association and the members on matters of common interest, and contain abstracts of literature relating to cast iron and foundry practice.

The Association conducts investigations for the purpose of learning more about the production, treatment, and the use of cast iron and malleable iron, and so enables members to improve their melting and moulding practice. The investigations are carried out at the most important laboratories in the country and in the works of members.

Periodical reports are issued as and when investigations are complete, and these appeal both to the ironfounders and to the engineer whose foundry is only part of his business.

The Association is working for the progressive standardisation of materials and methods of testing in the industry, acceptable to foundrymen. It aids members to meet specifications issued by various consumers and lends assistance in modifying specifications based upon inadequate metallurgical knowledge of foundry products.

These few words, whilst briefly indicating the activities of the Association, do not by any means cover the full field. It is an indispensable acquisition to the foundry trade, and I am looking forward to great strides being made in our business through the efforts which are being made.

Now with regard to our commercial associations, I think a field which might be profitably invaded is one which might be called commercial research. By this I mean that propaganda work should be instituted so that the consumption of castings might greatly be increased. For example, American railway trucks have cast-iron wheels; South African telegraph poles have cast-iron bases. Here we have " imported " wood poles, probably costing as much as steel and cast-iron poles.

In America and other countries they have cast-steel automatic truck couplers. A few cases of this sort instituted in this country would enormously increase the output of castings and thereby decrease our costs.

Shortage of Skilled Moulders.

We now come to another question which is causing a serious position in our industry, that is the shortage of really skilled moulders. Moulding is perhaps without exception the most skilled of all the engineering branches. I think that a moulder, and perhaps a blacksmith, is born and not made, and if statistics were taken out I am sure that a big percentage of boys apprenticed to the trade fail to become highly skilled men. Unfortunately moulding is a dirty trade, and it is difficult to get the best class of boy to take it up. It is therefore up to the employers to make conditions more attractive. Could we but get the boys interested in the metallurgical side of cast iron, even to a very elementary degree, I am sure that their interest in their work would be multiplied many times. It would, therefore, seem desirable that each works or a group of works should institute some sort of training class for apprentices. The most important, and by far the most interesting, subject for such boys to study would be that of cupola practice. The woeful ignorance of this subject shown by the average foundry operative is really terrible, although when one looks back to the days before the Institute of British Foundrymen the ignorance of the bulk of the employers on this same subject was equally abysmal. Therefore let us get at it, get hold of the boys, and train them up in the way they should go.

In conclusion, Gentlemen, may I sincerely thank you for having elected me your President. I am fully aware of the responsibility of the position, and of the difficult task it is to fill the chair, particularly when following such an outstanding personality as Mr. Stubbs, who has done so much towards bringing the Institute up to its present state. I know that I have his help at my disposal during the coming year, which I trust will carry with it the same success as last year.

Vote of Thanks to the President.

Mr. F. J. Cook proposed that a vote of thanks be accorded to the President for his very interesting and thoughtful address. He believed that what the President had said would show that the Institute had the right man in the right place.

Mr. Oliver Stubbs, who seconded, drew attention to the excellent work which had been done by Mr. Patterson, and expressed the opinion that in him the Institute had an excellent President. He had given them a great deal to think about in the course of his address. Referring to Mr. Patterson's remarks, he agreed that it was time the junior members came along and did some of the work, and he wanted to get junior members interested in the work as much as possible The older ones could not go on for ever.

The vote of thanks was carried unanimously.

The President briefly acknowledged it.

Vote of Thanks to Retiring Officers.

Mr. Russell proposed a vote of thanks to the retiring officers for the work they had done, mentioning particularly Mr. Stubbs and Mr. Broughall.

Mr. Cole-Estep seconded, and emphasised the work of the Test-Bar and Rules Committees.

The vote was acknowledged by Mr. R. Buchanan

THE BANQUET.

The annual banquet was held at the Grand Assembly Rooms, Barras Bridge, Newcastle-on-Tyne, on June 4, the President in the chair.

The toasts of "The King" and "The Prince of Wales and Royal Family" were proposed by the President, and were duly honoured.

Mr. Oliver Stubbs announced the receipt of messages of congratulation from the American Foundrymen's Association and the Dutch Foundrymen's Association; also, there were messages of regret for non-attendance from Sir William Noble, Mr. Summers Hunter and Mr. H. Hunter.

Municipalisation or Private Enterprise.

Mr. V. C. Faulkner (Vice-President) proposed the toast of "The City and County of Newcastle-upon-Tyne." He had had no time, he said, to go into the subject of his toast, but the guests were fortunate in that Mr. A. E. Johnstone, of "The Newcastle Chronicle," had given a description of Newcastle and the Tyneside industries in the souvenir booklet. Mr. Johnstone, a brother scribe, had been working in a larger sphere than himself, and was able to deal more adequately with the subject than perhaps any technical journalist could possibly do.

One would have imagined that, having lived on Tyneside for two years, as he had done, he would be able to give some real information about Newcastle, but two years was too short a period to learn of the many vicissitudes and activities of such a large city as Newcastle.

Mr. Johnstone in his article had said nothing of the municipal aspect. The municipality of Newcastle realised that it was advisable to leave to individuals the conduct of communal organisation, such as electricity and gas supply. He reminded his hearers that the cheapest gas in the kingdom in pre-war days, which must still be considered as normal, was supplied by the Sheffield Gas Company, and the cheapest electricity in Great Britain before the war was supplied by the Newcastle Electric Supply Company. Probably Newcastle was right, therefore, in leaving such services to private enterprise.

Again, Mr. Johnstone had not dealt with the diversity of industries which were carried on in the neighbourhood of Newcastle. In this respect the city largely resembled the foundry industry, because in the foundry industry they made anything from a sash-weight to a turbine casing, and they represented every trade operating in Great Britain. So, too, in Newcastle they operated the shipbuilding, the chemical, glass and pottery and other industries, and this phase might usefully be dwelt upon by any person to whom was confided the toast of Newcastle-upon-Tyne.

With the toast Mr. Faulkner associated the name of Dr. R. W. Simpson, the Deputy Lord Mayor, who had so kindly welcomed the members that morning. Newcastle contained about 333,000 inhabitants, but had made a finer show than many cities which could claim double the number. Dr. Simpson was chairman of the Health Committee, a very important position to occupy, and one which must take up a tremendous amount of his time and thought.

Finally, he said that as a result of this meeting he was sure that the story of Newcastle, with its wonderful enterprises and its works, would be talked about from Cleveland to St. Etienne.

The Problem of Local Government.

Dr. R. W. Simpson (Deputy Lord Mayor), in response, explained the regrettable absence of the Lord Mayor, who had had to attend an important meeting concerned with his industry in London. The Lord Mayor had asked him to express his sincere regrets and apologies for his absence.

Dealing with the problem of local administration, he said this was becoming very complicated. and emphasised to those present, who came from all over the country, that local government was becoming a very important business, and called for the very best brains. In local government they were trying to make intelligible and effective those half-digested Acts of Parliament which were dumped down on the local authorities, who were invited to administer them to the best of their ability. Therefore, he made an appeal to all who took a responsible view of their position in this world that it was their job to come forward—the very best of them—and help in solving this very difficult problem.

In expressing the enjoyment which his association with the foundrymen had given him, he said he had always associated foundrymen with Falkirk —(laughter)—but understood that there were quite a lot of foundrymen who had never seen Falkirk. There were two kinds of foundrymen, namely, real foundrymen and gentlemen who went in for light castings. He was almost ashamed to admit that he had been associated almost entirely with the latter. However, in future he would take a good deal more notice of the other man. He had been very struck with the high ideals of the Institute. He liked its motto, namely, the linking up of science with industry. If they could get that spirit to spread throughout the country—the linking up of the workman with the thinker, with the result that both were pulling at one end of the rope instead of opposite ends—then they would begin to see hope for the country. He considered that the British working man was the finest man in the world, and if he co-operated with the administrator, the thinker, and the scientist, the result would be that we should not have to worry much longer about the condition of Europe.

Meeting Competition by Research.

Sir Theodore Morison, K.C.S.I., K.C.I.E., then proposed the toast of the "Trade and Industries of the North-East Coast," and associated it with the honoured name of Lord Joicey, whom all at Newcastle-on-Tyne had so long respected and admired. When Lord Joicey that morning had welcomed the Institute, in the name of the Chamber of Commerce, he had taken occasion to point out that British industry was going to be faced with competition in the future such as it had never had to meet before, and he (Sir Theodore) would venture to corroborate that, from what he had seen in India and in Asia, because he could assure his hearers that the industrial arts which had first made England the workshop of the world were easily learned by the intelligent people of

Asia. Therefore he realised to the full the truth of what Lord Joicey had said, and how these people, who had hitherto been our customers, would in future make for themselves the goods which they had been previously in the habit of buying from England. But Lord Joicey had continued that we could only meet this serious competition by more intelligent workmanship and by associating the industries of England more closely with the advance of science. He was sure the Institute would bear the advice of Lord Joicey in mind. If he himself might speak of it from the University end, he would say that he thought the association of industry with science was going to be of distinct benefit to science as well as to industry. He hoped the Institute would always take a wide view of science and would not consider merely the direct and commercial application of it, but would realise that it was pure science which was material and which had in the past proved to be of the greatest utility to mankind. Researches which were pursued only for the sake of expanding the bounds of knowledge, and for the sake of truth alone, had in the course of time proved to be useful to the very highest degree. There was a time, for instance, when entomology was spoken of with a sort of laugh, as the most useless of the sciences, and the caricaturist who wished to make cheap fun of science found nothing easier than to draw a picture of a spectacled man of science rushing over the country with a butterfly net. That was supposed to be typical of the futility of pure science. Now, however, it is common knowledge that a great many of the diseases from which mankind has suffered most were insect-born diseases, and a knowledge of entomology had proved the means of meeting such terrible maladies as malaria, plague, sleepy sickness, yellow fever, and many others. Even a knowledge of entomology is now possessed by many laymen.

Sir Theodore then referred to the solution of many industrial problems which had been investigated by Pasteur as the result of his scientific researches, and said he was convinced that it was in the fruitful association of industry and science that both industry and science would get the best reward.

The toast was received with acclamation.

Science in Industry.

The Right Honourable Lord Joicey, responding, said that all industries, in whatever part of the country—he might almost say the world—were pretty much in the same position as the result of the Great War. Therefore, when he spoke of this toast he felt he was speaking upon a subject which was of vital interest to all present, and to all those throughout the country who were connected with the important industries which were carried on. In thanking Sir Theodore Morison for the kind manner in which he had proposed the toast, he said he was very glad indeed to find that Sir Theodore was at the head of the University at Newcastle, to which they owed so much, and to which they were looking for so much in the future. In these days science plays an important part in our industries; in fact, science was going to rule the world. In the war we had fought the enemies successfully by science; in peaceful occupations we used science. Our ships were the best ships in the world owing to the science displayed in their construction and navigation. It was the same with our industries. If we were anxious to maintain the great reputation which this country had had in the world in the past, depend upon it we should have to make use of science to the very greatest extent we could. We had had great competition to meet. Germany was our great competitor. Why? It was not that the working men of Germany were more skilful or better workers than ours, or that the men who controlled these industries were more clever. The real reason was that the Germans applied science more to their various industries, with the result that they were able to produce cheaper goods, and to supply the world and districts where we had been accustomed to be practically predominant.

Strikes and Industry.

Again, we were suffering from the chaotic condition of the world's exchanges, and it was a very difficult matter to see how we were going to alter that. Governments were trying to alter it, but so far had not met with very much success. Again, there were strikes in every industry, all over the country. Surely it was the duty of the Government, if any duty it had, to try to introduce some method of avoiding these strikes. We did not want to adopt the methods of Mussolini. He had seen it stated that the year before Signor Mussolini had taken command of the Italian Government there were between seven and eight million days' work lost by strikes. The first year in which he had taken command there were something under 250,000. Surely, if Signor Mussolini could do that, it should not be beyond the power of our Government to do it, particularly a Labour Government, who pretended to understand these matters better than the leaders of industry.

Sir Theodore Morison had spoken about microbes. He (Lord Joicey) could not help thinking that, if there were a microbe affecting nearly all classes to-day, he would call it a microbe of slackness, and, if anybody could adopt a means to get rid of that unfortunate microbe, we should see a very great change indeed in the industrial position of this country. As an illustration of the effect of slackness, he referred to the inability to solve the housing problem, and made an appeal to the trade unions in this connection. He believed that there was no one more responsible at the present time for the shortage of houses than the building operatives themselves.

In conclusion, his Lordship expressed the hope that the prospect might be better than he anticipated. He was not a pessimist by any means, but a natural optimist, but when he saw facts before him he had always been accustomed to judge from those facts.

The Work of the Institute.

Dr. J. T. Dunn then proposed the toast of "The Institute of British Foundrymen," in the absence of Mr. Summers Hunter, C.B.E., J.P., who was to have proposed it, but had been detained in London on important business.

Mr. Dunn said he did not know what qualifications he possessed for proposing the toast, other than the very essential one of not being a member of the Institute, and, if he showed no others, he could only crave the indulgence of his hearers for his failure to perform adequately a duty so suddenly imposed upon him. He knew little of the Institute, but, from the little he did know, it seemed to be, in one respect at least, unique among our technical and scientific societies. For long the reproach had been heard of British industry that it was not conducted on scientific principles, but that it depended upon rule-of-thumb. There could be no question that an industry, to be thoroughly successful, ought to be, and must be, conducted upon scientific principles. Science must play its part, and we must, in order to perform the necessary operations successfully, understand the why and the wherefore of them. But, whilst that was the case, possibly the rule-of-thumb had been a little under-rated. In every industry, many of the workmen who had to conduct the manual operations were destitute of any scientific knowledge of the problems which underlay that industry. But, at the same time, though they worked by rule-of-thumb, they had a technical knowledge and deftness of manipulation which was possessed by no one else. That was perhaps the case to a varying extent, according to the age of the industry. The foundry industry was a very ancient one. It dated back at least to the days of Tubal Cain, and if in one industry more than in others they had accumulated, under the rule-of-thumb, an amount of tradition and an amount of experience, which was transmitted through the workmen, to a greater extent than in many other industries, it was in the foundrymen's industry. It would be a foolish thing, in endeavouring to apply scientific principles to the industry, to neglect or to throw on one side all that vast mass of accumulated experience and detailed knowledge, and what appeared to be the distinguishing feature of the Institute of British Foundrymen was that it did not neglect that, but that it had endeavoured, through its membership, to include the whole. The membership consisted not only of the controllers and guiding spirits of the industry: not only of the chemists who supervised the work and had an insight into the principles underlying the whole of it; not only the foremen, who supervised the operations of the foundry; but also the working men—those who actually performed the manual operations. That showed that the Institute of British Foundrymen had taken the very best course to ensure that foundry work in the future should be founded upon scientific principles, and should prosper and succeed. The very wise King Solomon had said: "Happy is the man that findeth wisdom and the man that getteth understanding, for the merchandise of it is better than the merchandise of silver, and the gain thereof than fine gold."

It seemed that the Institute of British Foundrymen had found wisdom, and had endeavoured to get an understanding of all the principles which underlay its work; surely they might wish it Godspeed in its efforts.

American Foundry Conditions.

The President, who, when rising to respond, was greeted with loud cheers, said he had seldom heard this toast proposed in better form. Dr. Dunn had referred to the value of science in the industry, and he (the President) thought that they, as an Institute, could boast of having instituted science in their foundries and thereby having gained enormous benefit to the industry. They were primarily responsible for the formation of the British Cast Iron Research Association. Many of them knew all about it, but some may not know that in this country there is an Association entirely for the purpose of carrying out researches into the very complex question of cast iron and other foundry problems.

They had with them that evening Mr. Pearce, Director of the British Cast Iron Research Association, and it was with great pleasure that he extended to him a warm welcome. Mr. Pearce is doing valuable work for the industry, and he (the President) had no doubt that within a very few years they would be in a better position in this respect than they are to-day. They also had the hearty interest of such men as Professor Turner; indeed, they had had a paper by one of his pupils. Professor Turner has done immense work upon cast iron, and his books and papers are unique and very valuable. They also had with them representatives from America, France and Holland. This, naturally, went to show the strides that had been made by the Institute. He thought he was right in saying that theirs was the first Foundrymen's Institution in the world, and that other countries had copied, and are still copying, their example. On the other hand, speaking of the practical work, apart from science, he thought they were to be congratulated upon the class of workmen they had in Great Britain. Lord Joicey had certainly given them something to think about, but he (the President) had great hopes and great faith in our men, and thought that they were undoubtedly the most highly skilled men, without exception. He had paid a visit to the States some years ago, and was greatly struck by the fact that the workmen there who were doing the intricate class of work in the foundries were Britishers, but he must admit that a large percentage of them were Scotsmen. (Laughter.)

At the same time, he would say that our American friends stood predominant as regards repetition work, but, to be fair again, he thought they had been driven into that position because they had not the highly skilled men available there. They had had to make their castings by machinery because of their lack of skilled labour.

Mention has been made of the wide range of the output of foundries in this country. At his own firm they made castings ranging from sash-weights to turbines, and he thought that on Tyneside the workmen were as highly skilled, and turned out as high a class of work as any others in this country.

Education Facilities not Available.

Education had been touched upon, and they, as an Institute, were greatly concerned about the education of the younger men in the foundry. They would like some sort of classes to be inaugurated for the education of those boys. A year or two ago the Newcastle Branch approached the Elucation Authorities of Newcastle to see if some sort of popular lectures might be arranged for the benefit of those boys, and to give them interest in the elementary science of the business. They received the answer: "Yes, we can do that, but. of course, the boys will have to matriculate before they can do anything." He (the President) would like to know how many of those present that evening could go through a matriculation examination. He therefore thought that it would devolve upon themselves to institute classes to suit their own men.

Inadequate Engineering Support.

For many years the foundry industry had been the Cinderella of all the engineering trades. They had never had an adequate price for their products. and the result had been, and still is, that they were hard up. They simply could not afford any money to conduct researches. There were thousands of foundries which ought to have laboratories, but could not afford them. There are about three thousand foundries in this country, and how many of them had not joined the British Cast Iron Research Association because they could not afford it? He thought that this was a very deplorable state of affairs. Cast iron was a very complex material, and we really could not do without metallurgists, but we really could not afford them. Therefore, we should have to have better prices from our engineers. The Institute of British Foundrymen was very dear to him, and it had helped the industry immensely.

In conclusion, he wished to say that he was very much indebted to Dr. Dunn for the very able way in which he had proposed the toast, and, on behalf of the members, he wished to thank him.

The Guests.

Mr. Oliver Stubbs, Past-President, proposed the toast of "Our Guests," and said how very much the Institute appreciated their presence. The Institute had never had such a splendid gathering as they had on that occasion, and he was delighted to see all the guests. The Institute claimed that it was entitled to the presence of the guests, because it had been working very hard for a long time with very poor recognition from the heads of industry. The work it was doing was of a most important nature. He claimed that if we took the working classes of this country and got the thinking classes to talk to them and educate them, they would give of their best. It was entirely the fault of the thinking classes if they allowed other people to take the workers in hand, and he asked the guests, particularly those interested in the engineering industry, that they would give the Institute in the future very much greater support than they had done in the past.

Among the many guests present he mentioned

Lord Joicey, the Rev. Canon G. E. Newsom (Vicar of Newcastle), and Sir Archibald Ross. In regard to the last named, he said that, from his experience of Sir Archibald, the Institute had in him a very excellent character, and one which many of them might endeavour, as far as possible, to copy. It had been his privilege on many occasions to listen to Sir Archibald Ross when matters of extreme importance had been under discussion, and he had never found that in any case had he taken anything but an impartial view, and had always endeavoured to give the very best judgment.

On behalf of the Institute, he again expressed thanks to the guests for their presence, and complimented the Newcastle Branch upon the fact that they had been able to assemble so many important guests. He coupled with the toast the name of Sir Archibald Ross.

British Power Producing Plants.

Sir Archibald Ross, responding, said he liked to think that the reason he was asked to respond to the toast was because he was President of the North-East Coast Institution of Engineers and Shipbuilders. One might say, " What are all these Institutes doing, with banquets, beanos, speeches, etc.? " He, himself, was aware of the work which the Institute of British Foundrymen was doing on the technical side of the profession, and too much stress could not be laid upon that. Lord Joicey had said that it was not owing to the superiority of her workmen that Germany was forging ahead before she had made the great mistake of her history, but that it was because of superior technical knowledge. Though he agreed with Lord Joicey as to the wickedness and idiocy of restriction of output, he would not admit that we were lacking in technical education, but he did say that, at the present time, more than ever before, is it necessary to advance education because of the great advances that are being made in the engineering industry; and it was because of the crying necessity for economy that we had to seek for better results and higher efficiencies in all power-producing plants. Because of that, we had to have recourse to superheat, to the better use of oil and—although Lord Joicey might regret it—to the less use of coal, and it was because of these advances which were being made, which were to result in getting more power for less fuel, that the engineering industry had to look to the moulder to give it more complicated castings than in the past. The President had said that engineers did not pay an adequate price for castings. He (Sir Archibald) would say that engineers did not get an adequate price for engines either.

In conclusion, he expressed the thanks of the guests for the hospitality extended to them.

The Chairman.

Mr. Wesley Lambert proposed the final toast of the evening, that of "The Chairman," which, he said, he proposed with a very great deal of pleasure. On behalf of the General Council, of which he was a member, he could say they had no misgivings at all that the President this year would see them through his year of office with every credit to himself and to the Institute. He (Mr. Lambert) had no fear at all that there were any difficulties which the President would not plough through. Therefore, he had great pleasure in proposing the toast of the President of the Institute.

The toast was received with musical honours.

The President, in a brief response, thanked the assembly for the way in which the toast was received, and took the opportunity of expressing thanks to the Convention Committee for the way in which the banquet had been carried out. In particular, he mentioned Mr. Colin Gresty (Secretary of the Convention Committee)—(applause)—upon whose shoulders the bulk of the work had fallen. Indeed, he had worked like a nigger, with the results which were so apparent. Mr. Gresty had taken all the work from his (the President's) shoulders.

An excellent musical programme was rendered during the evening, and the banquet ended by the singing of "Auld Lang Syne" and "The National Anthem."

SECOND DAY.

On Thursday morning the conference was continued in the Lecture Theatre of the Literary and Philosophical Society. The President occupied the chair. After the discussion on Mr. A. Logan's Paper on "Non-Ferrous Alloys in Marine Engineering," THE PRESIDENT announced the receipt of a letter of congratulations from the President of the Italian Foundry Association.

An American Appreciaton.

MR. H. D. MILES, of Buffalo, U.S.A. (Past-President of the American Foundrymen's Association), who was present, then addressed the meeting, on the invitation of the President. When it was known that he was coming to this country, he said, the Secretary of the American Foundrymen's Association had asked him to attend the Convention, and he had been very glad to do so. Speaking of the visit of the American foundrymen to this country last year, he said that all those who had come over had expressed their very great pleasure at the way in which they were treated, and the interesting things they had seen. Mr. Miles then read the text of an illuminated address, which had been prepared and signed by the President and Secretary of the American Foundrymen's Association, and was to be presented to the Institute of British Foundrymen. It was as follows:—

"To the Council and Members of the Institute of British Foundrymen: Mr. Oliver Stubbs, its President; Mr. R. O. Patterson, its Senior Vice-President; Mr. E. H. Broughall, its Junior Vice-President; and Mr. W. G. Hollinworth, its Secretary. We, the Board of Directors of the American Foundrymen's Association, at our first meeting after the visit of our officers and certain of our members to your shores, on the occasion of the International Congress of Foundrymen, held at Paris, September 12 to 15, 1923, have, by unanimous acclaim, directed that this testimonial be transmitted to you. Verbal expressions, by those of us who enjoyed your generous hospitality and delightful comradeship, have been made.

"To those individual expressions we would add our sincere and heartfelt collective appreciation. To the joy of personal friendships formed, the happiness engendered by innumerable attentions and distinguishing entertainment, was added the sense of kinship and consonance of purpose. It was an inspiration to fraternise with those who think strongly, attempt fearlessly, and accomplish masterfully with magnanimity. Allied by blood, speech and similar ideals, may we embrace every opportunity to pool our pleasures as well as the problems that beset our calling, that difficulties may be bravely met and wisely overcome. May mutual esteem and purpose, seasonably planted, bloom and bring forth fruit.

" We ask that you accept this official expression as the composite of many, with wishes of happiness and prosperity to each of you, to your Institute, and to your great nation.

" THE AMERICAN FOUNDRYMEN'S ASSOCIATION."

Continuing, Mr. Miles said he was glad to be able to present the text of the address at that meeting, when so many members of the British foundry industry were assembled together. Referring to the forthcoming convention of the American Foundrymen's Association, on October 15 next, he said there were always a number of exhibits at those conventions, and they were showing a large number of machines which were manufactured in the United States for use in the foundry industry. This combination of papers and exhibits brought a large attendance, there being usualy an attendance in the neighbourhood of 3,000. There were a good many Papers, but not very much discussion upon them, but the attendance was greatly enhanced by reason of the exhibits. The latter were under the direct management of the Association, and, by that means, they were able to get a good deal of revenue, which helped along the educational work of the organisation. In conclusion, Mr. Miles again expressed his pleasure at being able to attend the Convention at Newcastle.

International Co-operation.

MR. OLIVER STUBBS, responding, said it was a very gratifying finish to his presidency of the Institute of British Foundrymen to hear from Mr. Miles the testimonial, a copy of which, he understood, was being forwarded by the American Foundrymen's Association to each of those branches of the Institute who had entertained the members of that Association during their visit to England last year. But, if he might be perhaps a little impertinent he would like to say that other branches, though they had not had the opportunity of entertaining the Americans, were none the less loyal in their kind regard towards them, and he would be glad if the American Foundrymen's Association would be so good as to send a copy of the testimonial to each branch of the Institute. Great strides were being made on the international aspect of the foundry industry, and they all knew full well that it was this interchange of opinion that was going to bring the nations still more closely together. We had been concerned often with regard to the question of another big war; but he would say, as he had said in the past, that if the people in the different countries, connected with industry, were allowed to get together and to discuss the matters which concerned their industries we should not be talking about wars. On behalf of the Institute, Mr. Stubbs welcomed Mr. Miles, who occupied a prominent position in the engineering world in the States, and, he believed, as far as the States were concerned, was very much to be thanked for the high pressure of blast at which they were bringing their metal down in their cupolas. The closer the alliance between the English-speaking nations, the sooner should we get to understand each other better, and reach the position of giving everybody credit for good intentions.

Mr. Stubbs then referred to a member of the Institute of whom they thought a great deal, and who was returning, in September, to his homeland—America. That was Mr. H. Cole Estep. Mr. Estep, he said, had been largely responsible for bringing about this good feeling between the U.S.A. and Great Britain, and the Institute felt that his going away would be a great loss to them. (Hear, hear.) They hoped he would come back pretty often. In fact, he was coming back in 1926, in which year he would be taking about 300 members of the Institute of British Foundrymen over to the States to attend the International Conference there. The members of the Institute had valued Mr. Cole Estep's presence in this country very much indeed. The high ideals and high principles he had expressed had been a great incentive to them, and if the American foundry industry sent someone half as good to take his place, then the industry in Great Britain would be fairly lucky. Finally, Mr. Stubbs expressed the hope that Mr. Cole Estep's future would be crowned with prosperity.

Mr. H. Cole Estep expressed his deep appreciation of the remarks to which Mr. Stubbs had given expression, and regretted his inability to deal with them adequately at a moment's notice. But it was well known that he had felt very much at home in this country, and in a good many ways he was very sorry indeed to be going back. Americans who came to this country were to be congratulated upon their good fortune, and he could heartily second everything that Mr. Stubbs had said with reference to the usefulness of a mutual understanding between the two nations.

Convention Committee Thanked.

After the various Papers had been discussed, Colonel W. F. Cheesewright, D.S.O., rose to propose a hearty vote of thanks to the President and the Convention Committee, and took the opportunity of endorsing the remarks made earlier by Mr. Stubbs in regard to Mr. Cole Estep, and said that, in the course of something like thirty years of journalism, he had seldom, if ever, met a man who combined such a charming personality with such efficiency as did Mr. Cole Estep. Therefore, it gave him very great pleasure, as a brother journalist, to add those few remarks regarding his friend.

Colonel Cheesewright then proposed that the heartiest thanks be given to the President, and to the Committee who had worked so well behind him to bring about this record Convention. He was perfectly certain that the President had put in a great deal of very hard work in order to bring about such a successful meeting. Also, he mentioned especially Mr. Colin Gresty (the Hon. Secretary of the Convention Committee), and asked all concerned to accept the heartiest congratulations and thanks of the members.

Mr. F. J. Cook seconded the vote of thanks with the greatest cordiality. Speaking of the Papers which had been discussed, he said their quality was very high indeed—so much so that he did not think any conference in any country had ever had a set of Papers to equal them. Another striking feature of the Convention had been the very great desire to discuss the Papers. It was within the memory of some of the members that in the earlier days there was great difficulty in getting members to discuss even Papers on somewhat elementary subjects; now, however, there is a great desire to discuss intelligently even the very highbrow Papers, and that indicated the very great progress they were making as an Institution.

The vote of thanks was carried with enthusiasm.

THE PRESIDENT, responding, disclaimed any credit to himself, because he had done nothing, but he paid a tribute to Mr. Gresty for having shouldered the bulk of the work, and to Mrs. Gresty, who had rendered valuable assistance. After agreeing with Mr. Cook that the Papers presented had been excellent, and expressing his gratification that the Convention had been successful and enjoyable, he returned thanks on behalf of the Convention Committee.

MR. COLIN GRESTY, who also responded, disagreed with the President that the bulk of the work had fallen upon his own shoulders, though he acknowledged the help that Mrs. Gresty had rendered. Also, he mentioned the names of Mr. E. Wood (Chairman of the Committee), Mr. H. J. Young (Vice-Chairman), Mr. H. F. Parsons (Hon. Treasurer), and Mr. Victor Stobie, all of whom had worked very hard, the last named having, to a large extent, made himself responsible for the catering arrangements. On behalf of the Committee, he said that the greatest thanks they could possibly have was that the members should thoroughly enjoy their visit to Newcastle.

MR. V. C. FAULKNER then put to the meeting an omnibus resolution, expressing the thanks of the Institute to the authors of Papers, especially the foreign contributors; it also included the thanks of the Institute to the Newcastle Literary and Philosophical Society for having placed their lecture theatre at the disposal of the Institute. This MR. R. A. MILES seconded. The resolution was carried with acclamation, and the meeting closed.

Civic Reception and Garden Party.

In the afternoon there was a civic reception and garden party in the Banqueting Hall at Jesmond Dene, by invitation of the Right Honourable the Lord Mayor and the Lady Mayoress of Newcastle (Councillor and Miss Easten) on behalf of the City

Council. There was a large number of members and visitors present, and the afternoon was thoroughly enjoyable.

The Lord Mayor, in welcoming his guests, apologised for having been unable personally to welcome the Institute on the occasion of the opening of the Convention. He expressed the hope, however, that the visit of the Institute to Tyneside would be both pleasant and profitable.

Both the President and Mr. Oliver Stubbs voiced the thanks of the Institute to the Lord Mayor, Lady Mayoress, the Deputy Lord Mayor, and the Corporation for the kindness and hospitality they had extended to the members.

In the evening the members and ladies attended the Theatre Royal, at the invitation of the Convention Committee. An enjoyable entertainment was provided by "The Co-optimists."

THIRD DAY.

Friday morning was occupied by the members and ladies in visiting various works in the neighbourhood of Newcastle.

Luncheon.

Later, the members and ladies were entertained to luncheon at the Grand Assembly Rooms, Barras Bridge, by the Convention Committee. The President was in the chair.

Colonel Cheesewright, D.S.O., who, in an amusing speech, proposed the toast of "The Newcastle-on-Tyne Branch," said all would agree with him that the Branch had put up a most wonderful show. The Convention had been such that he ventured to think it would be very difficult for other towns to follow Newcastle's example. He had been very much impressed with the hospitality which had been extended to the Institute by the Newcastle Branch, and, on behalf of the members and ladies, he offered grateful thanks.

Mr. R. Buchanan (Past-President), who supported the toast, said the whole Convention had been wonderful, and it had been a delight to be present. The labour of the Convention Committee and of all those who had contributed to the pleasure of the members of the Institute and the ladies so effectively, must have been a labour of love, and he expressed thanks to Mr. Wood, Mr. Young, Mr. Parsons, Mr. Gresty, and Mr. Stobie in particular, and to the Newcastle Branch in general. The Convention would certainly remain in the memory of those who had attended it as one of the brightest that the Institute had ever had. He coupled the toast with the name of Mr. J. Smith (President of the Newcastle Branch).

Mr. James Smith, responding, referred to the time when the last Convention was held in Newcastle, 18 years ago. At that time, he said, there was no Branch of the Institute in Newcastle, but there were three members of the then Foundrymen's Assocation on the Tyne, Wear and Tees, namely, the late Mr. McFarlane, the late Mr. William Dalrymple, and himself. He sincerely hoped that he would be present when the next Convention was held in Newcastle. (Hear, hear.) About 12 or 13 years ago the Newcastle Branch of the Institute was founded. They had started with less than 50 members, but had progressed steadily, and there are now fully 250 members on the register. His hearers could rest assured that the Branch would continue to increase its membership, and he had not the slightest doubt but that in a few more years it would be one of the finest Branches in the whole country. After paying a tribute to the Convention Committee, and particularly to the gentlemen named by Mr. Buchanan, he referred to the manner in which the ladies had contributed to the success of the Convention, making special mention of Mrs. Gresty, who had worked so hard for the Convention Committee. In conclusion, he presented a bouquet to Mrs. Gresty, on behalf of the Newcastle Branch, as a mark of appreciation of the valuable services she had rendered.

The presentation was made amid loud applause.

Both Mrs. and Mr. Gresty returned thanks, the latter again drawing attention to the tremendous amount of work done by other members of the Committee.

Mr. Van Aarst (of Holland) then expressed, on behalf of himself and Mons. P. Chevenard (France), their keen appreciation of the kindness which had been extended to them during the Convention. The treatment of them by the British foundrymen would always be remembered by their own countrymen, who always regarded the British as real friends.

Mons. P. Chevenard, speaking in French, also returned thanks for his very cordial reception; in the name of the Association Technique de Fonderie de France, and of his countrymen generally, he must say "Merci."

Following the luncheon, the members and ladies split into two parties, one of which drove by motor to Rothbury, at the invitation of the Convention Committee, whilst the other went for a sail down the Tyne, by invitation of the Tyne Improvement Commissioners.

THE PRODUCTION OF CASTINGS IN PERMANENT MOULDS.*

American Excnange Paper.

By Robert J. Anderson† and M. Edward Boyd.‡

INTRODUCTION.

In the production of castings, interest has always been shown in attempts to devise and employ moulds that would be permanent or semi-permanent in nature, thereby eliminating the procedure of destroying the mould with every pour, as in sand practice. In connection with an investigation carried out in the U.S. Bureau of Mines on the production of aluminium-alloy motor pistons in permanent moulds,[50] study was made of the permanent-mould process in general, and more particularly of its application to the aluminium-alloy field. Permanent moulds are now employed in many branches of the foundry industry, and in the present Paper it is the writers' object to discuss permanent-mould casting in general, and to point out the applications and limitations of the process as compared with other casting methods.

The principles involved in the production of castings in permanent moulds (*i.e.*, metallic moulds) have been known and practised since 3000 B.C., but the cast-iron mould as it is known and used to-day has been employed only about 150 years. Moreover, the creation of permanent-mould casting as an important and separate industry is a relatively recent achievement. The permanent-

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* Published by permission of the Director—U.S. Bureau of Mines, and read before the Newcastle Conference.

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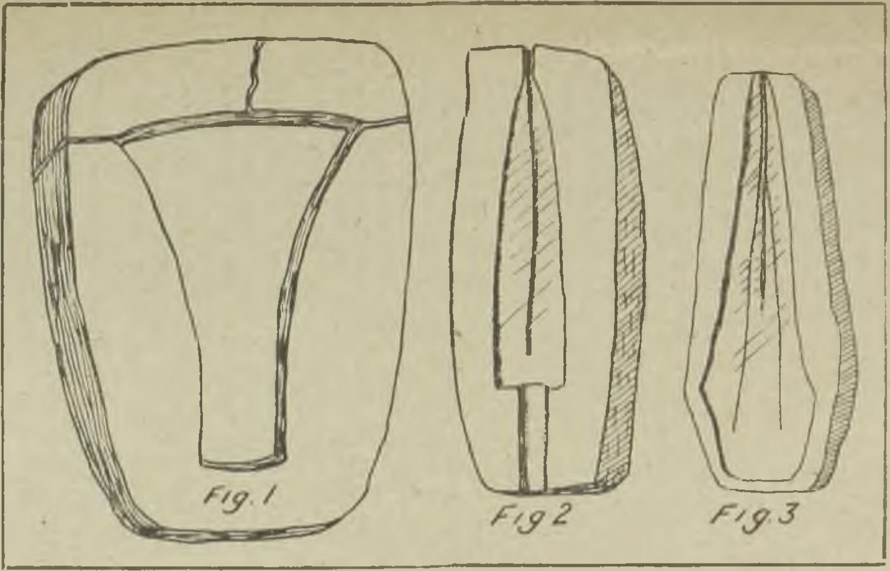

FIG. 1.—OPEN STONE MOULD FOR CASTING A CELT. (*Johnson.*)

FIG. 2.—HALF OF COMPOUND STONE MOULD, USED FOR CASTING A TANGED KNIFE. (*Johnson.*)

FIG. 3.—HALF OF COMPOUND STONE MOULD, USED FOR CASTING A DAGGER BLADE. (*Johnson.*)

mould casting of metals and alloys antedates sand casting by thousands of years, and stone and bronze moulds were employed by pre-historic man for casting weapons, ornaments, and tools. As indicated, the use of permanent moulds is desirable since in sand practice each mould is destroyed on pouring, and producers of castings desire moulds which can be used over and over again. The principal advantages of permanent-mould casting over sand casting may be summed up as follows:—(1) Permanent-mould castings are more accurate and uniform as to size and weight tolerances; (2) machining may be either greatly reduced or eliminated entirely; (3) permanent-mould castings have better surface appearance, are more sound, and have better mechanical properties; (4) the permanent-mould process is continuous, the output is normally more rapid than in sand casting, and production costs are lower; (5) unskilled labour can be used instead of skilled moulders; and (6) often parts that could not be made in sand can be made in permanent moulds.

The question of machining costs is especially important in the production of modern metal manufactures, and any process which will ensure lowered machining costs deserves especial consideration. Practically any mechanical part, unless too large or involving exceptionally complicated coring, can be made by permanent-mould casting, and such castings may be practically finished parts as they come from the mould, except for the removal of gates and fins and dressing on some surface. The requirements of the automotive industry for large numbers of small interchangeable castings offer a particularly adaptable field for permanent-mould casting, and at the present time a number of different castings for use in automotive construction are being produced in permanent moulds.

Acknowledgments.—The writers wish to acknowledge with thanks certain information supplied by concerns employing the permanent-mould process and by metallurgists and engineers connected with these companies. Certain photographs of French permanent moulds were supplied by Dr. Léon Guillet, and photographs were loaned by Dr. G. M. A. Richter, of the Metropolitan Museum of

Art; Dr. C. W. Mead, of the American Museum of Natural History; and Dr. B. Lanfer, of the Field Museum of Natural History. Other acknowledgments are made specifically in the text.

History of the Permanent-Mould Process.

While the history of casting metals and alloys is of unusual interest to the academic metallurgist and also of more general interest in tracing the development of foundry practice, the subject can be dealt with only very superficially here. So far as is known, casting in permanent and semi-permanent moulds antedates sand casting by thousands of years, and very early in the development of pre-historic man stone and bronze moulds were employed for forming tools and implements of warfare. According to Moldenke,* "so far as actual evidence is concerned, mention has been made of the ancients casting iron, and unquestionably in green-sand open moulds, but the art was lost during the early periods of history. The first mention of actual castings which can be documented is in 1370 A.D., in the testament of the Bishop of Poitiers. Here, unquestionably, the reference is to green-sand castings." So far as is known, the process of casting in permanent moulds dates back to the early Bronze Age (3000 B.C., at least), and the methods of casting as employed by the pre-historic founder have been very well discussed by Johnson.[24]

The first moulds employed by early founders, so far as is known, were very crude open moulds, formed of clay and burned hard. Such moulds were probably only semi-permanent and withstood only a few casts; very few of them are in existence to-day. Probably almost contemporaneous with the open clay mould, and doubtless the original precursor of the present-day permanent mould, was the open stone mould. Large numbers of these moulds have been found in the excavation of ruins, and are in the possession of the British Museum and other museums. These moulds were made by gouging out a cavity in the face of a soft rock, such as sandstone, micaceous slate, or soapstone, and most of them are of very simple design. Such castings as flat axes and celts were poured in the

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* Private communication. R. Moldenke, Dec. 24, 1923.

open stone moulds. By pouring copper or bronze into these moulds, simple weapons could be formed, and usually these were given further shape by hammering and then sharpened on a stone. Open stone moulds have been found in Ireland and England. Fig. 1 shows an open stone mould used for casting a celt. This mould was found near Ballymena, County Antrim, Ireland.

Following the open stone and open clay moulds came the compound clay and compound stone moulds. These compound moulds were parted in halves, and some of the specimens found exhibit truly remarkable skill and ingenuity in design by the prehistoric founder. The mould cavity and gates were cut in the two halves of the moulds, and these early moulds are similar in principle of design and operation to present-day permanent moulds. Fig. 2 shows half of a compound stone mould used for casting a tanged knife, and found near Ballymoney, County Antrim, Ireland. This mould was cut in close-grained sandstone. Fig. 3 shows half of a similar mould used for casting a dagger blade. The compound stone mould was developed to a high state of perfection, and was employed for casting daggers, sword blades, spear heads, and other weapons, as well as tools. Fig. 4 shows half of a compound stone mould obtained from the island of Crete; this mould was cut in steatite (a massive variety of talc, known usually as soapstone).

FIG. 4.—HALF OF AN OPEN STONE MOULD FROM ISLAND OF CRETE. (*Courtesy, Metropolitan Museum of Art.*)

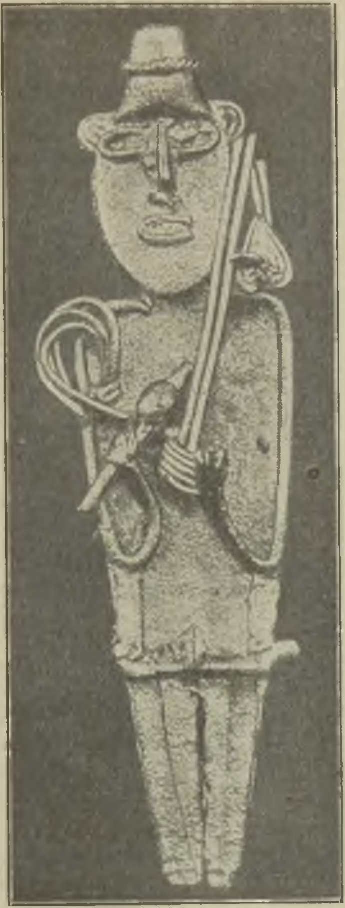

FIG. 5.—GOLD FIGURE WITH FILIGREE WORK FROM COLOMBIA. (*Courtesy, American Museum of Natural History.*)

Stone, terra-cotta, and some sort of wax moulds were used by the ancient Peruvians,* and Fig. 5 shows a gold figure with filigree work, cast in Colombia, probably in a wax mould. It should be pointed out that the filigree work on this object was not soldered on, but is an integral part of the casting.

Following the stone moulds, and marking another advance in the progress of the ancient founder in the art of casting, came the bronze moulds. These moulds were first copied from the earlier stone moulds. Bronze moulds withstood the erosive action of liquid copper and bronze better than the clay and stone moulds. Bronze moulds have been found in large numbers in Northern France and in England, and they were used for casting celts, daggers, gouges, palstaves, and other weapons, and tools. In these moulds there is shown a tendency toward more complication in design and in character of castings made. Fig. 6 shows a bronze mould used for casting gouges; this was found near Plenee Jugon, in Brittany. The two halves of the mould are shown in the figure. This was a cored mould, and, when put together, a bronze pin was inserted through the transverse

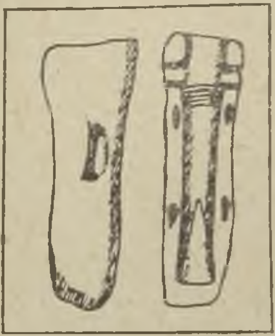

FIG. 6.—TWO HALVES OF BRONZE MOULD FOR CASTING GOUGES. (*Johnson*).

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* Private communication, C. W. Mead, Dec. 26, 1923.

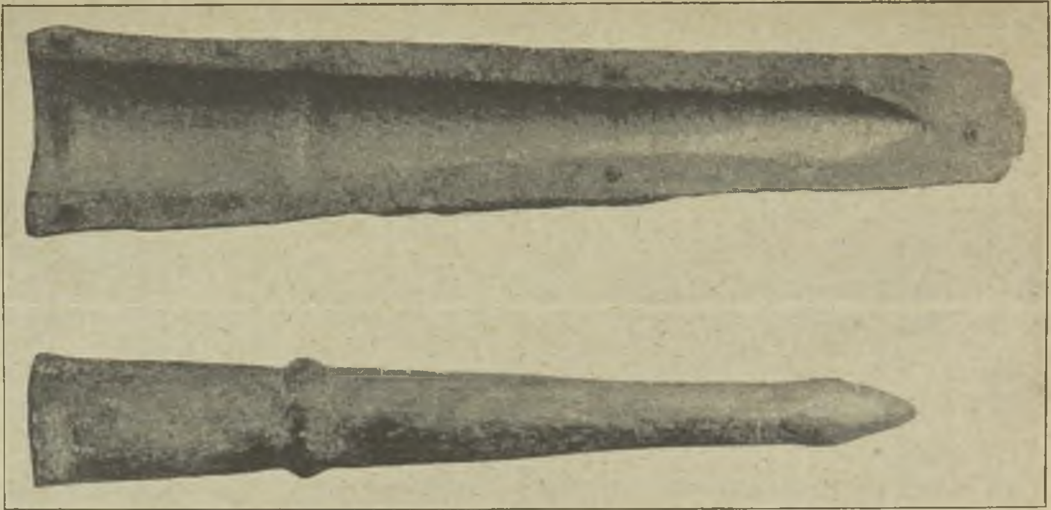

Fig 7.—Top Half of Copper Mould from China: bottom Spear Cast therefrom. (*Courtesy, Field Museum of Natural History.*)

hole shown in the left-hand half to keep the core in place on casting.

In Fig. 7 is shown, at the left, one-half of a copper mould used for casting a spear, and, at the right, the spear cast therefrom. The mould was obtained* at Si-anfu, China, and apparently dates from the third or second century B.C. As will be seen, there are small knobs along the edge of the mould half in the left of Fig. 7, and these apparently were to fit into holes in a corresponding half. Plaster halves were made up from the original half at the Field Museum of Natural History, and the spear shown in the right of Fig. 7 cast therefrom.

The guide to the antiquities of the Bronze Age in the department of British and Mediæval Antiquities of the British Museum[1] gives considerable information as to the types of castings produced by the prehistoric founder.

The discovery of iron and steel and the employment of these materials for weapons and implements required new methods of founding, and resulted in the employment of the sand mould. While the use of permanent moulds was not extensive for many years co-existent with the sand mould, the desire for moulds which would withstand more than one cast again asserted itself in modern times, and, early in the 19th century, patents bearing on the subject began to appear. The casting of iron and steel in permanent moulds presents greater difficulties than that of the non-ferrous alloys, and the process of casting ferrous alloys has been relatively slow in developing. However, the process of casting in metallic moulds—*i.e.*, steel or cast-iron moulds—has now been fairly fully extended to include all kinds of ferrous and non-ferrous alloys, and at the present time practically any type of alloy can be cast in a permanent type of mould. The permanent mould has been attracting much interest in recent years in connection with the centrifugal casting of iron and steel, but the permanent-mould process has not been used extensively for iron because of inherent difficulties involved.

The development of permanent-mould casting has progressed more rapidly in the non-ferrous field

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* Private communication, B. Lanfer, Jan. 29, 1924.

than in the ferrous, due largely to the fewer difficulties encountered in the former. However, even in non-ferrous castings, commercial production has been limited more or less to small castings of simple shape, although such castings as complicated motor crank-cases have been cast in permanent moulds using sand cores. As will be indicated later on, various modifications of permanent-mould casting, including die casting and Cothias casting, comprise separate industries, and the die-casting industry is operated on a large and profitable scale in the United States. Referring to iron castings, small articles of cast iron were made in permanent moulds for many years, but these were invariably chill hardened, and consequently unmachineable. About 1902 work was begun by Custer[3] [5] [10] [11] with permanent moulds at the Tacony Iron Company, Philadelphia, Pa., and a process was developed for casting sewer pipe, sash weights, pipe fittings such as Y and T sections, and other simple parts. In the production of sewer pipe, an arrangement of 30 moulds was mounted upon a revolving table and 240 pipes per hour were cast. The table carrying the moulds was operated mechanically in such manner that each mould was poured every 7-8 mins. The success of the process devised by Custer for avoiding the chilling of iron when cast in an iron mould depends upon the method of operation; in the process the iron is rapidly chilled to the freezing point by the mould, and then immediately removed from the mould so that the chilling effect is stopped, and then the casting is allowed to cool in air. Radiators, brake-shoes, cylinder blocks, and other cast-iron parts have been produced by the permanent-mould process. Just recently, a process for producing cast-iron parts in permanent moulds has been developed by the Holley Carburettor Company,[49] in which a so-called long-life mould is employed. The mould is made of ordinary grey iron, but a thin refractory lining made of ball clay and sodium silicate, or other suitable material, is applied to the face of the mould, and this lining is covered with a thin coating of amorphous carbon. The process of the Holley Carburettor Company is used at its plant for the production of cast-iron carburettors, and at the Ford Motor Company for the production of cast-iron pistons.*

Private communication, D. H. Meloche, Jan. 4, 1923.

In the non-ferrous field, the permanent-mould process is used for casting brass, bronze, aluminium bronze, and light aluminium alloys, and it can be adopted for the production of castings in any of the usual commercial non-ferrous alloys. The process has been employed very largely in the aluminium-alloy field for making pistons.[30] In a later section of the Paper the various kinds of alloys used in permanent-mould casting and the types of castings made will be discussed, and the applications of certain variations of the permanent-mould process to the production of certain types of castings will be taken up in the following section.

TYPES OF PROCESSES INVOLVING THE USE OF PERMANENT MOULDS.

At the outset, in discussing the permanent-mould process for producing castings, it is important to state that there are five essentially different commercial processes which involve the use of cast-iron or steel moulds. In trade parlance, there is considerable confusion in the use of terms applied to describe the castings made by these different processes, and it is accordingly desirable to distinguish sharply among them. The five processes involved are the following, viz.: (1) Die casting; (2) slush casting; (3) Cothias casting; (4) centrifugal casting; and (5) permanent-mould casting. In the present Paper the first four processes will be discussed only briefly, and for the purpose of distinguishing them from the process which should properly be termed permanent-mould casting. In the trade, the term "die castings" is often applied, either purposefully or unknowingly, to permanent-mould castings, and this is incorrect and misleading, since the properties and soundness of permanent-mould castings are normally much superior to those of die castings. The five types of processes are defined and discussed briefly below, and comparison is made of the different methods, and the suitable applications of the castings are pointed out.

Die Casting.

A die casting is defined as a finished, or practically finished, casting, made by forcing a liquid metal or alloy into a metallic mould or die. It is supposed that little or no machining other than drilling for screws, bolts, and the like, and removal of fins by dressing, will be required to put the casting into condition for use. Die castings are sometimes confused with die pressings, which are made by the hot pressing of metals and alloys, and die pressings are often referred to as die-pressed castings and die castings. A die casting is a *finished casting*, in the general meaning of the term, in contradistinction to a rough sand-casting, for which a greater or lesser amount of machining is invariably presupposed. Emphasis should be directed to an essential item in the die-casting process, which sharply distinguishes it from other processes involving metallic moulds, viz., the alloy is forced into the die cavity by pressure; such pressure may be mechanical, as a plunger working in a cylinder, or air pressure.

Die casting, as is the case with other processes involving metallic moulds, is essentially a quantity production process, and but few parts can be considered practical die-casting jobs in lots of less than 1,000. This is necessarily so because of the heavy expense involved in designing and preparing the necessary dies; in small lots, the heavy die expense will be proportionately reflected in the cost of the castings. The cost of any die-casting must normally be less than the cost of producing a sand casting plus the cost of machining to a finished casting equivalent to a die casting. The die-casting process is employed commercially for tin-rich, zinc-rich, lead-rich, and aluminium-rich alloys. Alloys of higher melting points, like the brasses and bronzes, can, of course, actually be die cast, but such alloys have so strong an erosive effect on ordinary die steels that the process is not commercial for these alloys. The life of a die when casting brass is exceedingly short, and at the present time the die-casting process is confined to alloys of relatively low melting points. Die-casting dies for aluminium alloy work are normally made of chrome-vanadium steel.

The die-casting process is especially applicable to the production of small interchangeable parts which do not need to be especially strong and sound, but which are required to be well finished and accurate as to dimensions. The die-casting process has been discussed at length in the technical literature, and attention may be directed to Papers by Pack,[28] [34] [43] Carman,[44] and Harriman,[45] and to the small book published by The Industrial Press.[36] The die-casting process has been applied very extensively to the production of small parts for automotive construction, household appliances, radio apparatus, adding-machine parts, cash-register parts, and for many other purposes.

Slush Casting.

A slush casting is defined as a practically finished casting made by pouring a liquid metal or alloy into a metallic mould, followed by immediately inverting the mould and thereby pouring out the excess unfrozen alloy in the centre of the mass, thus leaving only the solid shell formed by the contour of the mould. Slush moulds are made usually of brass or bronze, and zinc-rich, and other low-melting point, alloys are employed for casting. The mould is usually mounted upon trunnions, or otherwise arranged so that it may be rapidly inverted. The slush process is adapted for the production of certain types of hollow castings, but it is of no importance for making castings to be used in engineering construction. So far, the process has been confined to the production of vases, dolls, statues, figures, electroliers, and fittings. The process has been described by Rigg and Morse.[18]

Cothias Casting.

A Cothias casting is a finished, or semi-finished, casting made by first pouring a liquid alloy into a metallic mould and then forcing a top half of the mould containing the cores into the alloy whilst liquid, thereby giving internal shape to the casting. In the Cothias process, the lower half of the mould, which conforms in shape to the outside shape of the required casting, is heated, and a measured amount of liquid alloy is poured in; the top half of the mould, conforming to the inside shape of the casting, is then forced into the bottom half in the manner of a stamping press, thus forcing the alloy into the shape of the required casting. The plunger acts as the core. The process is adapted to fairly large castings in fairly low-melting point alloys, *e.g.*, aluminium alloys, where good surface finish and good mechanical properties are required. It is used largely for thin-walled castings of more or less open shape, and it is not applicable to complicated box castings with inside cores. Simple crank-cases, transmission cases, cylinders, and pistons for automotive construction are made in England by this process, in aluminium alloys. The Cothias system is little known in the United States, but is employed to some extent in England and Continental Europe. The process is described in an anonymous article.[31]

Centrifugal Casting.

A centrifugal casting is a finished, or semi-finished, casting made by pouring liquid alloy into a rotatable permanent mould, followed by rapidly rotating the mould so that the alloy is forced to the walls of the mould. In the process centrifugal casting machines are used, and these are extremely simple in design, consisting merely of a mould rotatable at high speed and a spout to supply the alloy. Moulds may be rotated on horizontal, vertical, or inclined axes. Moulds may be made of cast iron or alloy steel, and they may also be made of cast iron lined with clay; they may be run warm, hot, or water-cooled. The warm mould, by which is meant a mould which does not become especially hot and is neither heated by special burners nor water-cooled, was the first development. Water-cooled moulds, as in the De Levaud machines, have been used for making cast-iron pipe, while the hot mould, which permits the casting of quite thin sections, has been developed recently by Cammen. Special high-chromium steel is used for hot moulds.

Practically any cylindrically-shaped body can be made by centrifugal casting, and the process has been applied commercially to the production of pipe, railway-truck wheels, propeller sleeves, paper-mill rolls, tubes, and other parts. While the centrifugal casting of alloys is an old process, it did not assume much importance until about 1914. It has been used for both ferrous and non-ferrous alloys. The process has been described by Cammen.[42] [43]

Permanent-Mould Casting.

A permanent-mould casting is defined as a finished, or semi-finished, casting made by pouring a liquid alloy into a metallic mould, the alloy entering the mould and filling the cavity under the force of gravity solely. The process is the counterpart of sand casting, the only difference being in the nature of the mould. The terms "hand-poured die castings" and "gravity-run die castings" have been applied to the products obtained by permanent-mould casting. but these terms are quite unnecessary. By definition, the permanent-mould process can be very readily distinguished from other processes involving the use of metallic moulds, and this process will claim the greater part of attention in the present Paper. Objection has been raised to the use of the term "permanent mould" on the ground that the mould is not really permanent, but requires repairing and upkeep. Of course, nothing is actually permanent, but when several hundred thousand castings can be poured in a mould, either with or without repair, it may be regarded as permanent for all practical purposes.

In the permanent-mould process, when using collapsible steel cores, the liquid alloy is poured into a previously heated and assembled mould, and, after a short time, the cores are removed, the mould parted, and the casting taken out. The mould is then again locked, the core pieces are inserted in the reverse order of removal, and the mould is ready for another pour. Sand cores are also used in the permanent-mould process, and these are normally baked quite hard. For many years the permanent-mould process has been employed for the production of various kinds of cast-iron, brass, and aluminium-alloy castings, but the extensive use of the process is a comparatively recent achievement. At the present time cast-iron, brass, bronze, aluminium-bronze, and light aluminium-alloy castings are made by permanent-mould casting, and the use of this process is rapidly increasing. Permanent-mould casting, like die casting, is a quantity production process, and not many parts should be considered practical for casting in permanent moulds in lots of less than 500 to 1,000. This is so because of the expense of making the moulds, although mould costs in permanent-mould work are not nearly so high as die-casts in die casting.

The principles of permanent-mould casting as applied to cast iron have been discussed by Custer[3 5 10 11], as applied to non-ferrous alloys by Johnson[23] and an anonymous writer[37 38], and as applied to aluminium-alloy pistons by the present writers.[50]

Comparison of the Processes.

Sand casting, die casting, and permanent-mould casting are competitive processes, while Cothias casting, slush casting, and centrifugal casting occupy rather isolated positions except in the case of the production of special types of castings, when they become competitive to certain of the other processes. This statement is admittedly quite general, and is open to contradiction in numerous instances. In considering the various processes, the producer of castings is interested in knowing the advantages and disadvantages of each, their scope and applications.

Considered broadly, the permanent-mould process may be regarded as occupying a position midway between sand casting and die casting when the light aluminium alloys are considered, and it has a distinct field not covered by either. In comparing permanent-mould casting with sand casting, it is at once apparent that the former is economical only when a fairly large number of castings are to be made, since the cost of preparing the iron mould eliminates the process for consideration when only a few castings are to be poured. For large lots of castings that are suitable to the process, permanent-mould casting is much to be preferred over sand casting, since parts can be made more cheaply, more rapidly, and to closer size- and weight-tolerances. Machining may be eliminated to a considerable extent in permanent-mould castings, thereby effecting considerable savings over sand castings, not only for labour but for metal. One of the most important advantages lies in the fact that permanent moulds can be operated by unskilled labour, although the designing and building of the mould requires highly-skilled mechanics. Skilled labour is required for sand moulding. Referring to aluminium alloys, for large castings and complicated small castings the sand-casting method is generally best. For simple and small castings, and even fairly complicated small castings, which do not need to be particularly strong nor sound, the die-casting method is to be preferred. In the case of reasonably simple and small to moderately large castings, which are to be made in large numbers and which must be strong and sound, the permanent-mould process is advisable.

Compared with sand casting, the process of casting in permanent moulds has limitations as regards size of castings, and whilst large and complicated castings are not normally made commercially in permanent moulds, recent progress indicates that the size and complexity of the casting is limited largely by the ingenuity of the mould designer. There is little question but that many castings are made in the sand foundry which might profitably be made by die casting, and it is also true that some castings are made in permanent moulds which should be made by die casting. On the other hand, some parts are made by die casting which should be produced by permanent-mould casting, or in the sand foundry, and it is only possible to determine the correct method to employ by consideration of the type of castings to be produced. Emphasis should be laid upon the fact that the mechanical properties of permanent-mould-cast alloys are superior to those of die-cast and sand-cast alloys; permanent-mould castings, when properly made, are sound and free from porosity, while die castings are invariably unsound and contain numerous blowholes. Sand castings tend to have greater general unsoundness than permanent-mould castings.

Generally speaking, the permanent mould is cheaper to make than the die employed in die casting, first because the grey cast iron used for the former is more easily machined than the chrome-vanadium steel used for the latter, and second, because, ordinarily, the extreme accuracy specified in the die is not normally required in the mould. Moreover, the cast iron does not require heat treatment, whereas considerable heat treating is necessary in die making. The rate of output by permanent-mould casting is more rapid than by sand casting, but less than by die casting, and the accuracy is greater than in sand but less than in dies. The speed of production in permanent-mould casting is, of course, dependent upon the size and type of the casting being made, the composition of the alloy used, and the type of mould employed, referring more especially to whether automatic or hand-operated moulds are used. The rate of production is also affected markedly by the coring and as to whether sand or collapsible steel cores are used. Rate of output can be increased for small and simple castings by gating several together in a permanent mould and casting from one runner, as in a sand mould. The die-casting process has the advantage of great speed and accuracy, and it is much more economical than sand casting or permanent-mould casting for certain types of parts. However, where definite physical properties are demanded and where castings are to be heat treated, *e.g.*, aluminium-alloy castings, the permanent-mould process is to be preferred. Die castings cannot be heat treated to advantage, first because they are unsound and "blow-holey," and therefore unreliable as to strength, and second, because heating for annealing or quenching causes evolution of gas from the internal holes and consequent blistering. Larger castings can be made in permanent moulds than in dies, and definite and reliable properties can be secured. From the point of view of engineering construction, permanent-mould castings are much to be preferred over die castings or sand castings, since they possess better physical properties for the same alloy and are more free from blowholes and porosity.

In the matter of slush casting, this process occupies a distinct field of usefulness for the production of hollow and thin-walled castings in low-melting point alloys, but its scope of application is scant. The Cothias process does not offer any particular advantage over permanent-mould casting except that the use of mechanical pressure tends to give finer grained and stronger castings. At the same time, the process is limited as to the types of castings that can be made by it, and also by the circumstance that, so far, it is applicable only to fairly low-melting point alloys. It has not been used for brass and cast iron. Centrifugal castings is a useful process for the production of cylindrically-shaped castings, and owing to the pressure exerted by the centrifugal force, it yields fine-grained and strong castings. Moreover, any alloy can be cast centrifugally. The process cannot, however, have wide application in the foundry industry because of inherent limitations in the type of casting that can be made by it.

Any alloy and almost any type of part can be cast in a permanent mould as in a sand mould, and of the various casting processes involving the use of metallic or permanent-type moulds, this has the greatest scope and widest possible applications. The process cannot, of course, be considered for small lots of castings, nor for complicated castings with severe coring, so that for jobbing work and the production of large and complicated castings the sand foundry will always maintain its place in both ferrous and non-ferrous alloys.

Principles of the Permanent-Mould Process.

The process of making castings in permanent moulds, irrespective of the alloy and the type of moulds, consists essentially in pouring the liquid alloy into the previously heated and assembled mould, dissembling the mould as soon as the alloy has frozen, and then removing the casting. The mould is then re-assembled and is ready for another pour. In operation, the mould is first heated, and kept at a suitable temperature by the application of external heat, and the various parts are clamped tightly together, the alloy being poured as in sand practice. The casting freezes almost immediately, the core—if of metal—is withdrawn, and the mould is parted, allowing ejection of the casting. As stated in another place by the writers[50], the following three items are essential for the successful production of permanent-mould castings, viz.:—(1) A metallic mould which will withstand the action of the liquid alloy as well as rapid changes in temperature; (2) an alloy suitable for casting; and (3) a design of mould and casting and a method of gating which will ensure the production of good sound castings. In applying the permanent-mould process to the production of castings in specific alloys, especial consideration is to be given to the characteristics of the alloys, and this matter is dealt with at further length in a later section of the Paper.

There are a number of important factors governing the successful production of good permanent-mould castings with a minimum of wasters, and the following may be taken as the most important:—(1) Temperature of the mould; (2) pouring temperature of the alloy; (3) speed of operation, *i.e.*, number of castings poured per unit of time; (4) order in which core pieces are removed, if collapsible steel cores are employed; and (5) the size and location of gates, risers, feeders, vents, etc., *i.e.*, the method of moulding. The effects of these factors upon mould operation in the production of aluminium-alloy pistons have been discussed by the writers[59] in another place, and the principles there elucidated are applicable in general to the production of most kinds of castings in various alloys.

The fundamental principles upon which permanent moulds are built and operated are substantially the same, and Székely[*] has patented the general principles of permanent-mould casting.[2]

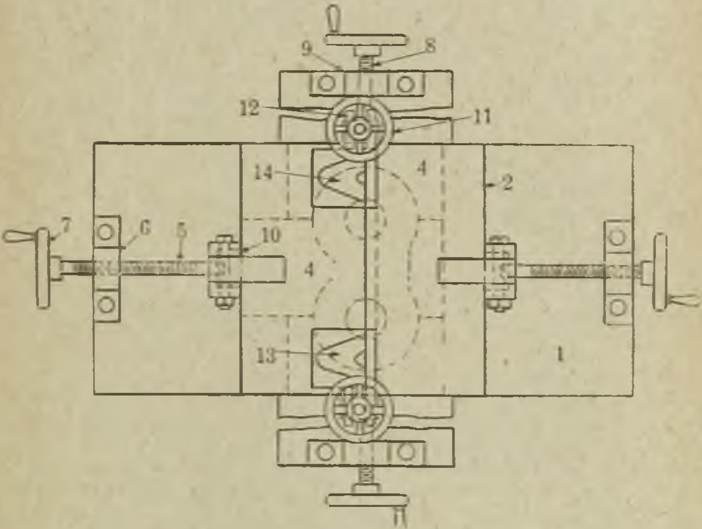

FIG. 8.—PLAN OF PERMANENT MOULD, CLOSED (*Székely*).

Many improvements have been made, however, in the past ten years, particularly in the construction and operation of moulds for the production of specific kinds of castings. Referring to the Székely patent, Figs. 8 to 11 inclusive show a form of permanent mould. Fig. 8 is a plan of the closed mould, which is made up in seven parts; Fig. 9 is an end view of the mould; Fig. 10 is a front elevation as seen from the left of Fig. 9; and Fig. 11 is a plan showing the mould thrown open.

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[*] U.S. Patent No. 841,279. January 15, 1907

Referring to these figures, *c* in Fig. 11 designates the casting produced in the mould. The mould itself consists of a base, *1*, movable sides, *2*, *2*, movable ends, *3*, *3*, and movable top plates, *4*, *4*. The mould sides, *2*, are slidable on the base and are moved thereon by screws, *5*, rotatable in nut bearings, *6*, on the base, and having crank-wheels, *7*. The mould ends, *3*, are also slidable on the base, and are operated by screws, *8*, rotating in nut bearings, *9*, on the base. The top plates, *4*, are hinged at *10* to the respective sides, *2*, and turn about these hinges, which connect the top plates to the respective mould sides, *2*. When the top plates are down in place, they are locked by means of swing bolts, *11*, which are hinged to the respective mould ends, *3*, and engage slotted lugs, *12*, on one of the plates, *4*. The swing bolts have a wheel nut. In one of the top plates there is an outlet, *14*, for the gases from the mould. Suitable core recesses are provided in the mould to suit the particular object being cast.

In the operation of casting, the sections of the mould are separated, the cores are set, and the interior surfaces of the mould coated with a suitable wash. The mould sections are then brought together by means of the screws, as in Fig. 8, and the liquid alloy is poured into the gate, *13*, until it appears at the riser, *14*. After the alloy has time to freeze so as to take the form of the mould, the mould is thrown open. The time during which the casting remains in the mould is about 20 secs. The mould is opened by first releasing the top plates, *4*, and turning them back on their hinges, and then running back the mould sides *2* and mould ends *3* by means of their respective screws. This is the position of the parts seen in Fig. 11, and it leaves the casting free from confining pressure or contact with the mould on all sides and at the top.

The mould described in Figs. 8 to 11 inclusive is for casting a rather irregular, intricate, and hollow pump section in cast iron or steel. In carrying out the process of Székely, it is specified that the mould is opened as soon as the surface of the casting shell has frozen sufficiently to retain the shape of the cavity, and a suitable wash or coating is specified for application to the cavity surfaces.

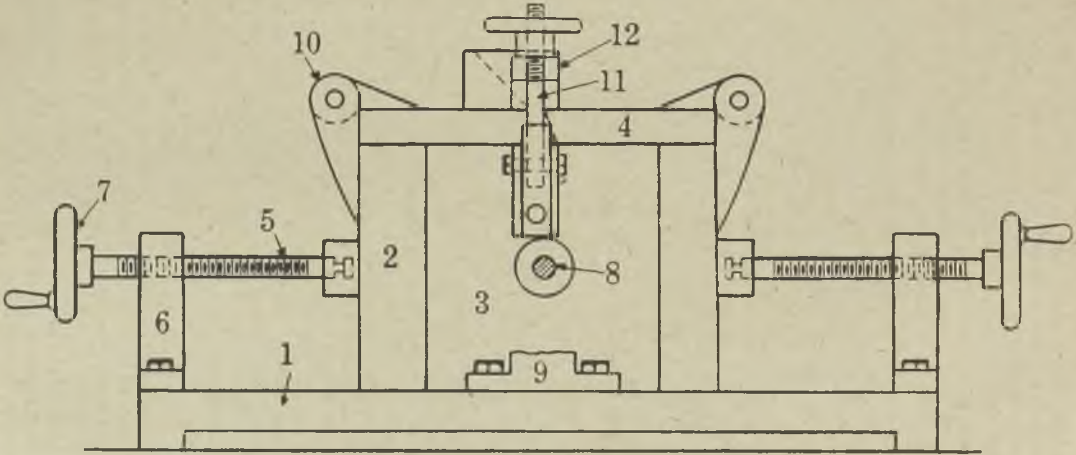

Fig. 9.—End View of Permanent Mould shown in Fig. 8 (*Székely*)

In this mould, a sand core is used, but collapsible steel cores can be applied.

In the operation of most types of permanent moulds, the proper relation between mould temperatures, pouring temperatures, and gating must be worked out to ensure the production of sound castings with a minimum of wasters.

Some Typical Examples of Permanent Moulds.

As pointed out previously, the three requisites for successful permanent-mould casting are as follows, viz.:—(1) A suitable mould from the point of view of the material employed for the body of the mould and for the core, and from the point of view of design; (2) a suitable alloy; and (3) a suitable design of casting. Since a different type of mould can be employed for every type of casting produced, it is useless to describe many types, but since the fundamental principles upon which permanent moulds are built and operated are the same, description of a few typical moulds will be sufficient for present purposes. Moulds may be entirely hand operated, semi-automatic, or practically entirely automatic, and in the automatic type of moulds mechanical devices are employed for opening and shutting the moulds. Cores are normally set by hand in most types of moulds, but in permanent moulds for casting pipe-fittings[8] they may be operated mechanically. In permanent-mould work, the casting impression of the mould must necessarily be larger than the desired finished casting, so as to allow for contraction, and the exact contraction allowance is dependent upon the alloy employed. A gate or gates must be provided in the mould for pouring, and suitable risers and vents are cut to permit feeding the cast and to permit the escape of air and gases, thereby preventing blowholes. In permanent moulds, the moulds are designed and constructed in sections, having in view the fact that, after a casting is poured, the cores must be removed if collapsible steel cores are employed, and the mould parted rapidly so as to prevent the casting from contracting on the core or around projections in the mould-cavity, and thus cause cracking.

As indicated, there are many types of permanent moulds employed for particular kinds of castings, but only a few of these can be described here.

Types of Moulds.

The shape of the casting to be made, and its size, as well as the coring necessary, determine to some extent the type of mould to be employed in permanent-mould casting practice. Generally speaking, there are about four basic types of moulds, each one adapted to meet the requirements in making specific castings most practically and economically. Typical moulds are described below, and the first three types are substantially the same as those used for aluminium-alloy piston production.[50]

In the first type of mould, the mould body proper is constructed of two halves or of several sections mounted upon a flat base plate which forms part of the casting and is essentially the bottom of the mould. Where the body is made of two halves, these may be hinged together and slidably parted, or else they may ride to and fro upon a track. The halves contain the mould impression and the gates and runners, and these cavities may be cut in only one of the halves or both. For flat castings, the cavity is usually cut in one-half. Fig. 12 shows a mould of the first type built upon a base plate that serves to form part of the casting, and in this mould the body

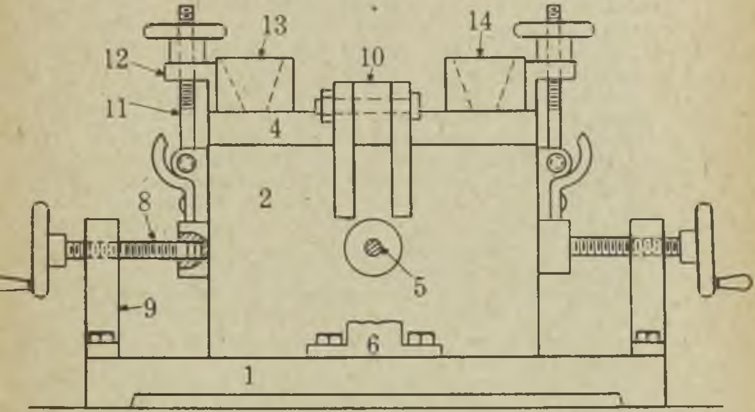

FIG. 10.—FRONT ELEVATION OF PERMANENT MOULD AS SEEN FROM THE LEFT OF FIG. 9 (*Szekely*).

proper is built up of several sections, and the largest section is fixed in position upon the base plate. The parting is not equi-axed with respect to the mould body, but the irregular sections (Fig. 13) are simply lifted out when the mould is dissembled. Fig. 12 shows the mould assembled and ready for pouring, while Fig. 13 shows the mould dissembled. This particular mould is used in French practice[40] for casting dynamo-starter castings in aluminium alloys.

In the second type of mould the body proper consists of two halves, which are slidably mounted upon a flat base-plate, which is simply a mounting and not used as part of the cavity proper. The mould halves are actuated by levers for parting and closing, and the halves are held in alignment by dowel pins or by a clamp and lock. The halves may either be hinged together or else ride upon a track, and the hinged type is more usual. Normally, the casting-cavity and the gates and runners are cut in both halves, but the gating cuts may be in only one of the halves. In such moulds the casting cavity is usually equi-axed with respect to the line of parting. In this type, when using the hinge arrangement, a flat, smooth surface is required upon which the halves will slide easily, while with the track arrangement the halves may be actuated on a rack, or by means of a worm screw, much in the same manner that a vice is opened and closed.

Fig. 14 shows a detail drawing of a mould of the second type. This mould was employed in England during the late war for casting aluminium-alloy packing-pieces for aeroplane-struts. The mould consists of the two halves, *1*, *1*, dowelled together and hinged around the stud, *7*, which is fixed to the base standard, *3*. The mould-cavity is equi-axed with respect to the mould parting, and the two inserts, *4*, *4*, are fitted to fill up the planed slots (section XX). These two inserts are screwed into position, but the screws are not shown in the drawing. This method of making the mould is adopted to simplify the machining operations. Runner blocks, *2*, *2*, are also screwed to the mould halves; here also, the screws are not shown in the drawing. The core, *5*, forms the slot in the casting and is riveted to lever, *10*, which moves on fulcrum, *9*, for raising and lowering the core.

When core, *5*, is in position, it is retained by core pin, *11*, which forms the hole in the casting. The two handles, *12*, *12*, are for opening and closing the mould. The small diagram in the upper right-hand corner of the figure shows the finished casting.

Fig. 15 is a detail drawing[38] of another mould of

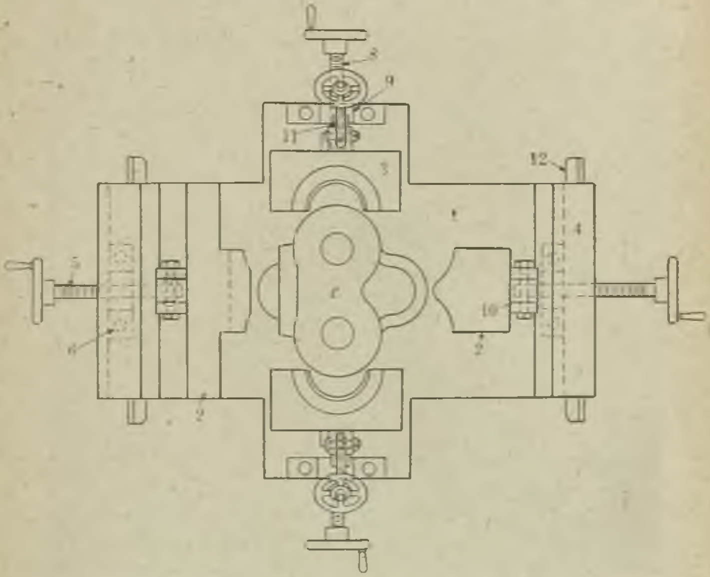

Fig. 11.—Plan of Permanent Mould, thrown Open; *cf.* Fig. 8 (*Székely*).

the second type. This was used in England for casting small gear-wheels in a zinc-base alloy, but the same mould could be used for aluminium alloys. The mould consists of two runner blocks, *1*, *1*, fitted with handles and hinged around the stud, *5*, which is screwed to the base-plate, *2*. The base-plate is screwed to the base standard, *3*. The two runner blocks form the upper boss, or hub, of the wheel, and are held in contiguity by the stop pin, *6*. The ring, *4*, is set in the base plate, and forms the teeth of the gear wheel, this ring having the reverse impression of the gear teeth cut on the inside diameter. The other hub of the gear is formed in the base plate. The core pins, *7*, of which there are four, and the single core pin, *8*, are made to sliding fit in *2* and *3*, all being operated by shank, *10*, as in the mould shown in Fig. 14.

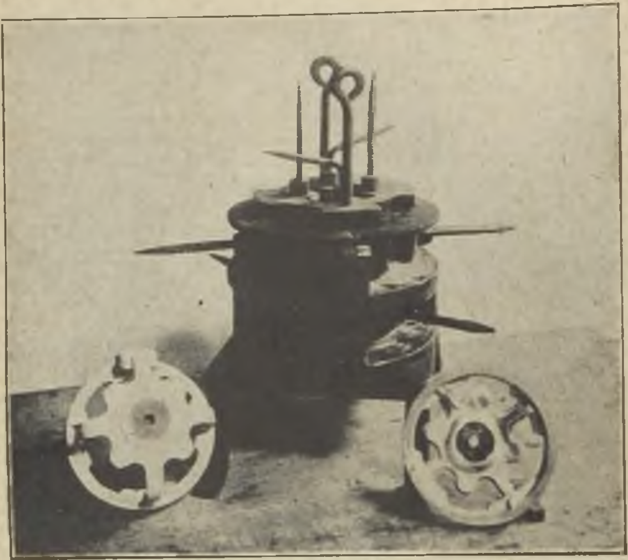

FIG. 12.—PERMANENT MOULD FOR MAKING DYNAMO-STARTER CASTINGS, ASSEMBLED (*Guillet*).

In the third type of mould the body proper consists of two halves, which are mounted upon a vertical arm so that one of the halves may be swung to and fro in the manner of a fence gate. The casting-cavity may be cut in one or both halves, as may be the runners and gates, but all cavities are normally cut in both halves, and preferably equiaxed with respect to the line of parting. Moulds of the third type have been developed by Custer and used for making cast-iron pipe fittings, such as T and Y sections.

In the fourth type of mould, the body proper consists of two halves, one of which is fixed in position on a suitable mounting, and the other is actuated mechanically for opening and closing the mould. The movable half may be slidably mounted upon rods or in other suitable way, and the movement is transmitted through gears and cams. Such a mould may be operated individually, but it is preferably set up as a battery on a revolving table.

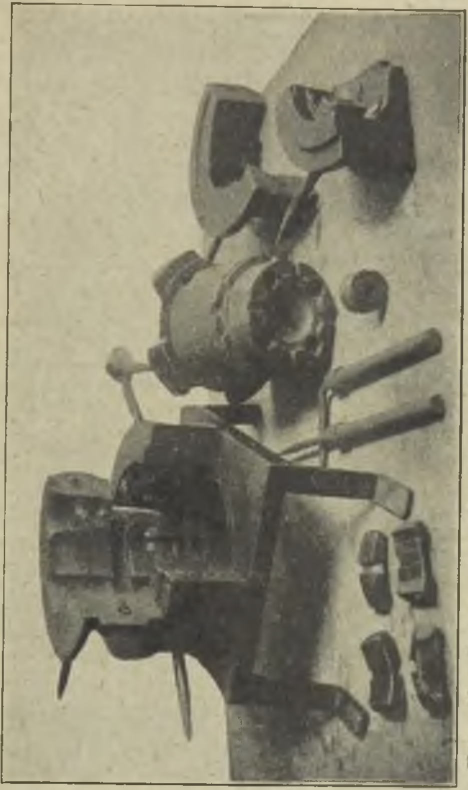

Fig. 13.—Permanent Mould for Making Dynamo-Starter Castings, Dissembled; *cf.* Fig. 12 (*Guillet*).

Six to twelve of such moulds may be mounted on a revolving table, and the pouring is done at one point from a platform, the operator remaining stationary. Such an arrangement is illustrated in photographs shown in Moldenke's Paper,[49] which show mechanically-operated mould tables employed at the plant of the Holley Carburettor Company, Detroit, Mich., for casting cast-iron carburettors.

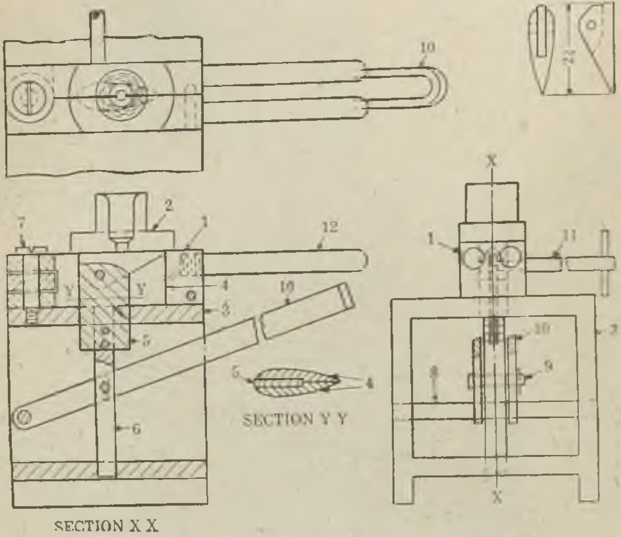

Fig. 14.—Detail Drawing of Permanent Mould for Casting Packing Pieces for Aeroplane Struts. (*The Metal Ind.*)

A sand core is used in these moulds. The moulds open mechanically on rotation of the table after a suitable short interval of time after pouring, the castings are ejected, and the moulds are then closed mechanically. By such an arrangement it is possible to increase the rate of production very markedly over hand-operated moulds.

For large and complicated castings, permanent moulds become more elaborate, and sometimes require two or more partings and intricate cores that slide into the mould halves. Usually this type of mould is mounted upon a heavy base-plate and rides upon tracks, the mould sections being actuated by means of a worm screw. In moulds of this type it is common to have a stationary middle section, with two movable sections working against it. The degree of mechanical perfection attained is, of course, dependent upon the ingenuity of the mould designer. With individual moulds, if very large, two or more operators are required, but for small work mechanical devices make it possible for one man to operate a mould.

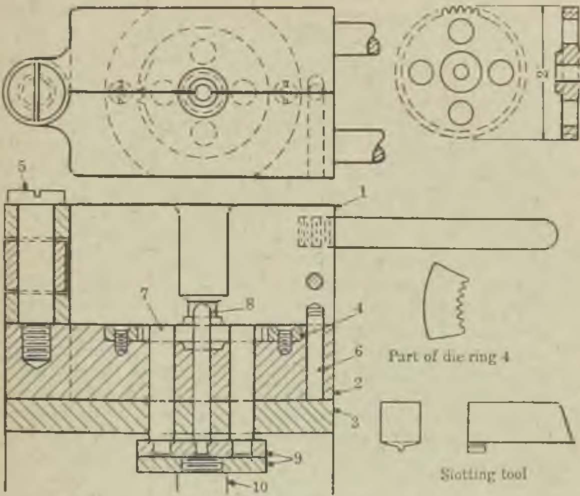

FIG. 15.—DETAIL DRAWING OF PERMANENT MOULD FOR CASTING SMALL GEAR WHEEL. (*The Metal Ind.*)

The question of cast-iron moulds for pouring rolling ingots in steel and non-ferrous alloys need not be discussed here, and while mention has not been made hitherto of plaster-of-paris moulds, a word on these latter may not be out of place in passing. Plaster-of-paris moulds are used to some extent for producing brass castings with a fine surface finish,[32] and such castings have the appearance of die castings or permanent-mould castings. Alloys cast in plaster-of-paris moulds are porous and unsound, and these moulds are not permanent but destroyed on each pour. Castings poured in plaster-of-paris moulds are often referred to as permanent-mould castings because they have a good surface appearance, but the term is incorrect and misleading, and should not be applied.

Patent Moulds.

Very many patents have been taken out relating to the permanent-mould casting of alloys, but the confines of space prevent detailed discussion of this subject here. Although the idea of casting in permanent moulds goes back to 3000 B.C., letters patent bearing on the process began to appear in the 19th century. The early patents dealt largely with the casting of stereotype plates and similar castings. Two typical early patents are U.S. Pat. Nos. 213,427, January 22, 1878, and 314,395, November 30, 1883. Earlier patents are on record. With the opening of the 20th century a considerable number of patents began to be issued bearing upon every conceivable aspect of casting in permanent moulds. The moulds described are to be made of cast-iron, steel, and other metallic materials, abrasive mixtures, graphite, refractories, and what not, and claims are made for mechanical principles of operation, and for alloys to be cast. The numbers of a few United States patents relating to permanent-mould casting are given in Table I.

TABLE I.—*American Patents issued in connection with Permanent-Mould Casting.*

U.S. Pat. No.	Date	U.S. Pat. No.	Date
695,091	Mar. 11, 1902	1,097,847	Oct. 26, 1910
714,061	Jan. 2, 1902	1,104,037	Oct. 22, 1910
841,279	Jan. 15, 1907	1,019,905	Mar. 12, 1912
859,612	July 9, 1907	1,360,655	Nov. 30, 1920
904,759	Mar. 3, 1908	1,368 445	Feb. 15, 1921
1,042,092	June 3. 1910	1.410,776	Mar. 28, 1922

A list of United States patents on the permanent-mould casting of aluminium-alloy pistons has been given by the writers[50] in another Paper.

Table II gives a few patent references to permanent-mould casting issued in other countries.

TABLE II.—*Patents other than American issued in connection with Permanent-Mould Casting.*

Country.	Pat. No.	Date.
Germany..	119,643	Jan. 16, 1900
France	338,645	Nov. 13, 1903
France	479,158	Feb. 28, 1916
England	105,101	Mar. 29, 1916
England	192,978	April 11, 1923

MATERIALS FOR MOULDS AND CORES.

Materials for Moulds.

Materials for constructing permanent moulds are rather limited, the more readily available being cast iron, steels of various kinds, nichrome, and malleable iron. Such materials as graphite and various refractory substances have been employed, but these have very definite limitations. Grey cast iron is a suitable material, and is much easier to shape and machine than is steel, particularly alloy steel. Mild steel has been employed satisfactorily, whilst semi-steel and malleable iron have been used to a less extent. Alloy steels such as used for die-casting dies are expensive, and the general tendency in permanent-mould construction is to employ grey cast iron There has been considerable discussion as to the best composition of cast iron for use in permanent moulds for non-ferrous alloy casting, but the writers are inclined to believe that this has been over-emphasised, since very satisfactory results have been secured using ordinary run of foundry iron. Close-grained iron of the order of semi-steel does, however, seem to yield longer life and less distortion than ordinary grey iron.

A satisfactory composition is stated to be as follows:—Combined carbon, 0.13; graphitic carbon, 2.98; silicon. 2.15; sulphur, 0.086; phosphorus, 1.26; and manganese, 0.41 per cent. Other analyses are given in another Paper by the writers.[50]

Grey iron moulds, particularly when used for pouring alloys melting above 600 deg. C., may warp, grow, and become distorted in service, and such growth and distortion are very markedly affected by the silicon-content of the iron. Rugan and Carpenter[4 12 14 25] have shown that the direct cause of growth of grey iron is due to the expansive force exerted by the oxidation of iron silicide, and the gases nitrogen and hydrogen increase growth when the silicon-content of the iron is between 1 and 3 per cent. Phosphorus, manganese, and sulphur in increasing amounts tend to diminish growth, and the results of all experiments made to date show that the growth of grey iron on repeated heating and cooling is a direct function of the silicon-content. However, unless graphite is present, silicon of itself is innocuous. Since the solution of growth difficulties lies in using material which contains no free carbon, and further, does not deposit carbon on heating, this rules out all grey irons and many white irons. White irons are, of course, unmachineable, and they almost always crack on heating, so that the only alternative in ferrous materials is to employ steels. The actual amount of growth in grey iron on repeated and prolonged heating may be 15 to 37 per cent. for silicon-contents of 1 to 3.5 per cent. respectively. Carpenter[12] states that an iron alloy containing carbon, 3.0; silicon, 0.6 to 0.7; and manganese, 0.5 per cent., does not grow, while one containing carbon, 2.5; manganese, 1.5; silicon, 0.50; and 0.10 per cent. each of sulphur and phosphorus contracts about 0.4 per cent. after repeated heating. Objection has been made by some to high-phosphorus-content on the ground that the iron-phosphorus eutectic has a low melting-point. The phosphorus in grey irons is usually present as a ternary eutectic, containing iron, 91.20; carbon, 2.0; phosphorus, 6.80 per cent., and the melting-point of ordinary grey iron is reduced about 27 deg. C. for each per cent. of phosphorus present.

Generally speaking, the life of a grey-iron mould is dependent not so much upon the number of castings poured as upon the number of times it is allowed to cool to the ordinary temperature. The growth of cast iron is accelerated by heating and cooling, and the strains set up by such treatment are more destructive than the erosive effect of the liquid alloys. It has been estimated that a mould used continuously will outlast four moulds used only at fairly frequent intervals. Usually, the gates and risers are the first points to show signs of disintegration, although some moulds have been reported as being in service as long as five years and in good condition. Frequently, however, it is necessary to renew the gates and runners by blocking in with new iron and re-cutting the cavities.

Refractory-lined Moulds.

Many attempts have been made, more or less successfully, to apply refractory coatings and washes to the mould-cavity surface in grey iron for the purpose of preventing erosion of the mould and so that steel castings could be made. In general, coatings that are easy to apply are unstable, and those that are most refractory will not adhere to the face of the mould. In British practice for casting both ferrous and non-ferrous alloys a number of washes and dressings have been used, including seal oil, lard oil, linseed oil, tallow, etc., mixed with graphite. Where carbonaceous dressings are not desired, Johnson[28] recommends an emulsion of bone-ash and water, and he also suggests a dressing made by burning a smoky flame against the mould surface—this depositing amorphous carbon. A mixture of lime and sodium silicate or of refractory clay and sodium silicate has been employed in American practice. Washes of alundum, carborundum, and various other refractories have been tried.

In the matter of refractory-lined moulds it is of importance to direct attention to the method of lining cast-iron moulds for pouring cast-iron castings, as devised and patented by Meloche* and used by the Holley Carburettor Company. The method, so far as is known to the writers, is unique, and details are given of the application of the lining method by Moldenke.[49] In this coating method a thin wash of a mixture of sodium silicate and fireclay is brushed on the mould (heated to about 175 deg. C.), several coats being applied so that a moderate thickness is secured. Each coat is baked on before the next one is applied. This refractory coating is covered and protected by a layer of lampblack (amorphous carbon), deposited by burning an acetylene flame upon the refractory coating. The mould proper is made of two light grey

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* U.S. Pat. No. 1,453,593. May 1, 1923.

cast-iron halves. It is of interest to state that easily machineable, unchilled cast-iron castings are made in this type of mould. This method appears to be capable of great development and to have many possible applications in the production of both ferrous and non-ferrous castings.

Material for Cores.

Cores for permanent-mould casting may be made of sand, as in ordinary sand-casting practice, or of steel or cast iron. Sand cores are used to a considerable extent for both ferrous and non-ferrous castings, particularly in the case of complicated coring, but collapsible steel cores are employed for certain types of castings Simple cylindrical cores of cast iron are used for hollow castings, *e.g.*, pipe fittings. Cast-iron cores are usually employed in pouring cast-iron casting when the internal shape permits, without the use of a collapsible core, while in other cases sand cores must be employed. Steel and wrought-iron cores are less satisfactory than cast-iron cores for pouring iron. Alloy steel, such as chrome-vanadium steel and high-speed tungsten steel, is satisfactory for non-ferrous alloys, but mild steel has also been used. Alloy steel cores are considerably more expensive and more difficult to shape and machine than ordinary steels, but they withstand usage much better

Design and Preparation of Moulds, and Methods of Gating.

Irrespective of the materials employed for constructing moulds and cores in permanent-mould work and of the alloy cast, the problems of design are essentially the same. The general aspects of mould design in the case of aluminium-alloy piston moulds have been discussed at length by the present writers[50] in another Paper, and the general remarks there made are applicable to the permanent-mould process as a whole. In the present Paper the question of mould-design will be treated only in a very general way Each type of casting to be made in a permanent mould presents a separate problem of itself and no general rules can be laid down to ensure successful casting. In general, a certain amount of experimental work, particularly in connection with gating, may be necessary with a new mould. There are, however, certain fundamental principles that may be followed to advantage.

The first item for consideration is the relation of the size and thickness of the mould body to that of the casting produced. Mould-wall-thickness and size of the mould is governed by the thickness of the casting, the object in non-ferrous alloys being to produce a chilling effect upon the casting. In the case of grey cast iron, chilling is to be avoided, and this is accomplished either by pouring very hot moulds and removing the casting rapidly, or else by employing an insulating refractory lining, as in the type of mould used by the Holley Carburettor Company. Regulation of chilling effect in non-ferrous alloys is also had by varying the mould temperature and the pouring temperature. For an aluminium-alloy casting the size of a 4-in. dia. motor piston, the mould-wall thickness is $\frac{1}{2}$ in. to $\frac{3}{4}$ in., and larger castings may require thicker moulds. Moulds with walls too thin warp readily and do not permit maintenance of uniform temperatures; consequently it is better to have the mould too heavy than too light. At the same time, in the case of hand-actuated moulds, heavy moulds are more difficult to operate. The shape of the mould body will depend in general upon the shape of the part to be cast, although the general tendency is to make simple geometrical shapes, having square, rectangular, or circular cross sections.

The same general principles of design apply in the construction of permanent moulds for both ferrous and non-ferrous casting, although generally the surface of the casting cavity when pouring cast iron need not be so smooth as for brass or aluminium alloys since ordinarily the finish on ironwork does not need to be as good. Moulds for pouring cast iron should be thicker than for non-ferrous alloys in order to resist better the effect of higher temperatures in causing warping. Heavier moulds must, obviously, be equipped with better fittings. The pouring temperature for any alloy cast in a permanent mould is higher than when casting in sand moulds.

In many types of permanent moulds no ejector pins are used for removing the frozen castings, and consequently the castings may stick to the mould, particularly if the mould surface is rough. Generally speaking, it is best to provide ejector pins. Moulds may be difficult of operation because of the draft or of many core pieces which must be placed before each casting is poured, and the removal of castings from a permanent mould normaly takes longer than from a die in die casting. The joints between mould sections should be perfect, since otherwise small fins of metal are formed on the casting, which may prevent rapid ejection. The question of mould operation and the gating and design of moulds in the case of aluminium-alloy piston production have been discussed at length by the writers[50] in another place, and the fundamental principles there given are applicable to permanent-mould casting in general.

Gating of Moulds.

Generally speaking, no definite method of mould gating can be described, since each casting requires separate consideration. The position of gates and risers on castings of simple and regular form is not specially important, but where account must be taken of bosses, webs, lugs, flanges, and other irregularities, the best general plan is to gate close to the thickest section and provide small risers near other heavy sections. This rule is, however, far from invariable, much depending upon the shape of the casting. Often the casting must be placed in a certain position in the mould, and this prevents gating at the most advantageous points.

There is great difference of opinion among mould designers as to the best type of gate to employ, some preferring bottom- or side-feeding gates, while others use a simple top-feeding gate. The present writers have tried various methods of gating, and believe that a gate which feeds along the side or near the top of the mould is more satisfactory. It has been the writers' experience that with bottom-feeding moulds the first-deposited and partly-chilled alloy is forced up into the mould cavity by the rush of hot alloy behind it, and such first-deposited alloy is never really sufficiently fluid to fill out the cavity, the result being cold shuts or overlaps. The object to be attained in gating is, of course, the adequate filling of the mould cavity with as little disturbance or splashing of the liquid alloy as is possible. In some cases it is not possible

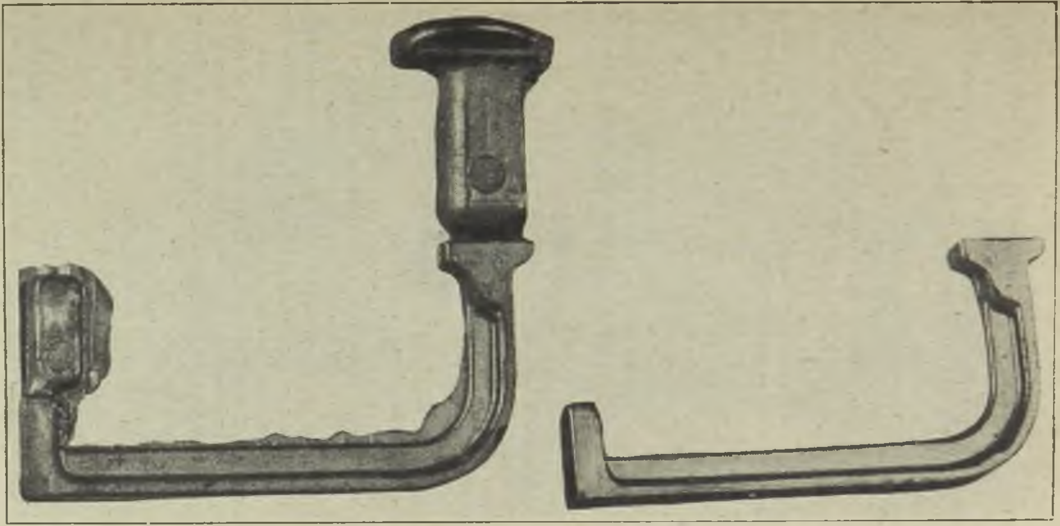

FIG. 16.—SMALL CASTING IN 92:8 ALUMINIUM-COPPER ALLOY, MADE BY PERMANENT-MOULD PROCESS; RIGHT, GATE AND RISER ATTACHED; LEFT, DRESSED.

to determine the proper gating until the mould is actually tried by pouring castings with some method of gating. Generally it is good practice to decide on a method of gating and then cut the gates and runners obviously too small; these cavities can then be enlarged as required.

During preliminary "try-out" of the mould it may be observed that certain areas of the casting do not fill out, or that draws occur at some points. These defects are usually remedied by attaching small shrink pads to the casting, these pads being connected by narrow feeders. If the defective spots are so situated that this method cannot be applied, the head of alloy in the gate may be increased. In casting alloys having high contraction in volume, cracks may occur at the juncture of thick and thin sections, and chills may be placed in the mould in contact with the thick section in order to increase its rate of cooling. Such chills in an iron mould may be made of brass or copper, which have greater thermal conductivity than the iron.

Coring.

As stated previously, both sand and metallic (cast-iron or steel) cores are employed in permanent moulds, and the type of core used depends upon the nature of the casting poured and the alloy used. Where sand cores are employed, the method of casting is often referred to as casting in semi-permanent moulds. Generally speaking, sand cores are used for casting ferrous alloys and steel or iron cores for non-ferrous, but both kinds of cores are used for the different classes of alloys. Sand cores are used where the coring is complicated, and where too many core pieces would be required in the construction of a collapsible steel core. In the case of steel cores, if the casting is of simple design, it is sometimes possible to construct the core in one piece, but in many castings undercuts are encountered, so that irregular coring is required, and this necessitates using a collapsible core made up of several pieces. The principle involved in constructing a collapsible core is the same as that followed in making collapsible mandrels for spinning metal hollow-ware. Cases of undercuts are handled by using a central core piece around which the actual interior contour of the casting is formed by additional core pieces. This method permits withdrawal of the outer core pieces from the mould after the centre core piece has been removed. A collapsible steel core for aluminium-alloy piston castings is shown in Fig. 15 of the Paper on the production of aluminium-alloy pistons in permanent moulds by the writers.[50] With collapsible steel cores, a taper of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. per ft. is allowed in order to permit easy removal from the mould.

While sand cores are used for making various types of castings in permanent moulds, they present several disadvantages, particularly when non-ferrous alloys are cast. Care must be exercised in placing sand cores, and they should be heated before being inserted into the mould. Sand cores do not give so good surface finish to the interior of a casting as steel cores, and for some classes of work this makes them undesirable. Moreover, castings made with sand cores are not so accurate.

Venting.

Permanent moulds may be vented by cutting small grooves $\frac{1}{16}$ in. to $\frac{1}{8}$ in. wide and 0.004 in. or more deep, across the core and mould joints from points which appear to require special venting. Simple castings are, as a rule, sufficiently vented by risers. Of course, loose cores and joint faces greatly aid venting.

Machining.

In preparing a permanent mould, it is advantageous from the point of view of economy in machining to construct the mould pattern so as to conform as nearly as possible to the desired finished mould. The cavity may then be finished by a minimum of machining. Details of machining need not be given here, but it may be emphasised that the important features to be considered, outside of gating and the general aspects of mould design, are the obtaining of a smooth surface finish to the casting cavity and making the proper allowance for contraction. There are so many factors affecting the contraction of the casting that no specific rules can be laid down to ensure the casting coming out to " dead size " at the first trial. It is customary to allow 0.1 per cent. for aluminium alloys in general, 0.07 per cent. for brass, and 0.05 per cent. for zinc alloys

Alloys Used and Types of Castings Made.

Like other casting processes, the process of casting metals and alloys in permanent moulds is restricted in its applications by certain inherent limitations. Obviously, better results can be obtained with certain alloys and upon certain types of castings. As pointed out previously, only castings that may be classed as repetition work and that are required in large numbers can be economically cast in permanent moulds. Thus, at the outset, the process is limited by economic considerations. At the present time, the commercial application of permanent-mould casting to non-ferrous work is restricted to a few alloys, but it may be expected that the process will be extended to all kinds of non-ferrous alloys. The applications of the process to several types of alloys are discussed briefly below.

Aluminium Alloys.

In the non-ferrous field, the permanent-mould process has been largely applied to the production of aluminium-alloy castings. The requirements of the automotive industry for miscellaneous castings in aluminium alloys offer a particularly adaptable field for permanent-mould casting, since these castings are required in large numbers. For this class of work there are distinct advantages in the process, since the castings can be made rapidly, have a good finish, and require little machining. The tensile properties of the aluminium alloys are considerably better when chill-cast than sand-cast, and aluminium alloys when poured in permanent moulds are sound. Die-cast aluminium alloys are very porous and unsound, and sand-cast alloys are also likely to be unsound.

Among other castings, pistons, instrument panels, brake-shoe arms, door handles, small gear-housings, steering-wheel spiders, small hardware, and other parts are now cast commercially in aluminium alloys in permanent moulds. Small castings for electrical equipment are poured in permanent moulds, and larger castings, such as gear-housings, and crank-cases, weighing 20 to 150 lbs., have been cast. Aluminium-alloy automobile wheels have been successfully cast in permanent moulds, but such wheels have not so far been employed to any extent. There are many specific castings in aluminium alloys which are now being sand-cast or die-cast which are better suited to the permanent-mould process from the point of view of soundness, mechanical properties, and production. Commercially, the maximum weight of permanent-mould castings made in aluminium alloys is about 25 lbs., and the minimum weight is 1 oz., although castings weighing up to 200 lbs. have been made. The minimum section thickness in permanent-mould castings of aluminium alloys is

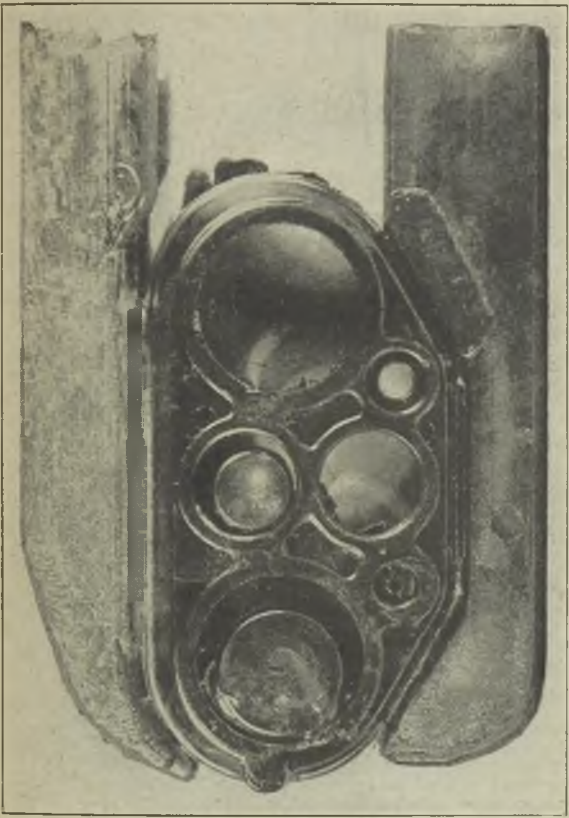

Fig. 17.—Instrument Panel Casting in 92 : 8 Aluminium-Copper Alloy, made by Permanent-Mould Process; Gate and Riser Attached.

$\frac{1}{8}$ in. The limit of accuracy to which castings may be made is about ± 0.010 in. Unless the casting is small and of simple design, difficulty is sometimes encountered in keeping within close size limits, due to uneven contraction caused by variation in section sizes in the part. Where machining is to be done on the casting, the limits usually worked are $\frac{1}{32}$ in. to $\frac{1}{16}$ in.; for long cored holes it is usual to provide a slight taper, which can be corrected by a reaming operation. Weight tolerances on aluminium-alloy permanent-mould castings are ± 2 per cent.

Of aluminium-alloy automotive castings made in permanent moulds, pistons are cast in by far the greatest number. Some concerns make pistons solely. Piston production has been discussed by the present writers[50] in another Paper, and need not claim further attention here. Small castings in aluminium alloys may be gated with two or more together, and the rate of output greatly increased. Fig. 16 shows a small aluminium-alloy casting made by permanent-mould casting; at the left, the pouring gate and riser are attached, while at the right the casting has been trimmed. Fig. 17 shows an instrument panel, for a motor car, with gates and riser attached. Various aluminium alloys are employed for permanent-mould castings, including the ordinary 92:8 aluminium-copper alloy and other aluminium-copper alloys containing 4 to 14 per cent. copper. Certain special alloys are also employed, including silicon-bearing aluminium alloys, nickel-bearing aluminium alloys, and aluminium-copper-magnesium alloys. Little work has been done to develop the most suitable aluminium alloys for permanent-mould casting, aside from piston alloys. At the present time the most suitable composition of aluminium alloy for permanent-mould work is a matter of considerable conjecture, but it should be well-fluid at moderate temperature above the melting-point and have small contraction, little solvent action upon the mould, and good strength at elevated temperatures in the solid state.

Copper Alloys.

Small castings in 67:33 brass and similar alloys can be successfully cast in permanent moulds. The fairly-high melting-temperature and corrosive action of these alloys have a deteriorating effect upon cast-iron moulds, however, and the moulds become inaccurate after 2,000 to 3,000 castings are poured. For this reason, unless considerable saving is effected in machining costs and from increased rate of production, these alloys are better cast in sand. High-zinc copper-alloys, especially at high temperatures, have very erosive action on iron, owing to the zinc, but alloys of the bronze type are not so erosive. Dynamo-brush holders, gear wheels, and various small castings have been made commercially in brasses in permanent moulds. Gun-metal and phosphor-bronze bars to be used in automatic-machine work for bushing and liners have been cast in permanent moulds. Bars $1\frac{1}{4}$ in. to 2 in. dia. and 3 ft. to 6 ft. long are used for this purpose. Aluminium bronze is cast commercially in permanent moulds, and gear wheels and small parts for electrical manufacturing are now being made. It is reported that gear wheels weighing 10 lbs. to 40 lbs. and with teeth cast of an accuracy of ± 0.001 in. are being produced. The life of cast-iron moulds when casting aluminium bronze ranges from 5,000 to 30,000 castings, according to reports.

White-Metal Alloys.

All sorts of white-metal alloys can be cast by the permanent-mould process, but in general the die-casting method is more suitable. Zinc castings, including gear wheels and "crows' feet" for wet-cells, are cast commercially. Permanent-mould casting is useful for these alloys when a white-metal alloy is to be cast on to cast-iron or steel bodies.

Iron Alloys.

In the iron trades, various articles are made by permanent-mould casting, including plough-points, brake shoes, soil pipe, pipe fittings, projectiles, colliery-tub wheels, bevel gears for agricultural machinery, grate bars, hammer blocks, etc. Most of these articles are cast in the ordinary run of foundry iron. Little work has so far been done in cast steel or semi-steel, but there seems to be no reason why these alloys should not be cast in permanent moulds. The development of the permanent-mould process for casting cast iron has been hindered by difficulties encountered in preventing excessive chilling of the iron. Various methods have been devised for overcoming the chill effect, including heating the mould, lining the mould with refractory material, and annealing the chilled castings. Custer[5] has discussed the effect of permanent-mould casting upon the chill of cast iron, and in the process devised by him chilling is avoided by taking advantage of the fact that an interval of time elapses between the temperature at which the metal sets and that at which it begins to chill. This interval of time is sufficient to allow removal of the casting from the mould and avoid the chilling effect. The usual time during which the casting remains in the mould is 2 to 10 secs., depending upon its thickness. The most successful process involving refractory-lined moulds of which the writers have knowledge is that used by the Holley Carburettor Company.[49]

Summary.

In this Paper the production of castings in permanent moulds is discussed in a general way, and the applications and limitations of the process to both ferrous and non-ferrous casting have been pointed out. The history of the permanent-mould process has been sketched briefly, it being pointed out that permanent types of moulds, including stone and bronze moulds, were used as long ago as 3000 B.C. Typical examples of such old moulds are shown. The development of the permanent-mould process in recent years has been reviewed briefly.

It has been indicated that there are five separate and distinct casting processes involving the use of permanent or metallic moulds, viz.: (1) Die casting; (2) slush casting; (3) Cothias casting; (4) centrifugal casting; and (5) permanent-mould casting. These different casting processes are defined, and the first four are discussed briefly, and then compared with the true permanent-mould-casting process, which is the counterpart of sand casting. It is explained that the permanent-mould process is the same as the sand-casting process in method of operation, and the chief difference lies in the type of mould employed. The use of permanent moulds is desirable, since in sand practice each mould is destroyed on pouring, and a mould that can be used over and over again is required, especially in repetition work involving large numbers of castings.

The general principles of the permanent-mould process have been discussed, and a typical permanent mould is described as illustrative of these principles. Some typical examples of permanent moulds are described, and the four main types of moulds are discussed. It has been pointed out that very many patents have been issued for claims bearing on permanent-mould casting, and a short list of patents is given.

The question of materials employed for making moulds and cores is taken up, and it is pointed out that grey cast iron is used largely for the mould body proper, while both metallic (collapsible steel) cores and sand cores are employed. The growth and distortion of grey iron moulds in service is discussed briefly. The use of refractory linings and coatings for permanent moulds is discussed.

The design and preparation of moulds and methods of gating are taken up in a general way, and the main principles of mould preparation have been discussed.

Finally, the various types of alloys used commercially for casting in permanent moulds have been considered, and the types of castings made in these alloys have been described.

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DISCUSSION.

Mr. H. Cole Estep presented this Paper, and said it was an exchange Paper on behalf of the American Foundrymen's Association. Mr. Estep regretted that the authors could not come to England for the purpose of reading the Paper personally. This was the fourth year in which the exchange of Papers between the American Foundrymen's Association and the Institute of British Foundrymen had taken place, and the arrangement come to was perhaps one of the most significant and important that had taken place for a good many years. The American Foundrymen's Association would always feel indebted to Mr. Cook for having gone to America two years ago to read his Paper there, and the American Association hoped to follow that example in the future. Speaking of the Paper, he said he hoped there would be some discussion upon it. Mr. Anderson was one of America's most prominent scientific foundry engineers who had had practical experience, and had carried out much work on the problem of permanent moulds for cast-iron shell and aluminium aeroplane engine parts during the war.

THE FORMATION OF GRAPHITE IN CAST IRON.

By L. Northcott, M.Sc. (University of Birmingham).

INTRODUCTION.

It has been recognised from the earliest days of the use of cast iron that white iron is hard, while grey iron is relatively soft. For more than a century it has been known that grey cast iron contains carbon in the graphitic state, but it is only in recent years that the effect of the size, shape and distribution of that graphitic carbon upon the mechanical properties of the casting has been recognised. The size and shape of the graphite is dependent upon two main factors, namely, the original composition of the fluid metal, and the rate of solidification and subsequent cooling of the metal. It is well known that ordinary cast iron is a complex aggregation of many substances, chief of which are iron and carbon, with smaller proportions of silicon, sulphur, phosphorus and manganese. Occasionally other elements are encountered in small percentages, such as nickel, chromium, titanium, aluminium, etc. The chief element which is regularly present in cast iron is carbon. It is an essential constituent of all cast irons, since with less than about 2 per cent. carbon the characteristic properties of cast iron are not obtained. The object of this Paper is to consider the occurrence and properties of carbon as it occurs in ordinary cast iron.

It is also a matter of common knowledge that certain kinds of grey iron, if cooled quickly, become hard and brittle, whilst some varieties of white cast iron, if allowed to cool slowly, or when long-annealed, become grey and soft. This change is connected with the fact that the carbon exists in two distinct forms, each of which can be divided into two kinds. In grey iron the carbon exists in its elementary form, *i.e.*, by itself, and is generally known as graphite. This graphite can be separated in a more or less pure form by dissolving a sample of grey iron in acid; the iron dissolves in the acid and the graphite remains.

In white iron, on the other hand, the carbon is combined with iron forming the compound cementite or iron carbide, Fe_3C, the properties of which are entirely different from those of either pure iron or carbon. Whereas pure iron is soft and ductile, cementite is intensely hard and brittle. White cast iron, in fact, may be considered as a high carbon steel containing an excessive amount of cementite, which renders the iron practically useless from the engineering point of view. Fortunately, however, one can change iron carbide into graphite and iron, and back again, by appropriate manipulations of temperature and by suitable additions of what might be called the minor elements of cast iron, such as silicon, sulphur and manganese, each of which elements exercises its own particular influence on the stability of one or the other of the two forms of carbon as found in cast iron. Since white iron as such finds little use in engineering construction, on account of its extreme brittleness, it is proposed to devote but little attention to it in this Paper. It must be kept in mind, however, that there is an important industry which deals with the conversion of the hard and brittle white iron into a soft and malleable material, suitable for commercial use. This phase of the subject is dealt with later.

From the point of view of industrial utility, therefore, foundrymen need a cast iron containing only such small proportions of cementite to impart sufficient hardness and strength to the iron, and the rest of the carbon to be in the graphitic state. Since the actual strength of graphite is very small, in fact negligible when compared to the strength of iron, it is essential that the graphite is in the shape or form in which it will do least harm to the metal. By removing the graphite altogether, and leaving in the iron a small quantity of cementite, giving a carbon content of, say, 1 per cent. or less, we should have, mechanically, a very good material, steel in fact, but the cost would be very much higher than that of the original iron, and cast iron owes its existence largely to its low price.

As would be expected, the graphite is most harmful to the iron when it exists in very long flakes, which break up considerably the continuity of the metallic matrix. Assuming that there is a small bar of cast iron subjected to tensile stress, then, taking the extreme case, the graphite would prove of greatest harm when it existed right across the specimen in a direction at right-angles to the length of the bar. Of course, in practice such a case never occurs, but it is easy to visualise how harmful large flakes of graphite can be. That graphite is contributory to fracture is shown in Fig. 1. A small broken piece of grey iron was copper-plated and then sectioned. When polished and examined under the microscope the fracture was observed to be along the graphite flakes. A micrograph of an iron containing large graphite flakes is shown in Fig. 22. Graphite also occurs in another or nodular form, when it is variously called temper-carbon, annealing carbon or secondary

TABLE I.

Fig.	Temp.	Time hrs.	Micro-Constituents
3	As received	—	Cementite and Pearlite.
4	750°	46	Cementite, Pearlite, and Temper-Carbon.
	750°	106	Similar to No. 4.
5	860°	32	Cementite, Pearlite, and Temper-Carbon.
6	900°	31½	Temper-Carbon.
7	990°	30	Temper-Carbon.
8	1,050°	17½	Graphite, Pearlite, and Ferrite.
9	1,100°	14	Graphite and Ferrite.
10	1,100°	25½	Graphite.
11	1,140°	8	Graphite, Cementite, and Pearlite.
12	1,140°	20	Graphite, Cementite, and Pearlite.
13	1,150°	1	Cementite, Pearlite, and Eutectic.
14	1,150°	3½	Pearlite and Ferrite.
	1,150°	5	Almost all Ferrite.

NOTE.—(1) Figs. 6, 7 and 10 were unetched. (2) All samples were heated *in vacuo*, except Figs. 9, 13, 14, and the last sample.

graphite. This form of carbon is best seen in good malleable cast iron, particularly the American black heart varieties. A photograph is shown in Fig. 2. On comparing Figs. 22 and 2 it is obvious that the graphite in the former is of the more harmful character.

The work described in the present Paper was undertaken in order to examine the process of the formation of graphite in commercial cast irons. The first section deals with the effect of annealing white cast iron at different temperatures and under such conditions as to produce temper-carbon or nodular graphite. Some observations regarding the precipitation of the carbon are made, supplementary to those of Fisher,[1] Hatfield[2] and Charpy and Grenet.[3] The second part of the Paper describes experiments on a typical grey cast iron of good quality to determine the mechanism of the formation of flakey or primary graphite as commonly found in grey irons.

PART I.

THE ANNEALING OF WHITE IRONS TO PRODUCE NODULAR GRAPHITE.

It is the general experience in the manufacture of malleable castings that the lower the annealing temperature, provided that complete annealing is obtained, the better the casting. Further, the annealing temperature has been considered to have some effect on the form of the precipitated carbon. An investigation was therefore carried out to determine exactly what effect different annealing temperatures had on the shape of the temper-carbon precipitated during the annealing of white iron. Temper-carbon may be defined as the finely divided graphite found in malleable cast iron, occasionally in heat-treated grey irons, or in badly heat-treated steels.

Experimental Details.

The iron used in these experiments was a typical sample of white iron used in the White Heart,

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[1] Fisher, Trans. American Foundrymen's Association, 30, 395. See also White and Archer, *ibid.*, 27, 331.

[2] Hatfield, "Journal Iron and Steel Institute," 1907, 2, 79.

[3] "Engineering," 1902, 73, 626.

FIG. 1.—SHOWING FRACTURE ALONG GRAPHITE PLANES.

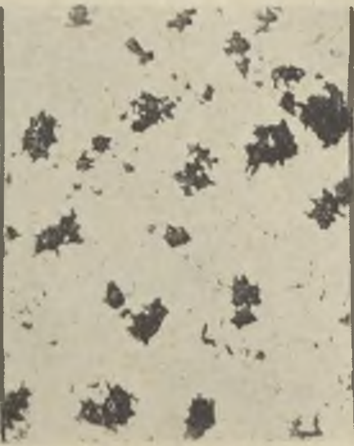


FIG. 2.—NODULAR GRAPHITE MALLEABLE IRON.

FIG. 22.— × 250. (AS RECEIVED.)

FIG. 3.—× 250.
(AS RECEIVED.)

FIG. 4.—× 200.
(46 HRS. AT
750 DEG. C.)

FIG. 5.—× 200.
(860 DEG. C.)

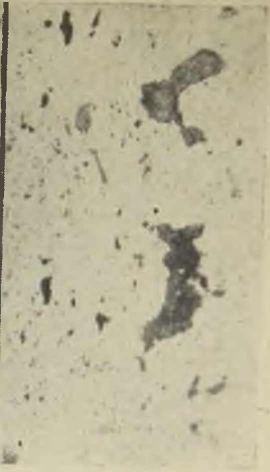


FIG. 6.—× 200.
(900 DEG. C.)

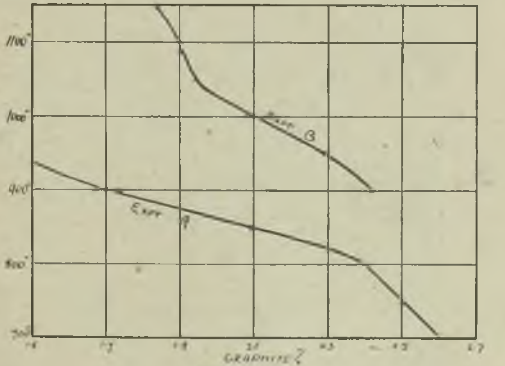
European or Reaumur process of malleable cast iron manufacture, and contained Cc 2.9; P 0.04; Si 0.61; S 0.38, and Mn 0.11 per cent. Fig. 3 shows the micro-structure, and it will be seen to be quite normal for this class of material, as it consists of pearlite (dark) and cementite (white), all the carbon being in the combined form. The metal was annealed in a silica tube resistance furnace, the temperature of which could be altered by means of four variable resistances, and read direct from a Cambridge indicator connected to a platinum—platinum-rhodium thermo-couple. It was found more convenient to heat for short periods of from six to nine hours at a time instead of one continuous annealing. In order to reduce oxidation and subsequent decarburisation, the specimens in the original experiments were annealed with a packing of China clay. As this did not have the desired effect, later experiments were carried out under reduced pressure.

Summary of Results.

Thirteen experiments were carried out, in which the temperature of anneal varied from 750 to 1,150 deg. C., and the results are shown in Table I. When the metal had been sufficiently annealed, a surface of the specimen was ground and polished. It was then examined under the microscope and photographed. The resulting micrographs are shown in Figs. 4 to 14, and are extremely interesting when considered with Table I. In passing, it should be noted that the precipitation of the temper-carbon is liable to be masked, particularly in the case of thin castings, if the iron be heated in an oxidising atmosphere. There is always a tendency for decarburisation to take place. This is encouraged in the manufacture of malleable castings by the European process, but not in the American process, which is finding greater application in this country. In the former process much of the carbon is removed by the oxidising effects of the packing material, so that in very thin castings there is often less than 1 per cent. of total carbon. In the Black-heart process, however, practically all the carbon is precipitated as temper-carbon, and decarburisation is confined merely to the edge of the casting.

Discussion of Results.

In the introduction it was shown that long flakes of graphite were far more harmful than the rounded nodules of temper-carbon found in good malleable iron, *i.e.*, the physical properties may be predicted from a study of the graphite in the iron. It was mentioned also that in the manufacture of malleable castings the lower the annealing temperature, the better the properties of the casting. Such a fact would be expected when we consider the micro-structure of the resulting irons. The photographs, which are arranged in order of ascending temperature, show that there is a gradual change in the shape of the precipitated carbon from the circular form of true temper-carbon to the flaky form of primary graphite. The annealing of No. 4 at 750 deg. is altogether insufficient; in fact, precipitation of carbon has just begun. Fig. 5 at 860 deg. shows typical nodules of temper-carbon, and although the length of annealing was insufficient, the temperature employed would yield a very satisfactory product. As the temperature ascends the increasing flakiness of the graphite is shown; Fig. 9 at 1,100 deg., for example, shows distinct primary graphite flakes, and it may safely be assumed that the physical properties will consequently be poor. In general, therefore, the physical properties of annealed cast-



Graph I.

Fig. 7.—× 200.
(990 Deg C.)

Fig. 8.—× 200.
(1,050 Deg. C.)

Fig. 9.—× 350.
(1,100 Deg. C.)

Fig. 10.—× 200.
(1.100 Deg. C.)

Fig. 11.—× 150.
(1,140 Deg. C.)

Fig. 12.—× 150.

Fig. 13.—× 200.

Fig. 14.—× 250
(1,150 Deg. C.)

ings of given composition will vary from those of good malleable to those of a grey iron casting, according to the annealing temperature. If it were possible, during the solidification of grey cast iron, to cause the graphite to occur in the nodular form as it does in good malleable cast iron, there is every reason to suppose that the iron would be as strong and as ductile. Most white irons used in the European process have fairly high content of sulphur, which happens to be one of the elements which tend to prevent the graphitisation of cementite. As it is known that the rate of graphitisation increases with increase of temperature, manufacturers of white heart iron have to employ a somewhat higher annealing temperature to hasten the process of malleableising. From what has been said before, it is natural to suppose that if manufacturers stipulated for an iron containing less sulphur, lower annealing temperatures could be adopted without increasing the time of anneal, and consequently a superior product would be obtained due to the improved form of temper-carbon produced at the lower temperatures.

Conclusions.

From Part I of the Paper the following conclusions may be drawn:—

(1) The eutectic temperature for the particular white iron under review is in the neighbourhood of 1,145 deg. C.; samples heated above this temperature show no signs of graphitisation. It therefore appears likely, at least in the case of hypo-eutectic alloys, that graphite is not the constituent separating from the melt.

(2) In the case of samples heated well above 1,000 deg. C., the carbon which is precipitated tends to assume the form of primary graphite, *i.e.*, thin flakes which break up the continuity of the metallic matrix, thus reducing considerably the strength of the iron.

(3) The typical rounded form of temper-carbon is produced at temperatures well below 1,000 deg. C., the lower the temperature (within limits), the more compact the carbon, and consequently the greater the malleability of the casting.

(4) There appears to be a definite change between specimens Nos. 4 to 7 and Nos. 8 to 12, *i.e.*, a

critical temperature between 990 and 1,050 deg. C., at which the carbon changes its form from spherical to flaky. It is suggested that this is related to the thermal points found by Carpenter and Keeling[4], between 1,000 and 1,100 deg. C.

(5) In a white iron, the higher the annealing temperature (as long as 1,145 deg. is not exceeded), the more rapid is the formation of graphite. This is the cause of the high annealing temperatures employed in the white-heart process, necessitated by the unbalanced content of the elements present. It has been suggested that a composition which permitted lower annealing temperatures to be employed would give a superior and more uniform product.

(6) Conversely, there is a temperature, depending upon the composition of the white iron, below which the amount of graphite which separates is negligible.

(7) By employing a very oxidising packing material and a high temperature, it is possible to eliminate completely all elementary carbon, leaving only ferrite and pearlite. Ultimately also the carbon in the pearlite is oxidised and only ferrite remains.

PART II.—THE FORMATION OF PRIMARY GRAPHITE IN A TYPICAL GREY CAST IRON

Previous workers have for the most part confined their attention to the total amount of graphite formed[5], although Wust[6] and Honda[7] quenched small samples of white iron just below the eutectic point and studied the formation of graphite with the microscope.

Annealing Experiments.

Experiments were carried out in order to trace, if possible, the mode or method of formation of primary graphite in an ordinary casting. The pig-iron employed analysed as follows:—

Total C 3.2; Graphitic C 2.5; Si 1.3; S 0.14; P 0.04, and Mn 0.77 per cent.

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[4] "Journal Iron and Steel Institute," 1904, I, 224.

[5] "Stahl u. Eisen," 1922, 42, 148. See also Hatfield, "Journal Iron and Steel Institute," 1907, 2, 79; and Brown, "Proceedings Staffs. Iron and Steel Institute," 28, 127.

[6] "Metallurgie," 1909.

[7] "Journal Iron and Steel Institute," 1920, 2, 287.

Fig. 15.—× 200.
G1 (1,240 Deg. C.).

Fig. 16.—× 350.
G1 (1,240 Deg. C.)

Fig. 17.—× 200.
G2 (1,145 Dfg. C.).

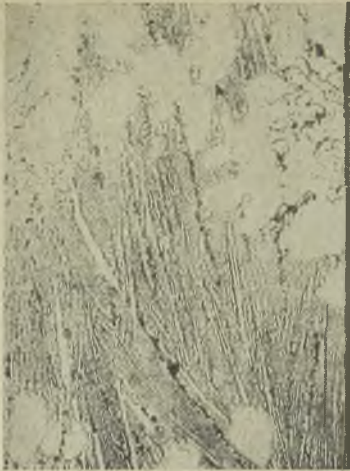


FIG. 18.—× 150.
G3 (1,083 DEG. C.).

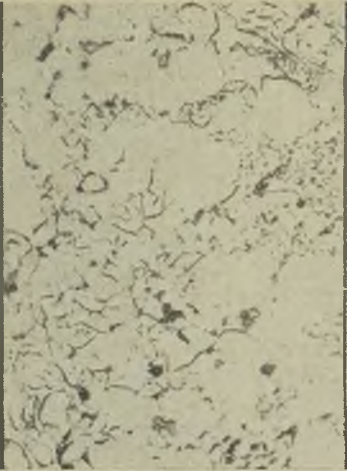


FIG. 19.—× 150.
G4 (980 DEG. C.).

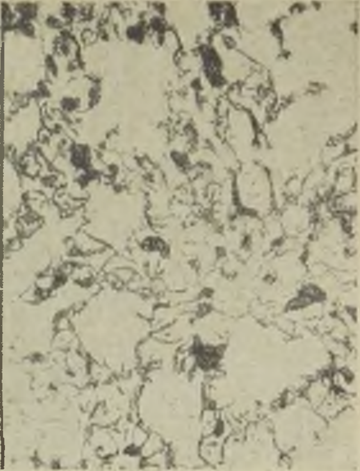


FIG. 20.—× 150.
(915 DEG. C.).

TABLE II.

Bar Number.	Quench. T., in deg. C.	Graphite per cent.
A1	940	1.5
A2	900	1.7
A3	850	2.09
A4	800	2.4
A5	750	2.5
A6	700	2.6

TABLE III.

Bar Number.	Quench T., in deg. C.	Graphite per cent.
B1	1,150	1.84
B2	1,100	1.9
B3	1,050	1.94
B4	1,000	2.1
B5	950	2.29
B6	900	2.42

The general method of procedure was as follows:—

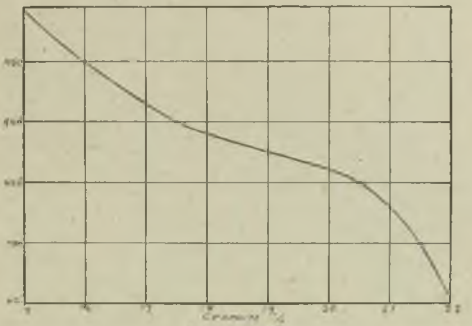
The pig-iron was cast into several bars (6 in. long × 1 in. dia.) in one sand box. Soon after solidification and whilst the iron was red hot, the bars were quickly transferred to a large gas muffle, heated to a pre-determined temperature. After an interval of five minutes the first bar was taken out and quenched in cold water. The temperature of the muffle was lowered and the remaining bars quenched at intervals of 50 deg. C. Samples were taken from the bars for chemical and microscopical analysis. The results of the first two experiments are shown in Tables II and III, and also in Graph I.

TABLE IV.

Bar Number.	Quench. T. in deg. C.	Graphite per cent.
F1	1,140	1.5
F2	1,050	1.6
F3	950	1.7
F4	900	1.9
F5	850	2.05
F6	750	2.15
F7	650	2.2

In the third experiment the quenching temperature range covered those of the first two experiments, and the results are shown in Table IV and Graph II.

As it appeared desirable to ascertain the time required in the furnace for the bars to attain a state of equilibrium for a definite temperature, a further set of bars was cast as before and transferred to the muffle at 1,000 deg. C. The first bar was taken out and quenched after five minutes in the furnace, and the other bars were quenched at intervals of five minutes. Table V shows the results of this experiment, and it will be seen that for a temperature of 1,000 deg. at least ten minutes are required in the furnace for equilibrium conditions to occur.



Graph II.

TABLE V.

Bar No.	Quench T. in deg. C.	Time Minutes.	Graphite per cent.
C1	1,000	5	2.03
C2	1,000	10	2.2
C3	1,000	15	2.22
C4	1,000	20	2.2
C45	1,000	25	2.25
C6	1,000	30	2.22

Discussion of Results.

From a study of Graph II it will be seen that a bar which contains 1.5 per cent. graphite at 1,140 deg., on cooling to 650 deg. increases its graphite content to 2.2 per cent. This increase, however, is not constant, but the rate of precipitation of graphite first increases and then falls off again, so that at about 900 deg. there is a maximum rate of precipitation. The shape of the curve is considered to be due to the combined influence of the tendency for the formation of graphite and the increasing rigidity of the metal. It may safely be assumed that in the solid state graphite is the stable form of carbon, and not cementite. In that case, the lower the temperature from the melting point, the greater the tendency of the unstable cementite to decompose into graphite and iron. It is, however, a recognised fact that decomposition of cementite causes an expansion in the casting; that is why white irons contract much more than grey irons. With lowering of temperature, the rigidity or strength of the iron increases considerably, as would be expected, and this resists the internal expansion caused by the decomposing cementite.

In the foregoing experiments the minimum amount of graphitic carbon was 1.5 per cent. out of a total carbon content of over 3 per cent. In other words, nearly half the graphite had been precipitated before the actual investigations had commenced. Further work was necessary, therefore, to account for the first quantities of graphite formed, and it was recognised that a different *modus operandi* was called for.

Quenching Experiments.

The iron used was an ordinary grey iron of the following composition:—

Total C 3.4; Graphitic C 2.7; Si 1.4; S 0.09; P 0.07, and Mn 0.9 per cent., and the method finally adopted was as follows:—

Using a small Morgan crucible as a pattern, five cast-iron moulds were prepared. One was heated to a bright red heat and into it was poured a small quantity (approximately 1 lb.) of molten iron, and the whole quenched in cold water before the iron had solidified, the temperature being determined with a nickel-chrome thermo-couple. Another ingot was poured, as before, but this time it was quenched at the solidifying point. Three more ingots were similarly poured and quenched at different temperatures below the solidifying temperature of the iron. Samples for chemical and microscopical analysis were obtained from the centre of each specimen. The results are given in Table VI, illustrated in Graph III, and microscopically in Figs. 15 to 20.

Graph II is the most important of the curves shown. It will be seen that between the eutectic point 1,145 deg. and 1,100 deg. there is a critical range in which most of the graphite is precipitated, *i.e.*, most of the graphite forms just below the eutectic temperature. It should be stated here that the actual graphite values given in Table VI do not represent equilibrium conditions, but are applicable solely to the particular case under review, with cooling rates, like those in actual practice, too rapid for equilibrium to occur. It will not be difficult to understand, however, that the general form of the curve, with in many cases different graphite values, may be applied to most grey irons and indicates the quantitative formation of graphite in grey iron castings. From Table VI it will be seen that the centre of the first specimen GI contains 0.27 per cent. of graphite, although quenching took place from the molten state. One must take into account, however, the fact that the quenched sample was comparatively large and weighed nearly 1 lb. without the mould, so that the quenching was not instantaneous. The

FIG. 21.—× 800.

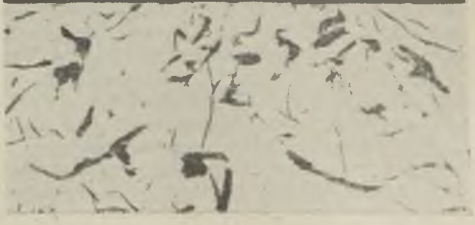


FIG. 23. J1 A.—EDGE.

FIG. 24. J1 B.—CENTRE.

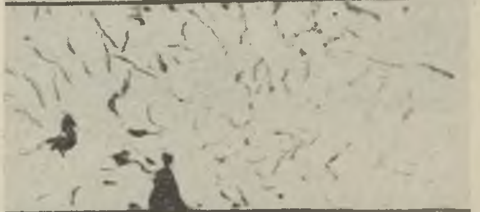


FIG. 25. J2 A.—EDGE.

FIG. 26. J2 A.—CENTRE.

FIG. 27. J3 A.—EDGE.

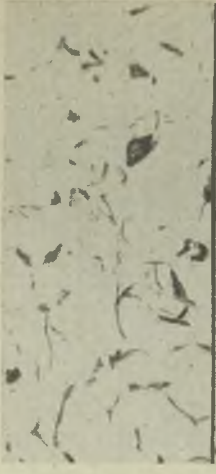


Fig. 28
J3 B.—Centre.

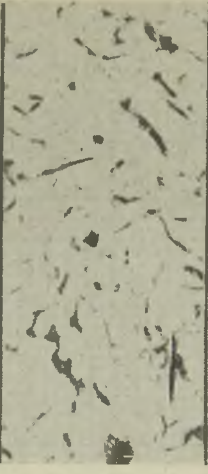


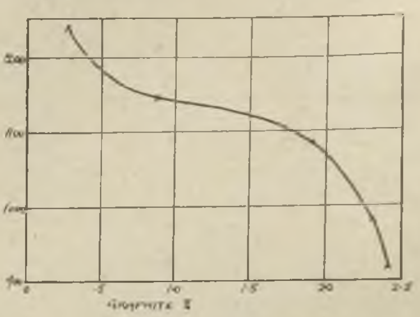
Fig. 29
J4 A.—Edge.

Fig. 30.
J4 B.—Centre.

Fig. 31
J5 A.—Edge.

Fig. 32.
J5 B.—Centre.

time factor must be considered. and it is most probable that the graphite in GI was formed just below the eutectic temperature. This view is confirmed by the microscopic examination (see Fig. 16), where it is seen that part of the graphite is shown in the austenoid areas.



GRAPH III.

Graphite Content of Molten Metal.

To decide whether graphite is present as such in the particular iron under discussion when molten, a sample of the cast iron as used in the previous experiment was melted in a Salamander crucible and poured, from just above the melting point, in as thin a stream as possible into cold water, in order to obtain the maximum quenching effect. A piece of the resulting metal was cleaned and then dissolved in nitric acid of 1.20 sp. gr. and the solution filtered. No trace of graphite could be observed, showing that in molten iron graphite does not occur in its elementary form, but as a compound with iron, as iron carbide. Another specimen of the quenched iron was sectioned and polished for microscopic examination. Fig. 21 shows the micrograph (×800), and it will be seen that the quenching has been sufficiently severe to retain crystals of austenite, containing needles of martensite, but no graphite can be observed.

Equilibrium Graphite Content.

In order to determine the maximum graphite content at different temperatures, six bars were cast and treated as in the first experiments, except that each bar was held at its quenching temperature for thirty minutes before quenching. The results are given in Table VII.

The composition of the iron was as follows:—Total C 3.4; Graphitic C 2.7; Si 1.4; S 0.09; P 1.07, and Mn 0.9 per cent.

In Graph IV the carbon solubility curve has been plotted on the iron-carbon equilibrium diagram, and will be seen to conform fairly closely with the line usually represented as Agr, although the iron has the usual minor elements or impurities as found in commercial irons. The dotted line shows at any required temperature how much carbon is dissolved in the iron as cementite or iron carbide; the difference between these values and the total carbon content is the amount of carbon present as graphite.

TABLE VI.

Specimen.	Quench T. in deg. C.	Graphite per cent.	Micro.
G1	1,240	0.27	Figs. 15 & 16
G2	1,145	0.87	Fig. 17
G3	1,083	1.9	Fig. 18
G4	980	2.3	Fig. 19
G5	915	2.4	Fig. 20

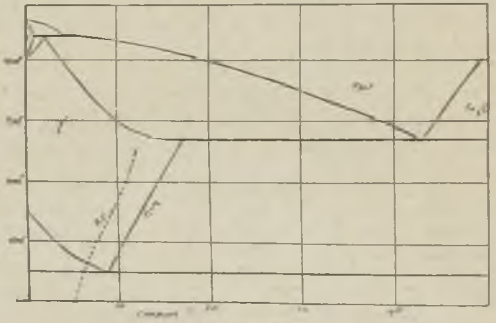
TABLE VII.

Bar Number.	Quench T. in deg. C.	Graphite per cent.
H1	1,100	2.2
H2	1,000	2.3
H3	900	2.45
H4	800	2.65
H5	700	2.8
H6	600	2.9

Effects of Casting Temperature.

It is now well known that casting temperature has a bearing on the physical properties of the iron. Longmuir pointed this out twenty years ago. Other workers have since carried out investigations on the same subject. It appeared desirable to ascertain the effect of pouring temperature on graphite formation, bearing in mind, as mentioned previously, the influence of the size and shape of the graphite on the properties of cast iron. The from 1,410 to 1,210 deg. C. The bars were broken the previous experiment. Five bars were poured from the same crucible, at temperatures ranging from 1410 to 1210 deg. C. The bars were broken and samples obtained for microscopical and chemical analysis. Hardness tests were carried out on the micro-specimens, using a 10-mm. ball for the centre and 1 mm. ball for the edge of the specimen, on a surface at right-angles to the length of the bar. The full results are given in Table VIII and shown in Graph V. It might be expected that a decrease in graphite content would tend to increase the hardness, on account of the implied increase of the hard cementite constituent in the mass. This supposition in general is borne out by the curves shown in Graph V. In addition, it will be noticed that although the graphite content of the centre of the bars does not vary considerably, there is a continual decrease in the graphite on the edge.

Referring now to microscopical evidence: micrographs were taken of each specimen at the centre and near the edge, at a magnification of ×100 dia.

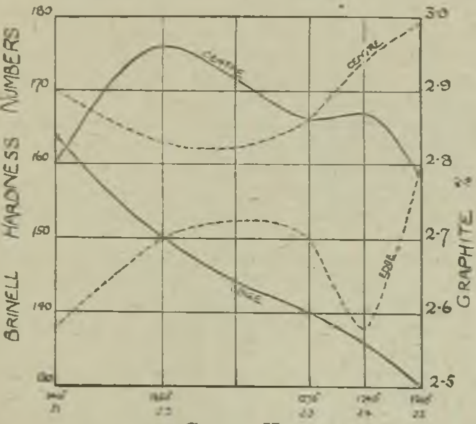


GRAPH IV.

and unetched (see Figs. 23 to 32). The comparatively large size of graphite flakes in the centres of the first three specimens contrasts largely with the size on the outside of the last three specimens. There is a distinct connection also between the hardness and size of graphite flakes, it being possible to correlate the graphite size with the shape of the hardness curve, both for the centre and the edge of the specimens; in other words, increase in size (referring now to dimensions, not percentage by weight) corresponds to decrease in hardness. This is shown by J3 and J4 centres. J4 is harder than J3, although its graphite content is not less, but the average size of individual flakes is smaller. Similarly a comparison between the edges of J3 and J4 shows that although J4 has the smaller

TABLE VIII.

Specimen and Quenching T. in deg. C.	Brinell No. for centre of specimen.	Brinell No. for edge of specimen.	Graphite per cent. in centre.	Graphite per cent. at edge.
J1 1,410 ..	170	138	2.8	2.84
J2 1,350 ..	163	150	2.96	2.7
J3 1,270 ..	166	150	2.86	2.6
J4 1,240 ..	174	138	2.87	2.56
J5 1,210 ..	179	159	2.78	2.5



GRAPH V.

graphite content, it has the lower hardness number, due to larger size of its graphite flakes.

Conclusions.

The following conclusions may be drawn from the work described in Part II of this Paper:—

(1) Free graphite is not present in molten cast iron, but the graphite which is present in a casting results from the decomposition of cementite in the solid state.

(2) On cooling from the liquid condition, the iron precipitates most of its graphite just below the solidifying point, *i.e.*, between 1,145 and 1,000 deg., in the particular iron under review.

(3) Smaller quantities of graphite are produced below 1,000 deg. C., due to the decomposition of the pro-eutectoid cementite.

(4) In one sample of cast iron it is shown that whilst after annealing at 1,100 deg. the graphite content is 2.2 per cent., on slowly cooling to 600 deg. and annealing at that temperature the graphite is increased to 2.9 per cent.

(5) At 1,000 deg. equilibrium of graphite content is obtained after a very short anneal.

(6) For any particular iron there is a definite graphitic carbon content under conditions of equilibrum for any given temperature.

(7) The graphite at the time of formation assumes the curvey flaky shape similar to that found in the final casting.

(8) Decreasing the pouring temperature lowers the graphite content, particularly on the outside of the bars.

(9) In the case under review the highest pouring temperature yields an iron with more graphite on the outside than in the centre.

(10) Graphite size is greater at the centre than at the edge.

(11) Increase in size of graphite tends to decrease the hardness.

(12) In general the less the graphite, the harder the iron.

Finally, the author wishes particularly to thank Professor T. Turner, under whose direction the work was carried out, for the many useful suggestions and criticisms made during the course of this research.

DISCUSSION.

Heat Treatment and the Production of Pearlitic Structure.

Mr. J. Shaw congratulated the author upon the work he had carried out and the results obtained. Discussing the first part of the Paper, he asked what was the section of the annealing specimens. Would the annealing effect on comparatively large sections—say 3 in. sq.—be the same all through as sample 8, Table I. In this case the temperature was 1.050 deg. C., the annealing time was 17½ hours, and the micro-constituents were given as graphite, pearlite and ferrite. It would be interesting to learn whether the author had annealed comparatively large sections of white cast iron and obtained a pearlitic structure all through the piece.

Precipitation of Graphite After Attaining Equilibrium.

In regard to Part II of the Paper. Frankly he could not reconcile the results obtained in one table with those given in the other tables. They were told in one case that equilibrium was attained at the end of 10 mins., and when the heat treatment was continued for 30 mins. practically no further graphite was obtained. Where they to understand from this that if a casting was held at a given temperature, above the change point, after a time no further graphite was formed. Casting temperature plays a part in the amount of graphite formed, yet no casting temperature is given in Tables II, III or IV. Mr. Shaw also pointed out that the time taken to reduce the temperature in the muffle from 940 to 700 deg. C. in Table II is not given. The same fact applies to Tables III and IV, so it is difficult to form conclusions. But Bars A2, B1, and F4 all quenched at 900 deg. C., yet 1.7, 2.42 and 1.90 per cent. graphite respectively are obtained. Again, B3 and F2. In the first case 1.94 per cent. graphite was thrown out, while in the latter only 1.6 per cent. was obtained, yet both these latter must have been held over the 10 mins.—mentioned as the time to obtain equilibrium at 1,000 deg. C

Free Graphite in Molten Iron.

As to the vexed question of whether graphite could exist in the free state in the molten metal, the fact pointed out by Mr. Northcott that in the quenched specimen, GI, in Table VI, it was possible to obtain 0.27 graphite in the very short time it took to solidify this specimen, gave a reason for some of things encountered that was considered proof that free carbon was present in molten iron. At the same time, it was quite possible that pouring a very thin stream of molten metal into water any free carbon might be washed away in the water. The figures given in Table VIII were in contradiction with those of Hailstones in his Paper before the Iron and Steel Institute. Hailstones stated that when casting at 1,428 deg. C. with the metal he used, the graphite was 2.83 deg. C. He cast fresh bars at intervals of 2 mins. The last bar was cast at 1,264 deg. C., at which temperature his graphite carbon content was increased to 3.126 per cent. Which result was to be considered correct?

Decarburisation Danger.

Mr. Northcott, replying to Mr. Shaw, said that the specimens he had annealed for the first part of the Paper were not more than 1 cm. square. His chief trouble with sections of such small size was that decarburisation took place on the outside. That was why they had been annealed in a partial vacuum. On the small specimens, or, for that matter, on big ones, if they were annealed for a sufficiently long time, particularly in an oxidising atmosphere, decarburisation would take place. With regard to pearlite, he certainly thought in white heart metal with high sulphur or chromium they would get a matrix of pearlite with nodules of temper-carbon. As to Mr. Shaw's remarks with regard to Tables II and III, it must be understood that those were not intended to be equilibrium conditions. In Table V there were inequilibrium conditions, and it was seen that after about 10 minutes at a temperature of 1,000 deg. equilibrium was attained. He could certainly say that at any temperature above 700 deg. there was only one carbon content when the metal was in equilibrium. In this case it was about 2.2 per cent at 1,000 deg.

A Speaker asked how Mr. Northcott accounted for the difference in graphitic content between specimens A2 and B6 in Tables II and III; the temperature was the same in each case, and each was held for 10 minutes.

Mr. Northcott replied with the aid of a sketch of the iron-carbon equilibrium diagram. His figures in Tables II and III were distinctly not in equilibrium. If these irons had been held at each temperature for at least 10 minutes he believed Mr. Shaw would see that the figures would have been equal in both tables, but with a descending temperature—the cooling was fairly rapid in a small gas muffle—equilibrium conditions had not been obtained. With regard to molten metal, he had no doubt that carbon in molten iron did not exist as graphite. He could not prove that very well at the moment, but if they made the experiment—not an original experiment—of pouring molten iron into a bucket of water, and then taking a small piece of it and dissolving up in acid, there would be no graphite there at all. He had heard it said that graphite was there in the colloidal state, but if they did not find graphite in the analysis they could be quite sure that graphite was not there at all. He doubted very much if any graphite would be washed away by the water.

Comparison of Brinell Results.

Mr. Simcox said he could testify that the author had entered into his work in a thoroughly efficient manner. With regard to Graph V, he asked if Mr Northcott could explain the difference in the dotted curve for the edge, giving a Brinell value of 138, as compared with the others. The top curve, for the centre, agreed very well with the view that with increase of graphite there was a corresponding decrease in hardness, which one could quite understand, or, at least, one would expect. But in the curve for the edge there was a dip near the end. Was that due to the idiosyncrasies of cast iron? Mr. Northcott in his experiments had used a 1 mm. ball in one case and a 10 mm. ball in another. Could they interpret the results from the 1 mm. ball into the results of the 10 mm. ball? In dealing with malleable iron on several occasions he had met a hard constituent, which usually occurred round the grain boundaries. Dr. Hatfield had mentioned it in his book on "Cast Iron in the Light of Recent Research." It appeared that there was some doubt about this substance, and he would appreciate further information concerning it.

Mr. Northcott, referring to Mr. Simcox's remarks as to Graph V, said he was glad Mr. Simcox had been able to find sufficient excuse for the dip in the curve for the edge in putting it down to the idiosyncrasies of cast iron. There was no doubt that that was so, but he had put it down to the large size of graphite flakes in that particular specimen. Why that should be so he did not know. With regard to the 1 mm. and the 10 mm. ball, he was afraid that the results were not consistent. The two instruments at his disposal did not give exactly the same values, so that the top hardness curve for the centre should certainly come down considerably. With regard to the point raised as to malleable iron, he should imagine that the constituent to which Mr. Simcox had referred was cementite. Although in good malleable iron there should be no free cementite at all, in some castings there were considerable areas of cementite round the boundaries. That was shown in Figs. 11, 12 and 13 of the Paper. The sample cooled far too quickly. It was the general practice to occupy at least two days for cooling down from a high temperature in commercial work, and he could only imagine that that practice was not followed in cases where there were free cementite areas in the irons.

Chilled Malleable Iron and Annealing.

Mr. F. J. Cook said that in regard to the formation of graphite or temper-carbon in malleable iron castings during annealing there was a difference in cases where the malleable iron had been chilled in manufacture as compared with other cases. In certain parts chills had to be used in order to produce sound castings, and it would be worth noting in future investigations what effect that had on the size, condition and formation of the graphite during annealing. Another important point was that which was mentioned in No. 7 of the author's conclusions, *i.e.*, the formation of the graphite in curvey flakes. When examined under a microscope, a curvey flake was a saucer-shaped flake. He had come to the conclusion, after a very long period of observation, that when it was in that form it was the very strongest form in which they could have it. If the author would bear that in mind in his investigations, he might be able to prove it to the satisfaction of foundrymen generally, and probably to their benefit.

Mr. Northcott said he had no experience with regard to malleable iron after chilling. He had been dealing recently with some special malleable cast irons which were taken out of the furnace at a red heat and allowed to cool down in the air, and then quenched from a black heat, and there were no good mechanical properties whatever.

As to Mr. Shaw's criticism of conclusion No. 8, which he had omitted to answer, he was convinced that his figures were the correct ones—at any rate for the iron he was using. It was not unreasonable to suppose that, by decreasing the pouring temperature—certainly on the outside of the casting—there was less graphite, for the simple reason that with a high pouring temperature they had an excess of heat to warm up either the sand mould or iron mould, whichever was used, and that would decrease the rate of cooling of the metal. Whether or not that would affect the inside of the casting would depend, to a large extent, on the size of the casting.

Total Carbon Content Queried.

Mr. H. J. Young, referring to Tables II and III, said that if the author had had a little more experience he would not have published those two tables, because the only answer to the criticisms made upon them was that the iron was not in equilibrium. If it were not in equilibrium, what was the good of publishing the tables? If the author had carried out the tests 99 times with the iron not in equilibrium he would have got 99 different results. He agreed with Mr. Shaw that they had no meaning whatever. He had noticed that the total carbon of these pig-irons was 3.2 per cent. He himself used a great deal of pig-iron, and would be very glad if it contained only 3.2 per cent. total carbon. He received it sometimes, but that was not the normal iron; it was a very low figure for pig-iron. He knew that makers advertised pig-iron containing 3.2 per cent. total carbon, but when the consignments were analysed, they usually found about 3.6 per cent., and when the makers advertised 3.6 per cent., they found about 4 per cent., and so on. Therefore, 3.2 per cent. was a very low figure, and the fact that Mr. Northcott had been working on a 3.2 per cent. total carbon pig-iron was a point of importance. If he had had a total carbon content of 4.2 per cent., as was the case with many hematites, some of the figures obtained might be very different. Mr. Young said he was astounded when the author said that the size of the specimens was 1 cm. square, and he did not think that those working in engineering works would be impressed with the results obtained on such small specimens. It meant that the author had been working on surface more than upon mass. The specimens dealt with in the second part of the Paper were 6 in. long and 1 in. in diameter. That being so, he would like to ask the author how he explained Table VIII. He did not think Brinell results of reliable value could be obtained on 1-in. diameter bars if the idea was to compare results on the edge with those taken in the centre. He was speaking from the practical point of view. Moreover, he did not think the graphite results in the table were correct. The graphite in the centre of a 1-in. bar would, in his opinion, be very little different from what it would be towards the edge, unless they took the outside skin—perhaps 1/32nd from the outside edge. Also with regard to the percentage of graphite in the centre, given in the table, he did not think there was much difference between any of the specimens.

Molten Iron is Free from Graphite.

He agreed with the author that there was no free graphite in molten cast iron, unless it were super-saturated and some pig-irons contained much carbon. With 3.2 per cent. total carbon, at any rate, he did not think there was any free graphite. In conclusion, Mr. Young suggested that the author, if he continued his work, might take one little table out of the Paper and carry out intensive work upon it, and then read a Paper on his investigations. All would find a great deal of interest in it.

What is Refined Pig-Iron?

Mr. Northcott, after thanking Mr. Young for his remarks, said, referring to the size of the specimens of white iron used for annealing experiments, as far as he could see—he did not wish to be dogmatic about it—the specimens used in the malleable industry in this country were generally not very big, in section at any rate, and, irrespective of the size of the specimen, he held that the temperature had the chief influence on the shape of the temper-carbon. Whether they used a big or a small specimen, if they used the same temperature and annealing conditions, they got the same form of graphite. As to the percentage of total carbon, the iron he obtained was a refined pig-iron, obtained locally. He had purchased it himself, the analyses were his own, and he held to them.

Mr. Young asked exactly what Mr. Northcott meant by " refined " pig-iron.

Mr. Northcott replied that, as a matter of fact, he did not know. (Laughter.) It was sold as a refined iron by a company which called itself a refining company. He had seen some of it made, and he supposed that, to a certain extent, it was refined. In reply to further questions by Mr. Young and by Mr. H. Field, Mr. Northcott said he did not know whether it was cold blast, but agreed that it was a cupola-melted iron.

Mr. Young: Then it is a cast iron?

Mr. Northcott agreed that it was. Continuing, Mr. Northcott referred to Mr. Young's remarks as to Tables II and III, and said he was afraid Mr. Young could not have appreciated the figures. He (Mr. Northcott) was doing research work, and it was his pleasure to find out things which, as yet, were not known. It was useless working on things that were known. The figures in Tables II and III were his figures, and the analyses were done by himself, and, even if Mr. Young did not think the two tables were of any use, he might or might not think that Table IV, which was a combination of those two, was of some use. Whether that was so or not, he did not know, but he hoped that several other members would take some interest in the results given in Table IV and in Graph II.

Brinell Hardness and Graphite.

Mr. A. Marks said those who had carried out research work on a large scale knew that their results did not always coincide with those obtained from work on small specimens. On the other hand, efforts to examine the question under somewhat different conditions were always to be considered with interest, and it was for those with more experience of work on a practical scale to give workers such as Mr. Northcott every assistance they could to apply the results to practice. There were one or two statements in connection with the Paper that those who had experience of work on a larger scale knew were not quite correct. For instance, the relation of Brinell hardness to the graphite content. If Mr. Northcott would try experiments with 3 or 4 tons of cast iron under various conditions he would find that he could get a Brinell hardness figure which was higher in a casting with a higher graphitic content than he could with a casting with a low graphitic content. One would anticipate, from ordinary experiments, that with iron with a high combined carbon content one would have a high Brinell figure, but it was possible to get an iron with a low combined carbon content with a higher Brinell figure, so that the author's conclusions, whilst quite easily true when working with small specimens, are not applicable generally.

Free Graphite and Molten Cast Iron.

With regard to free graphite, this was generally spoken of by scientific men as not existing in molten cast iron, but it still had to be explained why the practical man could walk round the foundry and watch a casting poured, noting the break of the metal, and know whether the casting would be hard or soft. The scientific knowledge of some very capable foremen whom he had met was remarkable, and one could not help but call it scientific knowledge. Without any laboratory knowledge of estimating his graphite, the foreman could say, simply by skimming the ladle, what kind of iron he had. He took skimmings off the top and ascertained the graphite content of it, and found that the graphite content was an accurate guide to the softness or hardness of the iron. Therefore, whilst it is held that free graphite did not exist in molten metal, it must be recognised that here was a practical test in everyday use, where the graphite content was an indication of the condition of the resulting cold metal. With regard to the diagrams in the Paper, Mr. Marks warned Mr. Northcott that most of the diagrams which had been published in connection with metals were the result of tests made on very small specimens, and they were very misleading.

Mr. Northcott thanked Mr. Marks for his kind remarks, and agreed to a large extent as to the scientific knowledge of the practical man. There was no doubt that foundrymen generally could tell the condition of irons, but there was no doubt also that there was a theoretical and scientific explanation for it. With regard to the soft metal, and the information obtained from skimming a ladle, he believed that might be due to the formation of kish. Kish, generally, was not formed except in high-carbon irons, and those irons generally had a considerable amount of graphite; consequently—though not necessarily—they were softer irons.

Mr. A. Campion, F.I.C., said he had only one suggestion to make with regard to this very valuable Paper. For a long time he had thought that insufficient attention was given to the size and formation of graphite. There was only one particular iron dealt with in the Paper, and to say that the equilibrium conditions were attained at 2 or 2.2 per cent. graphite did not convey very much. It would be better if after examination of many irons they could work to some definite ratio to the total carbon; for instance, if they said that when a certain percentage of the total carbon was in the graphitic condition, equilibrium conditions were obtained, it would be better.

Mr. Northcott said it was impossible to get out the formulæ for any iron.

Mr. Campion pointed out that nothing was impossible.

Mr. Northcott replied that perhaps it was possible, but the values would be quite useless. The values obtained for the iron he had used were to a very large extent approximately the same for any irons, and, even if they were going to vary the total carbon in any iron, he believed it was true to say they would not alter the combined carbon content at equilibrium temperature.

Mr. E. Longden, referring to statements made to the effect that graphite was formed after solidification, said that if that were so, why did one get a lesser shrinkage in grey irons as compared with white irons?

Mr. Northcott replied that white irons contained a considerable amount of their carbon in the combined state, and it was present as Fe_3C (iron carbide). That had a definite shrinkage value, just as all substances had. In grey iron, however, one molecule of carbide broke up into three of iron and one of carbon ($3Fe + C$). It was the expansion due to that reaction which prevented grey irons from contracting very much.

Mr. E. Longden asked whether the pressure exerted by the cooling envelope of the metal on the molten centre induced shrinkage.

Mr. Northcott said that the reaction generally took place just following the solidification point of the metal, and some metals actually expanded just after the solidification point was reached. Usually, however, there was shrinkage after the reaction had taken place.

ECONOMICAL MELTING WITH CUPOLAS.

By H. Van Aarst (Holland).

The demand for fuel is worldwide. In consequence of the world war, followed by strikes and other troubles, the production of coal and coke has materially decreased. The restlessness all over the world induces gloomy views for the future, and the regular supply of fuel is still by no means guaranteed. Therefore, economy in fuel is essential. This is well known, but the principles of its economical use are but little appreciated.

As a large quantity of fuel is needed for foundry work, this Paper is addressed more particularly to foundry managers and those connected with foundries.

" Few strokes fell great oaks " is a proverb that is certainly applicable to the melting of iron. What are these strokes? Some of them may be enumerated as follows:—

Insufficient air-supply causes an incomplete combustion of coke, the melted iron becomes dull and is not mixed, castings made of this material are often wasters.

Excess air-supply oxidises the iron, as not all the oxygen can be combined with the carbon of the coke. This excess of air burns the iron.

Insufficient limestone, added to the fuel and the iron, makes a thick and viscous slag, the tuyeres will be made up, the tap- and slag-holes being cleaned only with difficulty.

However, it is apparent that between too much and too little, the " correct " must be found. It is intended to deal with these matters in order to find the " correct."

Referring to Fig. 1, cupola practice may be described as follows:—Having attended to the lining and inspected the tuyeres (sometimes there are small pieces of slag or coke found lying in these holes), the bottom door No. 11 and the door of the receiver (fore hearth) can be closed, the sand bottom in the cupola can be made up. About two hours before the starting to melt, the cupola must be lighted by wood, peat or coke fire. When this fire is burning well, the bed-coke can be added, door No. 10 remaining open and the bed-coke allowed to burn through till the half of the quantity is added. The cupola is thus warmed all over gradually and the lining will not crack or burst.

Door No. 10 can now be closed, and blowing started. The air goes through the tuyeres into the cupola, passes through the bed and up the stack. A quantity of the warmed air passes also through the channel to the receiver, slag and tap holes, so that all parts of the cupola are heated intensively.

The heated cupola can now be filled completely through the charging door with coke, iron and limestone, added in definite proportions and quantities. Slag and tap holes must now be shut, after which the melting process starts.

Melted iron and slag drip through the coke, fall upon the sand bottom of the cupola, and run through the channel into the receiver. The furnaceman has to exercise care so that the fluid material—iron and slag—does not rise too high in the receiver. He must tap off before the material can approach the peephole. When the melting is finished, the door of the receiver must be opened so that the remaining slag can run off.

The bottom door of the cupola must also be taken away to prevent the rest of the slag and coke remaining in the furnace. After this resume of the melting process, which is known to all founders, it is proposed to discuss the different factors which may influence it.

The Influence of Iron on Fuel Economy.

Hard iron, with a low percentage of Si and Mn, has a higher fusing point than soft iron. It requires a higher temperature to melt it. Large pieces of iron are more difficult to melt than small pieces. Iron covered with sand will melt less easily than clean iron. Moreover, the required temperature of the metal will depend upon the sizes of the castings to be made. Thin castings, for instance, need an iron of higher temperature

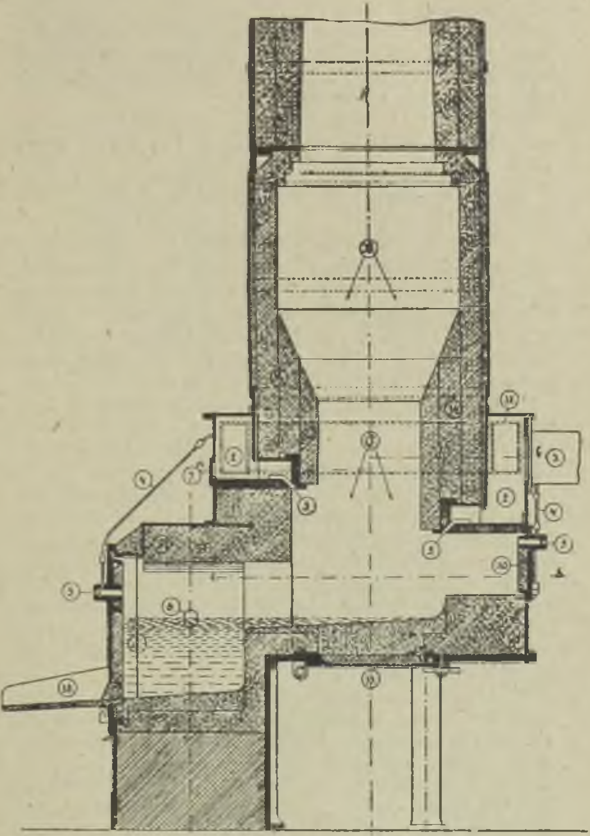


Fig. 1.—Section of Cupola.

A, Filling shaft; B, Heating zone; C, Melting zone; 1, Air inlet; 2, Wind belt; 3, Tuyeres; 4, Cooling tubes; 5, Peep holes; 6, Slag notch; 7, Valve; 8, Door in receiver; 9, Shutter; 10, Side door; 11, Bottom door; 12, Cover on wind belt; 13, Tapping spout; 14, Brickwork.

than heavy ones. The transport of the liquid iron in the foundry must also be taken into consideration

In the first instance, the foundryman must take into consideration for what purpose the melted iron is to be used, after which the quantity of coke must be determined.

The different temperatures are approximately as follows:—Cold iron, 1,200 deg. C.; warm iron, 1,260 deg. C.; hot iron, 1,320 deg. C.; very hot iron, 1,380 deg. C.; extraordinarily hot iron, 1,450 deg. C.

Coke Considerations.

Now the quantity of coke must be determined. Good coke is hard and coarse, and consists of 84 per cent C, 10 per cent. ash, 1 per cent. S, and 5 per cent. water. Bad coke is porous, and the specific gravity is low; also it has a higher percentage of ash and sulphur.

The combustion of coke can take place in two ways. When there is much air, and therefore much oxygen, one part of carbon combines with two parts of oxygen ($C + O_2 = CO_2$).

From this combustion carbon dioxide is produced with the evolution of 8080 calories. If there is too little air and too little oxygen, 1 of oxygen combines with 1 of carbon ($C + O = CO$), producing carbon monoxide with an evolution of 2,473 calories, or only one-third of the calories developed by full combustion. Thus, it is of the utmost importance to further the formation of CO_2 as much as possible.

It is easy to enunciate the platitude, "Take care to have sufficient air-supply." However, this is not so easy as it seems to be, as CO_2 cannot exist at any temperature. The escaping gases of the cupola chiefly consist of nitrogen, carbon dioxide, and carbon monoxide. Neglecting the nitrogen and considering only the carbon dioxide and monoxide, it is known that both can exist up to 400 deg. C. The higher the temperature becomes, the less carbon dioxide will be formed. This continues up to 1,000 deg. C., at which temperature they cannot exist at all.

There are, however, two opposite factors: (1) The coke, requiring a large air-supply, in order to assure the greatest possible useful efficiency; and

(2) the peculiarity of the carbon dioxide to dissociate at a temperature above 400 deg. C.

The Influence of the Mechanical Properties of Coke.

Hard, coarse coke imposes more resistance to the pressure of the upper layers of iron, coke and limestone than porous coke. More space will be occupied by the latter. With coarse coke there can pass more oxygen than with porous coke, and less surface of carbon is also exposed to the passing oxygen. The CO_2 combination, to be associated with good melting process, will assume its correct position, just as is required. Porous coke will give the opposite result, as the oxygen in passing meets a large surface of carbon, giving a com-

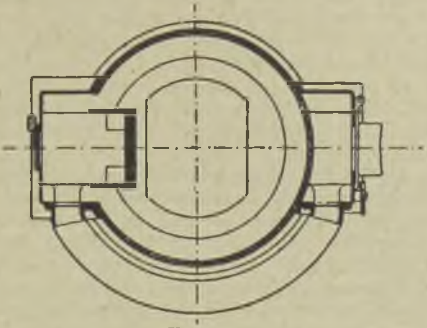


FIG. 1A.

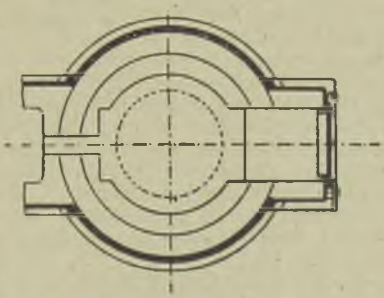


FIG. 1B.

bination of CO as a result. This uses more carbon with the same quantity of oxygen; additionally, both more oxygen and coke are required.

In many foundries it is usual to make charges of 5 cwt. It is better to use 10 cwt. The latter quantity of coke for each charge will give a better result when using hard coke. It will stand pressure and friction in the cupola better, and facilitate the descent of the material. The pulverisation will not be so great. The quantity of coke needed in a well-conducted furnace varies between 8 to 10 per cent. of the quantity of iron to be melted. It must be understood that this percentage also depends upon the quality of iron and coke used.

An important factor when melting is the quality of limestone. The limestone serves to make slag of the ash of the coke and to desulphurise the iron and coke. The slag may be either a thin fluid or a thick syrup. Liquid slag proves that sufficient limestone has been used. A thick one indicates the reverse. A thick, viscous slag may be disadvantageous, because the tougher the slag the easier it fastens itself near the tuyeres or into the channel of the receiver, in which case the melting process will be disturbed.

This type of slag is very difficult to remove from the cupola and receiver, so that—when cleaning the lining—the firebricks will be damaged severely.

The thin, fluid slag is of great importance for the refining of the melted iron. The molten iron loses some of its sulphur existing, chiefly rich sulphur-manganese alloys, which are lighter than molten iron and rise to the surface. A fluid slag will take up these impurities, and the more fluid it is the better will it do so.

It is worth recommending to tap the slag often, in order to prevent the slag from clinging to the lining and to keep the slag fluid and fresh. The correct colour for cold slag is glittering-black and very brittle. If it is dead-black, hard, and contains iron, there is something wrong with the melting process. Very often the fracture of the slag is yellow-green.

The quantity of limestone necessary when melting depends upon (1) the quality of coke, (2) the kind of iron to be melted, and (3) the lining of the cupola, Generally speaking, one may use 25 to 30 per cent. limestone of the quantity of the melting coke.

Air Supply.

Coke, limestone, and air-supply form a triple alliance, completing one another during the melting process. With an open fire with natural draught, the air supply constantly regulates itself with incomplete combustion. This is by no means the case when iron is melted with forced draught.

It is well known how necessary it is to use an exact quantity of air in order to obtain the most economical result of a good combustion. Insufficient air-supply gives an imperfect combustion of coke. On the other hand, excessive air-supply oxidises the iron and causes metallic losses. With an accelerated air supply, the gases leaving the cupola have too high a temperature; this is also a disadvantage. A perfect combustion of the coke has practically been found by using 8 to 10 cub. metres of air for 1 kilo of iron.

To calculate the amount of air used in the cupola, it is necessary to know the speed and the pressure of the air-supply. The speed can be controlled by using a **Pitot tube** (Fig. 2), which is placed, filled with water, as near the tuyeres as possible. The difference *h* in both pipes is also the length of the air column. If this *h* is 12 mm., this means 1.2 gr./cm^2. One cub. metre of air weighs at 0 deg. C. (760 cm. barometric pressure) 1.293 kilos. Assuming that the temperature of the passing air is 15 deg. C., and neglecting the position of the barometer, 1 cub. metre of air weighs 1.2 kilos or 1 cub. decimetre 1.2 gramme. On a base of 1 cm^2 the height of the air-column of 1.2 gramme becomes 1,000 cm. or 10 metres. Consequently the length of the air-column, corresponding with a water-column of 12 mm., is 10 metres.

The further calculation is as follows: When an object is falling from a height of *h*, it is well known that the acceleration is 9.81 metres every second. The speed upon the ground is found by the formula $V' = V'2gh$.

Instead of a solid body, foundrymen have to deal with air, which gives the following result when falling:—

Speed $V' = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 10} = \sqrt{196}$ = 14 metres per second.

By multiplying 14 metres per sec. by the section of the tube, the number of cubic metres of air per second is found.

Instead of the Pitot tube, there are also self-registering metres. They work on the same principle. One advantage is that they indicate all fluctuations of the melting process and control the actions of the furnaceman.

Cupola Linings.

Fig. 1 shows the construction to be divided into three main parts—charging shaft, heating zone, and melting zone. The bottom of the charging channel is somewhat enlarged in order to prevent the well-known difficulty of "hanging" of the material which often occurs in ordinary cupolas. That this hanging causes difficulties and bad melting results needs no explanation. Wherever the lining has burnt away it is necessary to rebuild it as soon as possible to prevent this occurring. The escaping gases will also be more free to leave the cupola chimney. The heating zone has a larger diameter than the upper part for two reasons: (1) Each time the charges fall on the enlarged coke bed the escaping gases are not obstructed and meet less opposition, and (2) above the melting zone there is a lower temperature with this construction than with a straight-lined cupola. The formation of carbon dioxide is promoted, the heat is better utilised.

The melting zone is the part for the melting process. Here the iron is melted and every obstacle which can take place before entering this part of the furnace is removed. Here the coke burns, the iron melts, and slags are formed. There is a continual movement there, the heated gases going upwards to the chimney, the melted iron running down to the bottom and receiver. The slag runs slowly to the bottom, often giving the furnaceman great trouble, especially when it adheres to the tuyeres, obstructing them or the channel to the receiver.

To prevent these difficulties, Fig. 1 shows how the tuyeres are built into the lining. The slag can pass these holes without causing any trouble.

Foundrymen must be sure that on the side of the receiver no difficulties arise from slag adhering to the tuyere. This cannot always be ascertained from the opposite side of the tuyere, as the coke lying near will be soon chilled by the blast. The dripping slag will cool there, and gradually the tuyere will be filled with slag and unburnt coke.

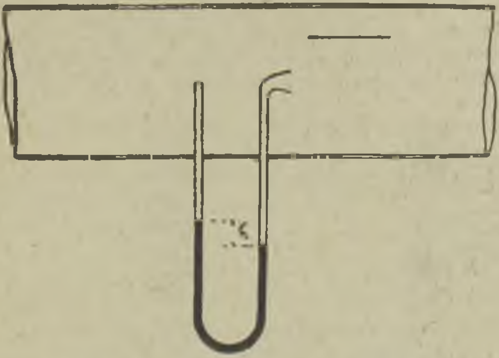


FIG. 2.—SHOWS A PITOT TUBE.

To prevent this difficulty the entering air must be divided as shown in Fig. 3B (Fig. 3A shows the wrong method). The coke lying in front of this hole will also burn much better. Thus there is a regular air supply, which is of the greatest importance to a good melting process.

Successively the author has discussed the different factors influencing the melting process. Now he wishes to draw attention more especially to the escaping gases. For this purpose it is necessary to go on the platform and inspect the gases passing up the cupola into the chimney. Sometimes these gases are white, transparent blue, and sometimes they are invisible. Sometimes there is directly upon the top of a charge a yellow-rose flame. To these phenomena it is desirable to draw attention, as they are the easiest to control, for after the combustion process a smoky flame indicates the incomplete combustion. White-coloured flames at the charging door during the melting process means incomplete combustion. These gases arise from too little air supply, more air being required. If the gases are invisible it may be that there is perfect combustion. However, care is essential. If the liquid iron is cold increase the air and coke supply. If possible try to regulate the combustion in such a way as to obtain a transparent light-blue coloured flame at the charging door. The fuel consumption is but a little higher, but then one can be more certain of a regular melting process, and in cases of breakdown the metal can stand a little time. A yellowish-rose flame shows that the temperature above the melting zone is too high, and a considerable loss of heat is the result.

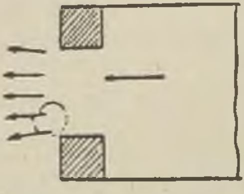


Fig. 3a.—Wrong Method. Fig. 3b.—Correct Method of Introducing Air.

The object of this Paper has been to show how to be economical with fuel in the cupola, and to make it understood how much there is to be done in this respect.

The iron to be melted determines the quantity of coke, the coke determines the air and limestone supplies, whilst the limestone influences the combustion. The height of the cupola is still another factor.

To save coke one has first to know what happens during the melting process. The knowledge of this subject is still very incomplete.

In the English, American, and German literature on this subject one finds different lectures, more or less scientific, derived from experiments by many foundry engineers in order to come to a more economical fuel consumption, less loss of iron, or to find pointers for the difference between iron which is or has to be melted.

For practical foundrymen it is thought that this Paper will be sufficient for their own practice, as it is taken and built up from experiments made by the author. It is hoped that this article may animate many foundry workers to improve their own methods. If these experiments are taken carefully and seriously, and if one does not mind meeting and overcoming difficulties, one is sure that better results will be obtained. The fuel consumption will decrease gradually, the iron will be melted more regularly, and the repair of the cupola will cost less.

DISCUSSION.

Mr. H. Van Aarst, Jun. (Holland), presented the Paper which had been contributed by his father. In doing so, he very much regretted that his father had been prevented from attending the Convention owing to illness. He had been charged to present to the Convention the heartiest greetings and best wishes from Dutch foundrymen, who hoped that the Convention would be as successful and valuable as the Institute itself hoped it would be. Also, he expressed the hope that members of the Institute would find an opportunity to visit Holland when a foundry conference was being held there. He was astonished to realise that English foundrymen had made such very great progress as they had during the last twelve years or so. Some years ago he had been to Tyneside in order to learn how to make castings, and he was pleased to be able to say that, with the aid of the English people, the Dutch had been able to make good castings themselves.

NON-FERROUS ALLOYS IN MARINE ENGINEERING WITH SPECIAL REFERENCE TO ADMIRALTY GUNMETAL, MANGANESE BRASS AND WHITE METALS.

By A. E. Logan (Member).

INTRODUCTION.

Although the introduction of the turbine, and more recently the development and introduction of the Diesel engine, are outstanding events, progress in marine engineering has been to some extent a process of evolution. Demands for larger and faster vessels have been met by increases in engine size, and the use of higher boiler pressures and superheat. This, together with the continual striving after weight reduction, with its consequent decrease in section thickness, has naturally led to more exacting working conditions for the materials of construction.

Fifteen years ago, boiler pressures of 180 to 190 lbs. per sq. in. were usual, at temperatures of about 375 deg. F., and superheat was just being introduced for the second time. In present practice, pressures of 220 to 225 lbs. per sq. in. are quite common, with 250 deg. or more superheat; giving total steam temperatures of 650 deg. F. and over, and the tendency is to go still higher. Outward and visible evidence of this, and how it affects the foundry, is to be found in the fact that increased demands are being made in specifications, the most obvious instance being the raising of the Admiralty requirements; in the case of gunmetal, from 14 tons per sq. in. with 7 per cent. elongation, to 16 tons per sq. in. with 8 per cent. elongation. In the case of manganese brass, the specification now demands 33 tons per sq. in., and 15 per cent. elongation, and for cast iron, 11 tons per sq. in.

This is undoubtedly an indication of progress, and as such is to be welcomed; especially as it signifies that there has also been progress in foundry work generally.

The moral, however, should also be noted.

Working stresses are increasing, and test figures are being raised, consequently working margins are reduced. The foundry must therefore take advantage of modern methods of efficiency, together with every aid of science. The foundryman who seeks to know more, can learn much from simple, practical experimental work in his own foundry, especially where a pyrometer is available. It is impossible to over-estimate the value of the pyrometer when used in this manner. It is obviously impossible to treat all the non-ferrous alloys used in marine engineering with any degree of completeness in one short paper, consequently attention is confined to one or two of the alloys in general use; namely, Admiralty gunmetal, manganese brass, and white-metal. It is hoped, by indicating the importance of structure from the practical point of view, to help those who handle these alloys towards a clearer understanding of their natures, and the reasons for the treatment they require.

Functions of Various Parts and Influence on Choice of Alloy.

In marine engineering, the parts dealt with can be roughly divided into three sections, excluding the Diesel, to which sections 2 and 3 only apply.

(1) The boilers, which are the source of energy.

(2) The engine, which may be either reciprocating, turbine, or Diesel, and which is the means of converting the energy into work.

(3) The transmission, or shafting and propellers (including the gears, if a geared turbine), which convert the work done by the engine into propulsive effort.

SECTION I.

Boiler Alloys.

In this section, very little of non-ferrous alloys are used—the boiler shell, tubes, etc., being of steel. Main stop valves are sometimes of gunmetal, but the tendency is to go in for cast steel bodies, to withstand the high temperatures and pressures of modern practice. Even so, it is often necessary to let rings of special alloys, such as Monel metal, into the valve seats. Gauges and similar fittings are usually of brass.

Of the actual engines, the turbine has by far the greatest proportion of non-ferrous alloys in its construction. Only moderately small amounts of non-ferrous alloys are employed in the reciprocating and Diesel engines, in merchant practice, at all events.

Admiralty gunmetal is greatly used for valves and steam fittings of all kinds, and in general constructional work, gunmetal, and phosphor bronze in particular, in addition are very useful as bearing metals, for a reason which is indicated later. Admiralty gunmetal is often used for such bearings as top end brasses, tail shaft liners, stern tube bushes, etc., and phosphor bronze for many other smaller bearings. In the turbine, such things as nozzles, and especially the first few rows of blades in the H P. turbine, must possess strength at high temperature; and be tough or hard wearing, to resist the erosive action of the high velocity steam. Such alloys as 96.9 copper; 3 tin; and 0.1 per cent. phosphorus for nozzles, and manganese copper containing 3 to 4 per cent. manganese, for blading, are therefore used. (See Fig. 1.)

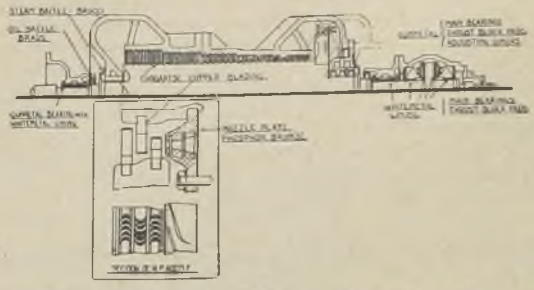


Fig. 1.—Section of Marine H.P. Turbine.

The main bearings of all types, and the crosshead guides, etc, of the reciprocating and Diesel engines, are lined with white metal. It is preferable that the bushes should be of gunmetal, as in the event of a " run out," less damage would probably result. Condensers are usually tubed with 70: 30, or 70 : 29 : 1 brass, but the great prevalence of corrosion trouble is clear indication that these materials are not satisfactory, but are only adhered to for want of a suitable alloy with the necessary immunity from corrosion, which can be as easily worked into tube form.

The propeller shaft is supported on white metalled carriages. The tail shaft, which actually carries the propeller, is cased in a shrunk-on gunmetal liner, and this in turn revolves in a stern bush, which is sometimes of gunmetal. All kinds of materials are used for the propeller itself, ranging from cast iron to steel and manganese brass. Manganese brass, although expensive, and sometimes not above trouble, due to erosion, is far superior as regards resistance to corrosion, and has a far longer life than either cast iron or steel. This, in conjunction with its increased efficiency, is held more than to outweigh its initial cost.

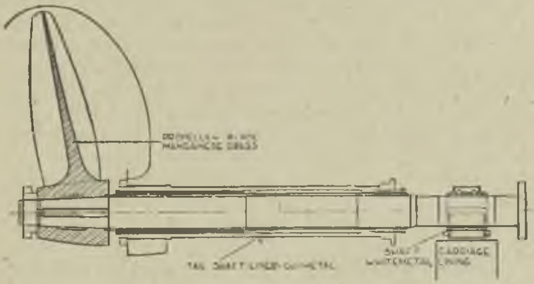


FIG. 2.—ARRANGEMENT OF PROPELLER AND STERN-TUBE.

Bronzes.

The name gunmetal, whilst it is generally taken to mean something substantially a bronze, as generally used in engineering, is really a very vague term, and may mean anything from a brass with only a percentage or so of tin, to a composition like 85 per cent. copper and 15 per cent. tin. On the other hand, Admiralty gunmetal is the definite 88 : 10 : 2 mixture, which is so well known, and as a high-class, all-round-purpose alloy is difficult to improve upon. Attempts to cheapen this alloy for merchant work take the obvious form of reducing the tin and increasing the zinc, with possibly the addition of a little lead. An alloy on these lines, containing 86 copper, 8 tin, 2 lead, and 4 per cent. zinc, has been used with a fair amount of success for general work. Another similar composition is 87 copper, 8 tin, and 5 per cent. zinc, and bars cast on tail-shaft-liners of this latter composition have given as much as 20 tons per sq. in. with 35 per cent. elongation.

Admiralty Gunmetal.

The alloy known as Admiralty gunmetal has more or less established itself as a "standard" composition, and with perhaps a little latitude in the lead content, is often used—apart from Admiralty work—where a high-class, strong bronze is required. It might be remarked in passing that there seems no reason why 1 per cent. lead should not be allowed, even in Admiralty work; in fact, from some points of view, it would be a positive advantage. Admiralty gunmetal has been the subject of a large amount of research work, especially of recent years, and much has been published concerning it.

Equilibrium Diagram of the Copper-Tin Alloys.

As an aid to the more complete understanding of gunmetal, the equilibrium diagram, or that

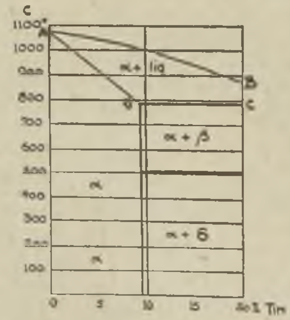


FIG. 3.—EQUILIBRIUM DIAGRAM OF THE COPPER-TIN ALLOYS UP TO 20 PER CENT. TIN. (FROM HEYCOCK & NEVILLE'S DIAGRAM.)

portion of it which includes up to 20 per cent. tin, should be considered. The equilibrium diagrams of the copper-tin and copper-zinc alloys are both recommended for the study of the practical foundryman, as much may be learned from them alone. The equilibrium diagrams show the freezing points, and changes which take place on cooling, for any proportions of copper and tin or copper and zinc as the case may be.

In the case of the copper-tin alloys, starting with pure copper, which has a melting-point of 1,084 deg. C., and adding tin, the freezing-point is gradually lowered. The line A—B is known as the liquidus, and marks the commencement of solidification. At temperatures above this line, alloys are entirely liquid. The line A—b—c is known as the solidus, and indicates the completion of solidification. Any further line shown below the solidus must therefore relate to changes which take place in the solid alloy whilst cooling. Such a change is indicated in the diagram of the copper-tin alloys, and occurs at 500 deg. C. Alloys containing up to 9 per cent. tin exist as a solid solution of tin in copper, known as the *alpha* solid solution. In material as cast, this is not homogeneous, owing to the difference in the melting-points of copper and tin, which are 1,084 deg. C. and 232 deg. C. respectively. This causes relatively pure copper to separate out first. When between 9 and 23 per cent. tin is present, a second constituent known as *beta* is formed. At temperatures above 500 deg. C. the structure consists of the alpha and beta solid solutions. If the alloy is being slowly cooled, a change occurs at 500 deg. C. whereby the beta breaks down, and the constituent known as the delta eutectoid, which is a definite compound of copper and tin ($SnCu_4$), is formed. The importance of this delta eutectoid will be seen later. Taking the case of an alloy containing 10 per cent. tin, solidification commences at about 1,000 deg. C., when a dendritic skeleton of alpha containing only about 2 per cent. tin is deposited. As the temperature falls the amount of tin contained in the alpha which is building up the structure, increases, as also does the concentration of tin in the still liquid portion, until at about 790 deg. C. the alpha formed holds 9 per cent. tin, and the whole solidifies.

The period round about 790 deg. C. is favourable to the formation of the undesirable beta constituent, consequently the cooling through this range should be rapid if segregation is to be avoided. Cooling proceeds to 500 deg. C., and any beta which is present is split up, and delta eutectoid formed. It is obvious that with only 10 per cent. tin, only very small amounts of beta, and consequently delta eutectoid, should be formed under normal conditions. The above applies strictly to an alloy of 90 per cent. copper and 10 per cent. tin. but is approximately correct for Admiralty gunmetal.

Casting Temperature.

The casting temperature of Admiralty gunmetal has been thoroughly investigated. By itself, casting temperature is not everything, but in conjunction with good melting practice, will go far to ensure success. Although Admiralty gunmetal has a wide range of pouring temperature within which sound castings can be obtained, trouble is experienced if this range is exceeded in either direction. In a Paper presented to the Institute of Metals in 1918, Carpenter and Elam give the range of casting temperature as from 1,120 to 1,270 deg. C. It is interesting to place on record the fact that the casting temperature of Admiralty gunmetal, as applied to works' practice, was investigated by Messrs. Dance and Lillie as far back as 1911. The conclusions arrived at, which were not published at the time, coincide substantially with what is known as Admiralty gunmetal to-day. On this account, therefore, the following extracts from their conclusions are given :—

"The highest limit at which it is advisable to cast Admiralty gunmetal without fear of segregation taking place is fixed (after much practical experimental work) at about 1,220 deg. C.

"The bottom limit is decided by the temperature at which the metal melts, the speed of pouring, and the size and shape of the object. A casting having thin places in it, or sharp impressions, would naturally require a higher pouring temperature than would a thick solid casting. . . The bottom limit may be fixed at 1,100 deg. C.

. . . . At this temperature it is possible to cast thick solid objects successfully. Therefore, between 1,100 and 1,220 deg. C. there is a range of 120 deg. C. in which all classes of Admiralty gunmetal may be poured without fear of low results through segregation, *provided that the metal has not been overheated previously.* (The italics are the present author's.) . . . . 1,220 deg. C. is the highest temperature at which Admiralty gunmetal can be cast without fear of segregation; we have good results from metal taken to 1,250 deg. C., but the metal was not allowed to 'stew' in the fire; even in these cases segregation was present to a certain extent. It seems that the length of time the metal is allowed to stand at these high temperatures before pouring has a bad effect, not only by 'burning' the metal, but also by increasing the tendency to segregation of beta. . . ."

It is inadvisable in ordinary foundry practice to work with such an extended range as that given by Carpenter and Elam. It is suggested that a range of casting temperature from 1,120 deg. C. for thick sections to about 1,220 deg. C. for light work will probably be all that is necessary. A safe rule to follow is to consider the nature of the casting carefully, and cast at as low a temperature as possible within the range given above.

Equal in importance with correct casting temperature is the need for careful preparation and melting of the alloy. Practice varies in different foundries as to the exact method of making the alloy. Some melt the copper and bring it up to a high temperature, withdraw the crucible from the fire, add the tin and zinc, and cast; the idea presumably being to have as little loss as possible. This method is not considered good practice. Every foundryman knows the great rapidity with which pure copper takes up oxygen when molten. In the foregoing method the copper is melted and considerably superheated, to ensure that after the addition of the tin and zinc the casting temperature will not be too low. In addition, therefore, to a tendency to produce oxidised material, there is a possibility that the loss is actually greater with this method than where the additions are made to the crucible as soon as ever the copper is sufficiently molten. A good covering should be maintained, and the crucible withdrawn from the fire as soon as the correct casting temperature is reached. On no account should the material remain in the fire longer than is absolutely necessary.

"Liquation."

Neglect of the above precautions or carelessness on the part of the melter will certainly lead to trouble. In addition to actual unsoundness, the phenomenon known as "liquation" can be caused by improper melting. This trouble is more common with large castings, and is generally indicated by the appearance of a greyish white extrusion on the surface of the runner, or it may be seen welling up if the runner is knocked off too soon—this being known as "bleeding" in the foundry. Fractures of these castings will probably show what are known as "tin spots." The author is of the opinion that under circumstances which favour this form of trouble gunmetal will tend to "liquate" according to its degree of oxidation. In other words, the greater the state of oxidation the greater the tendency to "liquate." "Liquation," for instance, will occur in a casting where the section, casting temperature, and rate of cooling, etc., do not appear to justify it.

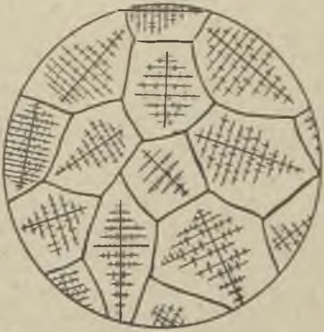


FIG. 4.—ILLUSTRATING THE FORMATION OF A DENDRITIC STRUCTURE.

Those who deal with gunmetal will have noticed how "sluggish" or "pasty" it becomes when oxidised. It is thought that this falling off in fluidity, together with the possibility that the actual solubility of tin in copper is diminished when in this state, prevent the alpha solid solution from holding its full quota of 9 per cent. tin. This would have the effect of causing a greater accumulation of tin-rich liquid, which as solidification proceeded would be pushed about, and eventually trapped. In portions where there was very slow cooling quite big quantities of this tin-rich liquid would accumulate, and as the pressure of solidification came on some of it might even be squeezed through the wall of the casting. Some actual extruded material has shown from 22 to 25 per cent. tin on analysis.

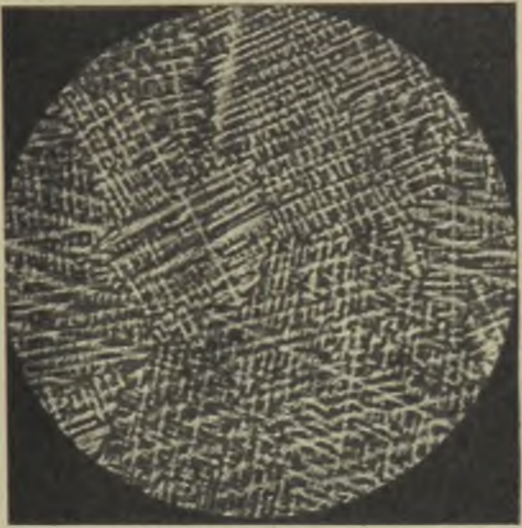


FIG. 5.—GOOD GUNMETAL. × 25.

It is a fact certainly that the poorer the quality of the gunmetal the less characteristic its structure becomes and the more delta eutectoid is found, indicating that the alpha solid solution has not taken up its proper share of tin in the initial stages of solidification.

The remedy for this form of trouble is primarily to ensure that the material is carefully made, and not overheated or left in the fire longer than necessary.

Secondly, the casting temperature should be as low as possible, in order that the mould may not absorb an undue amount of heat. Obviously the higher the casting temperature the more heat will be transferred to the mould and the longer it will take to cool through the danger range. In some cases special means may have to be taken to ensure sufficiently rapid cooling.

Structure.

It is generally possible to tell the quality of a piece of gunmetal by its fracture, and in this way it is really being judged on its structure. The actual examination of the structure under the microscope is very interesting, and it is often possible to determine the cause of trouble by this means.

By reason of it being a solid solution and having an extended freezing range (which, as indicated in the equilibrium diagram is from 1,000 deg. C. to 790 deg. C. approximately), gunmetal has what is known as a dendritic structure. The manner in which a dendritic structure is formed and an idea of its characteristic appearance will be seen by referring to Fig. 4.

In Fig. 5 is illustrated a typical photo-micrograph of good gunmetal, where the dendritic structure is very pronounced. This actual specimen was cut from a test-bar which gave 20.96 tons per sq. in. tensile, and 44 per cent. elongation. The other extreme is represented in Fig. 6, which is from a test-bar cast on a casting, and which gave only 10.0 tons per sq. in. and 5 per cent. elongation.

Examination under slightly higher powers reveals the delta eutectoid. This is a hard, brittle, bluish-white compound. Good gunmetal contains only very small amounts of this constituent, and then in very small pieces and evenly distributed. When a large amount of delta is present as in poor gunmetal it is usually found to be more or less in the form of a network, and it is the lines of weakness which are thus introduced which are the chief cause of low tensile and elongation. Figs. 7 and 8 show the relative amounts and distribution of the delta eutectoid in the strong and weak gunmetals in Figs. 5 and 6 respectively.

The specimens shown in Figs. 5 and 6 have been etched with an alcoholic solution of acid ferric chloride, which leaves the copper-rich portions almost unattacked, but considerably darkens the tin-rich portions. There is no sudden line of demarcation between the two, as the photographs may lead one to suppose, but a gradual merging of one into the other. An examination of a large number of bars, of which a comparison of Figs. 6 and 8 with Figs. 9 and 10 may be taken as being fairly typical, indicates that the physical properties of gun-metal are principally dependent on the structure.

FIG. 6.—WEAK GUNMETAL. × 25.

The bar illustrated in Figs. 6 and 8 was cast on the casting, and, as previously stated, gave only 10 tons per sq. in. and 5 per cent. elongation. The bar shown in Figs. 9 and 10 was cast separately at the same time, and gave 15.44 tons per sq. in. with 21 per cent. elongation. The structures, and especially the relative amounts of the delta eutectoid in the three bars (21 tons, 15 tons, and 10 tons respectively) should be noted. The delta eutectoid has somewhat the same characteristic shape as the phosphorus in cast iron, and for much the same reasons. Fig. 11 illustrates a piece of this delta eutectoid at a higher magnification.

It may seem incredible that the change of beta to delta can occur in the solid material, and at as low a temperature as 500 deg. C., but this is nevertheless correct. The presence of much of this delta eutectoid may indicate that the casting temperature has been too high, and/or the rate of cooling too slow, or that the material has been oxidised through standing too long at a high temperature. In this latter case, evidence of oxidation will also be found. Whatever the cause, however, the result is the same, namely, weak gunmetal.

Heat Treatment.

As is to be expected, Admiralty gunmetal is amenable to heat-treatment. The correct annealing temperature undoubtedly appears to be round about 700 deg. C. Annealing at this temperature removes the "cast" dendritic structure, and gradually absorbs the delta eutectoid, giving finally a homogeneous solid solution of tin in copper, with improvement of the physical properties. For such castings as liners and bushes, etc., and, in fact, for all castings where sliding or rubbing contact is to take place, annealing would be distinctly harmful, as the value of gunmetal as a bearing material is dependent on its "cast" structure, and particularly on its delta content. For this reason an alloy of 85 per cent. copper and 15 per cent. tin is even more suitable for a bearing metal, and is often used as such.

It is thought, however, that annealing would be an advantage with steam and hydraulic castings, etc., and although the author has had no experience of this as a regular works' practice, it is believed that it is carried out in some places. Experiences and opinions are invited as to the desirability or otherwise of annealing such castings as indicated.

Brasses.

Copper and zinc alloy in all proportions, but beyond 49 per cent. zinc the alloys cease to be of commercial value owing to extreme brittleness. The equilibrium diagram is interesting and worthy of study.

The line A—B—C in Fig. 12 represents the liquidus. The dotted line Ab Bc indicates the solidus, at which temperatures solidification is complete. Up to 37 per cent. zinc approximately, at atmospheric temperature, the structure consists of a solid solution of zinc in copper known as the alpha solid-solution. With alloys containing more than 37 per cent. zino a second constituent known as the beta solid solution is found. Additions of zinc increase the amount of beta, until at about 46.5 per cent. zinc the structure consists of all beta. Further additions of zinc then cause the formation of a third constituent known as

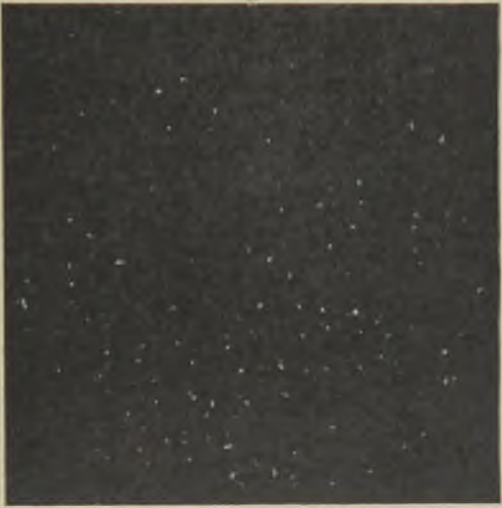


FIG. 7.—DELTA EUTECTOID IN GOOD GUNMETAL, SHOWN IN FIG. 5. × 50.

"gamma." The presence of gamma causes a considerable falling off in strength, making the alloys containing it useless. There is quite a large difference in physical properties between the alpha and beta constituents. The alpha, with its increased proportion of copper, being soft and ductile, whilst the beta, on the other hand, is harder and does not possess much ductility.

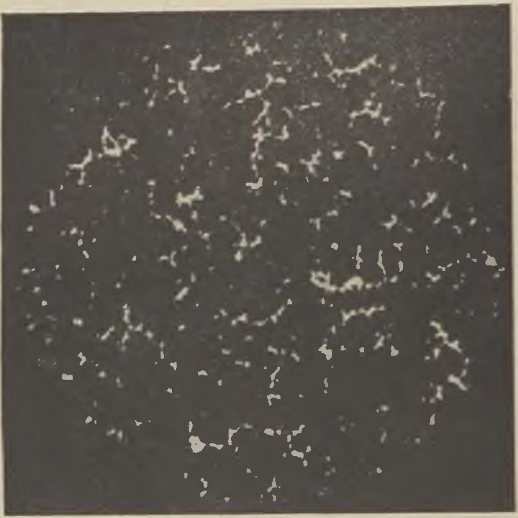


Fig. 8.—Delta Eutectoid in Weak Gunmetal, Shown in Fig. 6. × 50.

As regards ordinary cast brass, almost anything is used, and compositions are very variable.

The most remarkable feature of the alloys of copper and zinc is the fact that the usual metals which are added, such as tin, lead, iron, manganese, aluminium, etc., are definitely soluble in the alloy also, up to certain amounts; and do not form third constituents unless added in excess of their limits of solubility. In other words, these metals have the same effect on the structure as additional zinc would have, but with the exception that the strength is increased, providing they are not added in excess of their solubility. The metals mentioned have different limits of solubility, and replace different amounts of zinc in the structure. For example, a brass containing 60 per cent. copper will hold up to 8 per cent. manganese without another constituent forming, and every per-cent of manganese so added, acts as an additional 0.5 per cent. zinc on the alpha-beta structure. Tin will dissolve up to slightly over 1 per cent., and will equal twice its amount in zinc. Lead is held in solution to the extent of 0.9 per cent., and has the same effect as an equal amount of zinc. The solubility of iron is slight, and is not known exactly, but in practice it is not advisable to add more than about 1 per cent. Aluminium has a very considerable influence, 1 per cent. of this metal being equivalent to 6 per cent. zinc. In these facts we have the explanation of what are known as the high-tensile brasses.

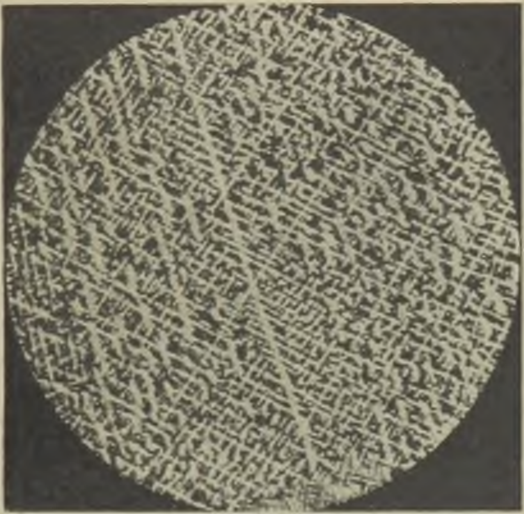


Fig. 9.—× 25.

Manganese Brass.

A manganese brass of approximately the following composition will probably be familiar to many, and is greatly used, amongst other things, for the making of ships' propellers. Its composition is approximately 58.0 copper; 1.0 tin; 0.5 lead; 1.0 iron; 0.5 manganese; 0.4 aluminium; and 38.6 per cent. zinc, etc. An ordinary brass containing 38.6 per cent. zinc, would possess a structure of approximately 83 per cent. alpha area, and 17 per cent. beta area; but the manganese brass given above would have a zinc value or zinc equivalent of 43.5 per cent., and this gives a very different structure, having only 31 per cent. alpha area and 69 per cent. beta area approximately. The tensile strength of this material when correctly made and cast is in the neighbourhood of 34 to 35 tons per sq. in.

Fig. 10.— × 50.

The structure of a sample of manganese brass of approximately this composition is illustrated in Figs. 13 and 14. Fig. 13 shows the "blue etching constituents," which are probably a solid solution of iron and copper, with possibly some tin, manganese or aluminium. These "blue etching constituents" should not be present in excess—which should not be the case, if the iron is kept to about 1 per cent. If present in excess, segregation will almost certainly occur. Fig. 14 shows the alpha-beta structure—the white areas being the alpha constituent. The actual amount of alpha in this specimen is approximately 30 per cent.

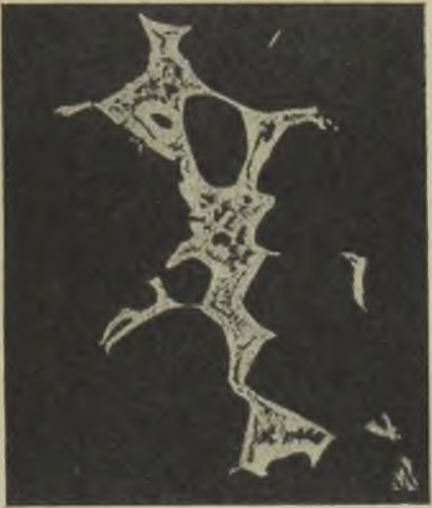


Fig. 11.—Delta Eutectoid. × 500.

Casting Temperature.

The casting temperature of this material is very important, and as the range is very limited, the use of a pyrometer is essential. The range may be given as 1,000 deg. C., plus or minus 20 deg. C.

Owing to the physical properties of this material depending so much on the relative amounts of the alpha and beta constituents, the zinc content must be under control, if a consistent product is desired. This may be accomplished by either micro-examination, or by actual determination of the copper content in samples drawn at intervals, from the furnace, before tapping. Adjustment is then made if necessary.

The liquid contraction of this alloy is large, and necessitates special attention being given to "feeding." The method of casting a propeller blade is interesting, and is illustrated in Fig. 15. This is cast upright, and run from the tip. The pouring basin should be of ample capacity, and is kept closed with a plug until filled. When the plug is removed the pouring is regulated to keep the basin full. As the metal gradually rises into the flange, dirt is prevented from being trapped in the corners by means of rods. This can be done by observation, as the head is quite open. Pouring is continued until the level in the head reaches the height at the top of the runner. The runner then solidifies, and, at intervals, fresh hot metal is introduced into the open head, the metal in which is worked up and down with rods, and thus "fed." The size of head required is very nearly one-third of the weight of the casting.

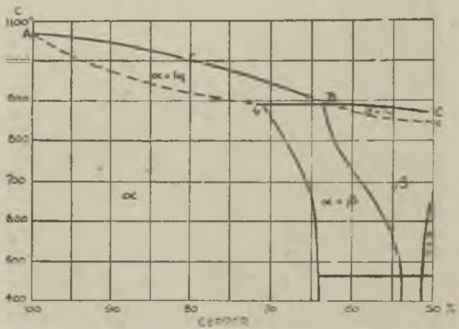


Fig. 12.—Equilibrium Diagram of the Copper-Zinc Alloys, up to 50 per Cent. Zinc.

Manganese brass has two marked characteristics. One is its remarkable fluidity and the other is its high surface-tension, due apparently to the instantaneous formation of an oxide film on the surface. For this latter reason, the filling of the mould must be continuous and the initial pouring done without splashing; consequently pouring basins with plugs are necessary.

White Metal.

The important bearings in marine engineering are lined with white-metal, usually of a tin base. Freedom from bearing trouble seems to depend upon the continual maintenance of an oil film. Thus, in a bearing correctly adjusted and lubricated with suitable oil the metal surfaces should not actually come into contact, but should always be separated by a layer of oil.

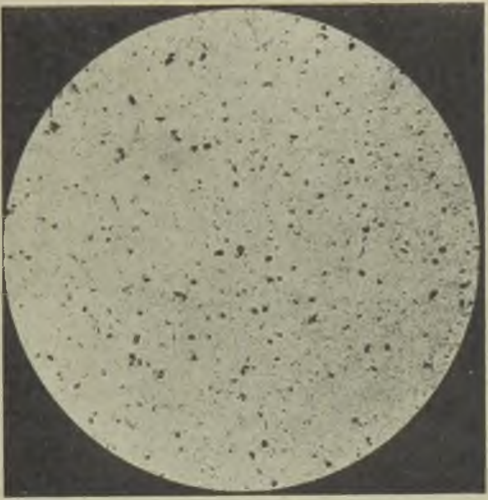


FIG. 13.—" BLUE ETCHING CONSTITUENTS."
× 50

The most perfectly machined surface has somewhat a resemblance to a ploughed field when seen under the microscope, even under low powers, so that the bearing material must necessarily be slightly plastic to enable small surface irregularities to be accommodated; also to allow for slight inaccuracy of fitting or alignment. On the other hand, it has been proved that hard bodies have smaller co-efficients of friction compared with softer bodies, and in the case of a bearing, wear longer. It is evident, therefore, that the perfect bearing material must possess two somewhat contradictory properties—on the one hand, that of being hard, to ensure low co-efficient of friction and long life; and, on the other hand, that of being soft and slightly plastic. Obviously, no single metal, or an alloy that is a homogeneous solid solution, can combine these two dissimilar properties, so that compositions are sought to produce structures where hard constituents are supported in a softer and slightly plastic matrix.

How perfectly an alloy of 5 per cent. copper, 86 per cent. tin, and 9 per cent. antimony fulfils these conditions is shown in Fig. 16, which is a photo-micrograph of a specimen of this composition cut from an actual bearing. Two distinct compounds are present, the most striking being the almost perfect cubes of the tin-antimony compound. The other compound, which is that of copper and tin, not only serves the useful purpose of stiffening the almost pure tin matrix, but, being the first to solidify, and separating throughout

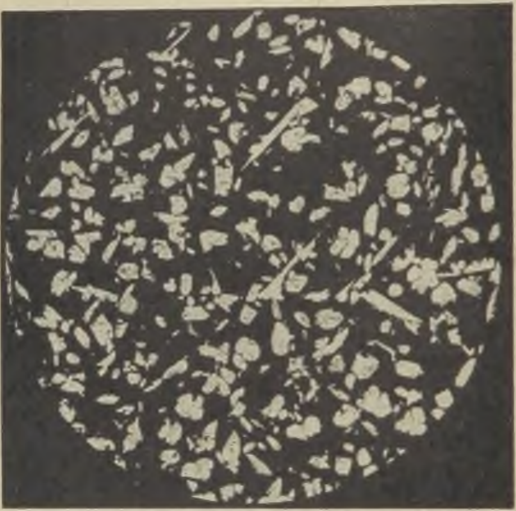


FIG. 14.—ALPHA-BETA STRUCTURE. × 50.
APPROX. 30 PER CENT. ALPHA AREA.

the mass in the form of a dendritic network, prevents segregation of the tin-antimony cubes which are later formed.

It is desired to emphasise the importance of correct structure in connection with bearing metals, as the whole life of the bearing appears to depend upon it. It is therefore a matter of importance that the actual manufacture of the white-metal and the subsequent filling of the bearing be conducted with the necessary care and attention which it deserves. In many cases little thought is given to this side of foundry work (it is considered that the correct place for this work is in the foundry), and it says much for the amount of abuse which this material will stand that it does not give trouble more often.

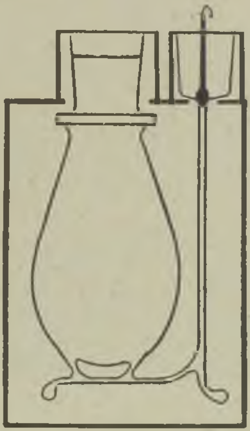


FIG. 15.—ILLUSTRATING METHOD OF POURING AND "FEEDING" PROPELLER BLADE.

First and foremost is the matter of temperature control. This is a comparatively simple matter with such a low melting-point alloy, yet it is often neglected. A suitably protected glass thermometer is all that is required, and should be in the hands of the man who has charge of this work. Preferably, the furnace itself should be fitted with a dial type of indicating thermometer. Melting should be carried out in some form of container where the atmosphere is excluded, or if this is not possible, special attention should be given to the surface covering.

A furnace that has been found satisfactory is shown in Fig. 17, which illustrates the actual pouring of a bearing. The furnace is gas-fired, and is fitted with an automatic regulator, by means of which the temperature can be kept round about a determined figure. It is also fitted with a "mixer," which consists of a perforated plate worked up and down in the liquid, by means of the outside handle. The rate of pouring is controlled by a handwheel, which regulates the opening of the outlet valve at the bottom of the container.

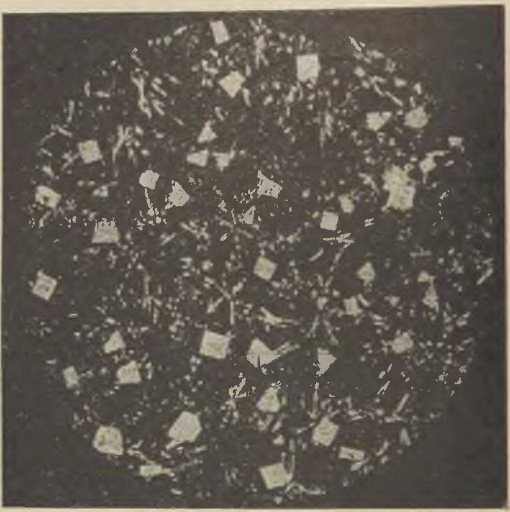


FIG. 16.—STRUCTURE OF WHITE-METAL SPECIMEN CUT FROM BEARING. × 50.

Overheating, or standing for long periods without a protective covering, should be avoided at all costs.

It has been found necessary to obtain sound bearings, free of oxide inclusions, "sponginess," holes, etc., to run the whole bearing at one time from the bottom. For this purpose the casting to be lined should be evenly heated to about the melting point of tin, and tinned if possible. The bearing is fitted with a suitable size of "former," which is clamped on. Some of these are shown in Fig. 18. A stock of formers is gradually accumulated as new sizes come along, so that almost any size of bearing can be accommodated after a while.

FIG. 17.—FILLING A BEARING.

The metal after skimming and "mixing" is run direct from the melting furnace, the bearings being filled from the bottom. The actual casting temperature should not be higher than necessary. With the particular composition given previously, the pouring temperature in use is about 420 deg. C.

The lower portion of the casting is cooled with an air blast, whilst the top is just kept sufficiently hot with a blowpipe to keep the metal liquid and enable "feeding" to proceed.

Additional metal is added into the head from a small hand ladle, as required. This method has been found to give perfectly clean and sound bearings, which machine up without a mark.

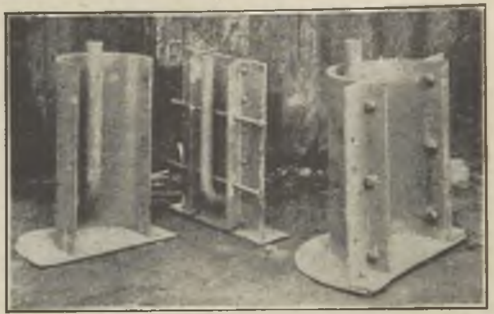


Fig. 18.—"Formers" Used in Filling Bearings.

The actual size of the tin-antimony cubes is believed to have an influence, and this method of filling gives an average size of approximately 0.0025 inch, which is considered satisfactory.

In conclusion, the author desires to express his thanks to Messrs. R. and W. Hawthorn, Leslie and Company, Limited, for their kind permission to publish this Paper.

DISCUSSION.

Mr. E. Longden asked whether better results would be obtained by running the bearings from the bottom instead of from the top.

Mr. Logan said that was actually what was done.

Water-cooled White-Metal Bearings.

Mr. F. J. Cook asked whether the author had had any experience of water-cooled white-metal bearings, and whether water cooling assisted in the formation of the cubes, which were so essential.

Mr. Logan said it had never been the practice at his works to water-cool a bearing immediately it was cast.

Mr. Cook said he meant water-cooling whilst casting.

Mr. Logan replied that they had never done that, because a certain amount of contraction or shrinkage took place and the bearing was practically allowed to remain liquid a short while to enable feeding to proceed. In his opinion if they water-cooled while casting they might stand a chance of getting spongy places. They cooled with an air-blast and had tried what was really a fine water-and-air spray. It was certainly advisable to cool off as bearing to remain hot longer than was necessary gave it time for the crystals and grain size to grow. In his firm's bearings the actual size of the tin-antimony cubes was 0.06 in.; they did not want them too large. For the size of bearing they were dealing with he did not think water-cooling was essential, and these were the largest marine bearings.

Mr. Cook said that, after 20 years' experience, he had found that water-cooling when casting was of very great importance in dealing with bearings larger than 13 in., and for small bearings, for high-speed work, it had been essential. It gave sounder castings with less porous places and better formation of the cubes.

Temperature Control.

Mr. A. Campion, F.I.C., said the author had finished up with a very important warning to foundrymen with reference to temperature control, and had pointed out that temperature, beyond everything else, should be most carefully adjusted, or else the final result would be failure. But he (Mr. Campion) considered that the author should have mentioned the time factor as well as temperature, more particularly the rate of cooling, because, after all, one of the main objects in controlling the casting temperature was apart from preventing overheating to secure proper cooling conditions. The properties of metals, and especially the non-ferrous alloys, depended very much upon the rate of cooling. Therefore, Mr. Logan had done foundrymen a very good service in impressing upon them not only the necessity for buying instruments, but for actually using them.

Bottom-Pouring Linings.

Mr. A. Marks, speaking of bottom-pouring white metal, said this was advocated by quite a number of people, but white metal could be poured quite satisfactorily from the top, and, at the same time, it could be fed from the top. The essential factors in order to have a clean casting were that they should pour vertically, and allow the dross to rise. At the National Physical Laboratory they had made quite a number of experiments on the pouring of aluminium alloys from the bottom, but pressure-fed from the bottom of the ladle—not poured from the top of the ladle; but, if they tried to pour a 24-ft., or even a 20-ft., job from the bottom, they would find they were against difficulties in more ways than one. The author had mentioned that he had had trouble with a bearing made with one of his alloys, and a micro he had exhibited had shown a copper constituent —which was a hard constituent—standing out in its soft matrix. If the antimony crystal was essential for the job, then either the author's theory—that a hard constituent in a soft matrix was necessary—was wrong, or the bearing should have worked perfectly, because the essential conditions which he had claimed for a bearing, namely, that there should be a hard constituent in a soft matrix, were present. He (Mr. Marks) suggested that the trouble was probably due to the presence of lead; anyone who had been responsible for bearings for large jobs knew the trouble that might arise when there was lead present. If they took friction tests on alloys containing lead, it was found that the coefficient of friction rose very rapidly with the percentage of lead. In his view a bearing alloy could be made quite successfully without antimony present. It could be made by utilising just the copper constituent, and one of the best methods of dealing with bearings for Diesel engines was to increase the copper constituent, to give a little more stiffness, in order to enable it to resist the sudden impulses which occurred in the best regulated Diesel engines. Then the author had asked for experiences on annealing Admiralty bronze.

Tensile Strength of Bearing Metals.

According to the theory enunciated that morning, which was generally accepted—although he personally did not altogether agree with it—a bearing metal should have a minimum tensile strength, owing to the fact that they were trying to put in a large number of these hard spots. These hard spots were usually very brittle alloys. The more that were put in, the better the bearing metal, but also the more they put in the weaker the bearing metal, and therefore for a Government Department to raise the tensile strength figure to 16 tons was a ridiculous proposition. He referred to a particular liner which he had cast for a cruiser. The liner was 22 ft. long and something of the order of 16 in. in diameter. When tested it was found to be half a ton under the minimum tensile strength. Accordingly, he went to an officer at the Admiralty and had pointed out that the liner was a perfect one, free from oxide, and it was a bearing metal, but the reply was that they must have the other half ton. Without that extra half ton, said Mr. Marks, it was a better bearing metal than with it. However, he obtained permission of the Admiralty to anneal the liner, and had brought it up to over 20 tons tensile. That was accepted without a word. It is now running on one of the large cruisers, and he has not yet heard that it had worn out. He had not the slightest doubt that the liner, with its low delta constituent, was giving as good service in the Navy as was any other job, and therefore he was sure that this theory of hard spots in lubricating metals was really rather ridiculous.

Casting Temperatures.

There had been much nonsense talked in scientific societies about casting temperatures. In the foundry they had to drop-cast a metal by anything from 10 to 20 ft., and one found that by doing so they broke up the oxide and prevented it adhering to the mould. Great emphasis had been laid upon the temperature of the metal, but he had heard nothing yet as to the temperature of the mould, the amount of moisture in the loam, the amount of venting, or the construction of the mould, all of which had a far more important bearing on the resulting casting than the actual 10 or 20 deg. variation in the metal, on which such great emphasis had been laid by various writers.

Much careful work had been done at the National Physical Laboratory on the question of casting temperatures. In casting a liner the mass of the mould was a very different factor from the mass of the metal. If the liner weighed 15 tons the crane, when lifting the job out of the pit for opening the mould, was lifting something of the order of 20 to 30 tons. Supposing the temperature of the core-drying or mould-drying stoves were 10 or 20 deg., or even 100 deg., lower than usual, it was probable that, even after giving the mould three days drying, it might not be satisfactory. But the Admiralty, or whoever required the liner, wanted to get their ship on the water, and the man in charge of the operations might risk it. He might have 10 per cent. excess of water in the mould which had to be shifted, and he had to have excess temperature in his metal in order to remove it. Therefore they must take these statements with regard to the necessity for the exact measurement of temperature with a grain of salt.

Zinc Equivalents and Manganese Bronze.

Mr. Logan had referred to the zinc equivalent of certain alloys, and he (Mr. Marks) would like to know whose figures he had taken for calculating the zinc equivalent. There were various figures available, and the author would get 1 or 2 per cent. difference in his figures by using different people's equivalents. Again, reference had been made to the "blue-etching constituents" in manganese brass, and also to the question of iron in manganese brass. His own opinion was that iron in manganese brass was one of the chief disadvantages of that material. The author had given a figure of 1 per cent. That was quite a usual figure, but, on the other hand, it had been proved conclusively that 0.7 per cent. was about the maximum which would go into solid solution, and even then, on a large job, they were liable to have trouble. It was one of the chief causes of trouble in propellers. He had been running some experimental propellers over a period of six years, and this question of iron was a very important one. However, propeller troubles were like foundry troubles in that there was a great deal of difference of opinion about them.

Bottom Pouring White Metal Bearings.

Mr. Logan, after expressing his thanks both to Mr. Campion and Mr. Marks for their kind remarks, referred to Mr. Marks' criticism of bottom pouring. When he had mentioned bottom pouring in the Paper he was speaking particularly of white metal. Mr. Marks had also mentioned gunmetal, but he did not think that came into the discussion at all. His firm had found that the best means of getting sound white metal bearings with the least trouble was the method of casting on end and running from the bottom, and he still held that they could get quite sound bearings by doing so, provided they kept the head liquid and allowed feeding to take place. The melting furnace they used might have something to do with the soundness they obtained. The metal was very clean, and kept under non-oxidising conditions. The only dross likely to get into the bearing was simply that formed during pouring, and was very, very small. The whole of the bearing was molten for a minute or so, and that was a sufficient time to enable any dross in the material to come to the head. As to the theory of the hard constituents in the soft matrix, Mr. Marks did not think that the very small antimony content was the cause of the bearing failure mentioned. There were many compositions on the market—one of Messrs. Stone's compositions, he believed, contained about 15 per cent. lead, but it also contained a considerable proportion of antimony. The main point was that, although the copper-tin dendrites were relatively hard, the total area of such hard constituents was not enough. In other words, the Cu-Sn solid solution had to be backed up by the additional area of the antimony cubes also. Mr. Marks had said that increasing the copper content was as effective as increasing the antimony, but he (Mr. Logan) did not quite think that. He considered that the tin-antimony cubes were very much harder and with them a bigger area has a special part to play.

With regard to the annealing of Admiralty gunmetal, Mr. Marks was quite correct in saying that they could get a considerable increase in the tensile strength simply by annealing, possibly, even an extra 4 tons. From a 12-ton gunmetal they might easily get 16 tons by annealing, but the effect of annealing was to remove entirely the as-cast structure and to give a completely homogeneous tin-in-copper solid solution. The result was completely to absorb the delta constituent, and, of course, to reduce the hardness, which was also to reduce that constituent which was vital to a good wearing bearing. The liner referred to by Mr. Marks was running satisfactorily, because the pressures in use were only a few lbs. per square inch, but if they wanted satisfaction from a bearing subjected to strenuous conditions they must have the delta constituent present in quantity. As to Mr. Marks' view that a few degrees difference in the temperature of the mould, or a few per cent. difference in the moisture content, would make more difference than 10 or 20 deg. difference in casting temperature, Mr. Logan agreed. In green-sand work especially, the differences in the condition of the mould would have a very large effect; but when he was talking of casting temperatures he was assuming dry-sand work, which was the work he was concerned with mainly. Given similar conditions, casting temperature was very important, and it should be attended to, even though there might be differences with green-sand moulds.

Iron Content of Manganese Bronze.

With regard to Mr. Marks' reference to iron in manganese brass, and his statement that 0.7 per cent. of iron was the maximum that would go into solid solution, he (Mr. Logan) was not prepared to dispute it, but he had given 1 per cent. as the maximum for general work, and he believed that that was lower than some people worked to at present. Some manganese brasses on the market contained more than 1 per cent. of iron—sometimes 2 per cent.—but he considered that 1 per cent. was quite safe. They did not get segregation of the "blue etching constituent," or a great excess if the iron was kept to about 1 per cent.

THE TECHNICAL SIDE OF OIL-SAND CORES.

By C. W. H. Holmes, M.Met. (Member).

I.—INTRODUCTORY.

It was the writer's original intention to prepare a somewhat complete Paper dealing with the production and use of oil-sand cores, in which not only would the fundamental principles have been explained, but the results of practical tests would also have been included to support or to refute the various conflicting statements which have occurred in the technical Press regarding oil-sand core production.

Unfortunately this has not been possible, and, as the result, the Paper has been divided into two parts, the first of which deals with the principles and practice of the subject, and is presented for discussion at this meeting. The second part will consist of data collected in the foundry and the laboratory, and will be prepared when the writer has more time at his disposal.

The particular object of this Paper, or at least, this part of it, is to explain the " reason why " to the practical foundryman, and thus help towards an understanding of a few of the many problems which are met in this branch of foundry work.

It has been the writer's experience that attempts to introduce oil-sand cores into a foundry either result in success or rather dismal failure, and it may be well to state that whilst such a failure may be due to the core oil, or the sand, or the baking equipment, or to oneself, the fact remains that by careful thought and investigation the failure is most certainly traceable to one or the other. There is no magic about oil-sand cores.

Given suitable core-baking equipment, every foundryman should be able to make oil-sand cores successfully, and the problem then ceases to be a technical one and becomes a commercial one.

Will it pay? This is the question which each foundryman must decide for himself. Generally speaking, when loam or dry-sand cores are replaced by oil-sand cores, the increased cost of core-making materials (and possibly tackle) is more than covered by the decrease in labour costs, both on the core-bench and on the fettling floor, and by the decreased percentage of defective castings.

The second question which must be faced is: Is it practicable? There are some cases in which the use of oil-sand cores is unwise, but such cases will be discussed at a later stage of the Paper.

II.—THE SAND.

The selection of a suitable sand is equally as important as the selection of a suitable core-oil, and it may be of interest to note that whilst the really unsuitable core-oil is usually taken off the market as the result of lack of business, the unsuitable sand is always with us. It is often, perhaps, close at hand, and the price may be tempting, but the practical difficulties that lie in the way of improving unsuitable sands by mixing, grinding, sieving or washing are so great as to be uneconomical. It is very difficult to improve an unsuitable sand, but it is remarkably easy to spoil a good one.

What, then, is a good sand? Obviously it is the sand that produces successful cores. Why do cores made from some sands produce blown castings? Why are cores weak and friable when made with certain sands? Why has a properly-made oil-sand core such excellent venting properties? These are practical questions, and an attempt will be made to answer them and others as simply as possible.

So far as the general run of grey iron castings is concerned, the chemical analysis of the sand is a factor of so little importance that we need not consider it, but for heavy iron castings and for steel castings it is important that the sand should be refractory; if it is not, the castings will be dirty and fettling costs will be excessive.

Broadly speaking, then, sea sand or river sand or dune sand is used for core making in the iron foundry and silica sand for core making in the steel foundry.

But there are great differences between one sea sand and another, not only in the unimportant matter of chemical analysis, but also in the vitally important matter of mechanical analysis (or, to put it more simply, size of grain).

If a glass jar that will just hold one pint is taken and filled to the brim with marbles, it will be found (provided that the marbles are all the same size) that one is still able to pour into the jar between one-quarter and half-a-pint of water. Now, if we consider these marbles to be the grains of sand in a core, highly magnified, we see that there are considerable spaces between the grains along which the gases generated by the heat of the metal can travel; and so long as the particles are rounded *and of regular size*, it does not matter how big or how small they are, we shall still be able to find the same high proportion of spaces.

For instance, if we take another pint jar and fill it to the brim with No. 5 lead shot, we shall still be able to pour into the spaces between the shot as much water as we could in the case of the marbles.

But if we take a third jar, and, having filled it with marbles, we run in lead shot or other fine material between the marbles, we shall find that we cannot run in nearly so much water as we could in either of the previous cases. These simple experiments show that, if it is thought desirable (as, of course, it is) to have the maximum amount of spaces in a core for the gases to escape through, there must be used a sand of regular grain size. The importance of regularity of grain size is especially important in the case of fine-grained sands, for this reason.

Take the case of two sands—a coarse one with grains $\frac{1}{50}$ in. diameter and a fine one with grains $\frac{1}{100}$ in. diameter; gases escaping from a core made from the fine sand will have greater frictional resistance to overcome, because not only are the spaces between the grains narrower, but there are twice as many turnings and twistings round the grains than in the coarse sand. Hence a small amount of very fine material might not matter in the coarse sand, but added to the already greater frictional resistance in the finer sand, it might cause trouble through blown castings.

The tabulated results of this explanation may be clearer :—

Type of sand.	Air spaces %.	Frictional resistance.	Venting properties.
Coarse regular grain ..	High	Low	Best
Fine ,, ,, ..	High	High	Good
Irregular grain ..	Low	High	Bad

There are several reasons why coarse sands have their drawbacks as well as their advantages. They do not give such a good skin as finer sands to the casting, neither are cores made from them easy to handle when much rubbing down has to be done, as, for instance, when a core is made as a simple block and is radiused off after baking.

Further, when using coarse sands, the weakness of the core in the green state is accentuated, because its strength in the green state depends on the number of contacts between the grains per square inch (for it is only where the grains touch that they can be held together). Obviously the finer the sand, the greater the number of grains, and hence the number of grain contacts per sq. in. of core section.

Reference to Table I will make this clear; it must be borne in mind, however, that these figures are only approximate.

TABLE I.—*Grain Size and Contact Points of Sands.*

Grain Size.	30 mesh.	60 mesh.	90 mesh.	120 mesh.
Grains per cub. in. ..	240,000	2,000,000	6,600,000	16,000,000
Contacts per sq. in. ..	8,000	32,000	72,000	130,000

This weakness, encountered when using coarse sands, is very strongly marked when the sand is not dried, or at any rate, when it is appreciably damp, before mixing with the core-oil and water; the core is " heavy " and falls readily.

Table II shows the mechanical analysis of the sand used by the writer for general work. For very large cores, the sand might be somewhat coarser, although no difficulty has been experienced as regards the venting properties; for small delicate work, such as automobile jacket cores and the like, a finer sand would be preferable.

TABLE II.—*Mechanical Analyses of Sea Sand. (A) Metric Grading (Round hole Sieves); (B) English Grading (Square Mesh Sieves).*

Grade.	(A)		(B)	
	Grade Size.	Per cent.	Grade Size.	Per cent.
Coarse sand ..	1.0 —0.5 mm.	nil	On 30 mesh	nil
Medium ,, ..	0.5 —0.25 ,,	7.60	30—60	1.50
Fine ,,	0.25—0.10 ,,	91.20	60—90	58.50
Coarse Silt	0.10—0.05 ,,	1.00	90—120	36.70
Fine ,, ..	0.05—0.01 ,,	0.20	Through 120	3.30
Clay	0.01	nil	—	—

It will be noticed that the regularity of grain size is very marked.

This particular sand is a sea-sand, and although it answers its purpose excellently a wind blown or dune-sand is preferable to a sea-sand or river-sand.

This is due to the fact that the friction between the grains as they move over each other in air is greater than in water; hence the wind-blown grains lose their sharp corners and become rounded more readily than the water-worn grains.

Rounded grains give better venting properties than angular grains, although general opinion is to the contrary; this error is probably due to the incorrect use, in the foundry, of the term "sharp," which, as generally used, means "coarse and free from clayey matter."

A number of so-called "sharp" sands have well-rounded grains.

If the term "oil-sand" is used to denote a mixture of sand with a binding agent, the basis of which is linseed or a similar drying oil, then it is important that the sand should be "clean," that is, it should be free from clayey matter. In the case of such binders as resins, gums or similar proprietary materials, this is not so important.

Mixtures of naturally-bonded sands and core-oil can be baked to make more or less successful cores, and such mixtures have the great advantage of being strong in the green state. This type of core, however, requires more oil than would be used with a clean sand; has a tendency to be soft inside, and, in consequence of the extra oil content and poorer venting properties, is more liable to blow. Also, they are not so easy to remove from the casting.

The explanation as to why "dirty" or naturally bonded sands require more oil than clean sands will be given in the section dealing with the mixing of oil and sand in order to avoid repetition.

The old sand from the fettling-floor may be used again in proportions varying with the intricacy of the core; but great care should be taken to avoid the mixing of old loam cores or similar fine material with the burnt oil sand, as this may (probably will) choke the natural vent in the oil-sand cores and result in blown castings. The old sand, with its coating of soot, appears to cause less trouble than clayey sands, as regards core-oil consumption.

Nothing has been said, so far, regarding the use of silica sands, but the foregoing statements apply in general to sea, river, dune or silica sands.

It remains, however, to warn those who propose to mix sea or river sand with silica sand that both sands should have similar sized grains if the best venting properties are to be obtained.

Speaking generally, the chances of improving the venting properties of any sand by mixing it with another are very small. On the other hand it is quite easy to produce any number of mixtures from two sands, each having inferior venting properties to either of the original sands.

Finally, the ideal sand for oil-sand cores will be briefly considered:—

It must be more or less refractory, according to the class of casting to be made, it must be of uniform grain size, and it should be free from clayey material or organic matter.

III.—THE OIL.

Core oils consist essentially of vegetable oils which have the property of becoming sticky, and ultimately hard, when exposed to the air. This group of vegetable oils is known as the "Drying Oils," and linseed oil is the best known and most commonly used member of the group.

In practice, the linseed oil is usually heated or "boiled" together with gums or resins to increase its binding properties.

Subsequently to this, mineral oils may be added to reduce the viscosity of the mixture, and make it easier to handle.

The following combination of properties is desirable in a good core-oil:—

(1) It must be moisture-proof; (2) it must have sufficient strength when green to enable the cores to be handled; (3) it must not stick to the core boxes; (4) the viscosity must be low enough to enable it to mix easily with the sand; (5) the fumes given off on heating the cores must not be poisonous or objectionable; (6) it must have a high "film value," which in plain language means that it must have the property of binding a large amount of sand together; (7) the rate of oxidation must be such that whilst the core takes readily, yet it does not become sticky and crumble on the core-bench; (8) the physical properties of the oil must be such that the oil is not easily drawn to the surface of the core whilst baking, and this property is fairly common with gum binders, and results in a core with a hard skin and a soft centre, which, if rubbed down, is fragile and washes readily; (9) the core must stand up against a reasonable wash of metal; and (10) after casting the core should crumble readily, and the sand run from the casting freely.

Generally speaking, any core oil will possess one or more of these properties in a marked degree; some core-oils are excellent productions, having many good points; others are not.

It is most regrettable that during the last few years almost every firm connected either with the oil trade or with the foundry industry has seen fit to add yet another to the already long list of core-oils.

And it is also certain that many of them have neither the requisite equipment nor the detailed knowledge of foundry work required in the manufacture of a satisfactory core-oil.

The cost of a core-oil should not be confused with the price per gallon: the true cost should be based on some unit quantity, say, 100 or one hundredweight of good cores.

IV.—THE PREPARATION OF THE CORE MIXTURE.

To obtain the most economical and the most satisfactory results, and to obtain regularity in the mixture from day to day, the core mixture should be prepared with great care. The preparation should be divided into two stages; first the mixing of the core-oil with the water, and second the incorporation of this mixture with the sand.

The core-oil and water should be mixed in the required proportions, usually varying from one of water to one of oil, to three of water to one of oil, and then vigorously agitated so as to form an "emulsion."

This emulsion consists of a very intimate mixture of very small globules of oil in water, and may be readily prepared, either as a matter of interest or for use in the foundry in small quantities, by shaking equal parts of core-oil and water in a bottle. The bottle should not be more than two-thirds full, and should be shaken vigorously for about a minute; the bottle will then be seen to contain a yellow creamy liquid consisting of emulsified oil and water. In practice emulsification is best carried out by turning a jet of compressed air into a mixture of core-oil and water.

On standing, these emulsions usually separate out more or less completely into two layers of oil and water, and should be re-made just before they are required for use.

Before proceeding to discuss the method of mixing this emulsion with the sand it is advisable to consider briefly what has to be accomplished, and why.

If there is a heap of sand which has to be moistened uniformly—and it is essential in foundry work that sand for any purpose should be uniformly moistened—there are two factors which must be taken into account—the character of the liquid and the quantity to be used.

It has already been shown in discussing the core-oil that it is difficult to mix stiff, viscous liquids satisfactorily with sand, and, again, the liquid must not only be fluid, but must have the property of easily wetting the sand grains; in other words, the "surface tension" between the sand and liquid must be low.

Further, the smaller the amount of liquid, generally speaking, the more difficult it is to obtain a homogeneous mixture.

From this it is seen how the emulsion helps; instead of trying to mix oil with water and to coat the mixture around the grains of sand in one operation, oil and water have been mixed under the best conditions, and have as the result a larger volume of liquid which has good mixing qualities.

The ideal mixture consists, of course, of the thinnest possible coating of emulsion, uniformly spread around each and every grain of sand, that will give the requisite strength in the finished core.

Some idea of the area to be covered by the oil in 1 cwt. of sand and the thickness, or rather the thinness, of the oil coating may be gathered from Table III.

TABLE III.—*Surface to be covered with Oil in* 1 *Cwt. of Sand*

Grade.	30	60	90	120
Total surface (sq. ft.) in 1 cwt. sand	3,150	5,670	9,100	13,740
Thickness of oil film (ins.) using 1 : 40 of oil	0.00011	0.000058	0.000033	0.000025

As a matter of fact, so soon as mixing ceases and the grains of sand are at rest the liquid coating is no longer uniformly spread over the grains; it is drawn towards the points of contact between the grains where, of course, it is required.

However, if the foundryman succeeds in spreading the coating uniformly the natural force known as " surface tension " will look after the drawing up of the liquid to the grain contacts without further assistance.

Methods of Mixing Sand and Oil.

Turning now to the methods available for mixing the emulsion and the sand with a view to obtaining the ideal mixing described above, any of the following methods can be used:—(1) Hand mixing; (2) mechanical riddle; (3) pan mill; (4) centrifugal mixer; and (5) paddle mixer.

Method (1) is fairly good if care is taken; it is, of course, costly where much sand has to be mixed, and the oil content of the mixture cannot be cut down to a minimum where this method is employed. The mixture is also likely to vary from day to day, and if viscous binders are used is liable to be heterogeneous, causing washes and scabs.

Method (2) is slightly better than (1), but mechanical riddles, like hand riddles, are of little use for anything except removing stones and scrap.

Method (3) is not advisable, primarily because there is more than a risk of grinding the sand and thus impairing the venting properties; secondly, very few foundries can keep a pan mill solely for mixing oil-sand, whilst if this is not done either some clayey material is picked up from the mill or else a man has to clean it; and the cleaning of the average pan mill, being a lengthy matter, costs money.

Method (4), like method (3), has been tried by the writer, and is fairly successful after a preliminary hand mixing. It does not, however, seem to be an ideal method, especially when old sand is used in the mixture, as the old sand contains many grains which have been cracked by the heat of previous casts, and are liable to be broken up in the centrifugal mixer. Sand grains are certainly cracked by heat, and the writer has shown elsewhere* that centrifugal mixing does break up the sand slightly, but in this particular connection no data are to hand. The suggestion is put forward only as a probability. Centrifugal mixers tend to become choked by the core mixture drying around the steel studs with repeated use.

Method (5), provided that the paddle mill is designed to give a kneading or spreading action to the sand, presents advantages over any of the four previous methods; it tends towards perfect and rapid distribution of the oil (or emulsion). Hence it is probable that less oil can be used to give as good results as were previously obtained by hand mixing; there is no chance of grinding up the sand grains as in the pan mill or centri-

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* "J.I.S.I." 1922. No. 2. An Investigation on the Factors nfluencing the Grain and Bond in Moulding Sands.

fugal mixer; and the labour required consists simply in loading and unloading the mixer.

Wherever the output of oil-sand cores is considerable, the paddle mixer will prove to be the most efficient and economical machine.

Should Sand be Dried before Mixing.

The subject of mixing cannot be dismissed without reference to the somewhat vexed topic concerning the use of dried sand or moist sand.

Whilst it would appear at first sight to be rather foolish to dry sand and then moisten it again, yet there is a great deal to be said for this practice.

Leaving out of the question sand received in such a wet state that it contains more moisture than is desired in the core-mixture (for such sand will usually cost more in wasted time and materials than it would cost to dry it), it will be considered why one should, or should not, dry the sand.

The principal argument in favour of not drying the sand is that it is less trouble.

So it is, on the face of it, but when examined more closely it is found that a bucketful, or a barrowful, or a mixer full, or whatever measure is used, of dry sand contains more grains of sand than it does of wet sand.

This may not sound convincing, but it can be proved by anyone who cares to fill a bucket with wet sea sand, shake it down by bumping the bucket on the floor, put it in the stove until it is thoroughly dry, and then bump it on the floor again.

The bucket will no longer be full of sand, but probably somewhere about three-quarters full.

So that there is not the same amount of sand in a bucket of wet sand as in a bucket of dry sand; there is less surface, and hence require less oil to coat it with. It follows that if one is using sand in the raw state one is either using an excess of oil as an insurance against the sand being drier than usual, or is running the risk of having a batch of weak cores.

To ensure economy in oil consumption and to ensure regularity in the core-shop product from day to day, it is better practice to pre-dry the sand.

V.—THE BAKING OF OIL-SAND CORES.

Strictly speaking, oil-sand cores are baked rather than dried; as will be explained later, there is more in the process than simple evaporation.

It would be much easier to write a book on the baking of oil-sand cores, dealing with the process completely, than to attempt to compress an explanation of the process into a few lines.

Suppose that there is a ton of oil-sand cores, containing 5 per cent. of moisture and 1 per cent. of oil by weight; there is a hundredweight of water to heat up to its boiling point, to evaporate, and over and above this, there has to be supplied the energy required to lift this weight of water vapour out of the stove.

As a matter of fact the whole of this water could be evaporated without heating the stove up to boiling point (212 deg. F.). It could be done by taking advantage of the fact that air at all temperatures will hold a certain amount of moisture, and the hotter the air the more moisture it can contain.

But as a cubic foot of air below 212 deg. F. (100 deg. C.) can only contain a comparatively small amount of moisture, one would have to pass such an enormous number of cubic feet of warm air through the stove that the time taken and the fuel consumed would be excessive.

This method of moisture evaporation operates to some extent whilst the stove is heating up, but as has been pointed out, it is not economical to have a larger volume of air than is necessary to heat up the stove passing through at this period.

When the stove has reached a temperature of 212 deg. F. (100 deg. C.) a new set of circumstances arise. The water is now rapidly evaporated, and occupies a very great volume; the hundredweight of water from the ton of cores will occupy 3,000 cub. ft. when completely evaporated; enough to fill a stove 30 ft. × 10 ft. × 10 ft.

But as it requires, roughly, five and a half times as much heat to evaporate the water in the cores as it does to heat the same amount of water from the cold state up to boiling point, there is a rather heavy demand for heat at this period, and the stove temperature rises very slowly, especially if it is well filled with cores.

During this period in the heating of the stove there is a tendency for the moisture to be evaporated at one part of the stove and then become slightly cooled and condense to a heavy fog, which falls to the bottom of the stove.

(This can be observed in many old-fashioned, natural-draught, stoves, especially if the door is lifted a fraction of an inch to admit cold air to the floor.)

In the writer's opinion it is this stage, in the drying of cores generally, that has led to the many heated controversies which have raged around the question as to whether the exhaust flues should be at the top or at the bottom of the stove. The "fog" is so heavy that it requires a considerable amount of energy in the form of draught to lift it, whilst it is difficult to evaporate, because often only the top surface of the "fog" comes in contact with the heat.

This matter will be referred to later in connection with stove design.

Sooner or later the bulk of the moisture is evaporated, and the temperature of the stove rises to such an extent that further condensation cannot take place; under suitable conditions the remaining moisture is then easily evaporated.

If at this stage an oil-sand core is removed from the stove it is apparent that it has stiffened considerably, but it is still soft and sticky, and quite unlike the desired product; it has been dried, but not baked; the physical change of evaporation has taken place, but the chemical change of oxidation of the core-oil has hardly started.

In order that this chemical change shall take place with sufficient rapidity for commercial requirements, the heat must be raised to a temperature varying between 350 deg. F. and 500 deg. F. (176 deg. C. and 260 deg. C.).

The intricate chemical changes taking place under these conditions cannot be discussed here, but the oil is gradually converted into a hard, resin-like body, and at the same time absorbs about one-fifth of its weight of oxygen.

This oxygen can only be supplied by atmospheric air, hence we see that if the cores are to be baked hard and strong, the "foggy" atmosphere (which cannot supply the oxygen) must be replaced, not by burnt air which has passed through a coke fire, but by hot, unburnt air which has passed either over or round the fire.

In practice, the oil is not completely oxidised, the absolute completion being a slow and unnecessary procedure; what should happen is that the oil should be nearly completely oxidised to give the core strength, and then the resultant resinous bodies should be still further heated until they begin to be slightly charred. By this means is produced a core which has almost the maximum strength, coupled with the minimum gas content.

As a result of this brief survey it is seen that the baking of an oil-sand core may be divided into five stages:—(1) Heating up and slight evaporation; (2) moisture evaporation; (3) heating up the dried core; (4) oxidation of the core-oil; and (5) slight charring of the resultant resin.

Choice of Stoves.

The simple natural-draught stove, with a door at one end and a firebox at the other, leaves much to be desired, both as regards control and fuel economy when drying cores, especially oil-sand cores.

A stove working under forced draught with either:—(*a*) A sole flue, ensuring a hot floor, or (*b*) a large flue area at floor level, and a hot chimney stack to lift the moisture out of the stove, is what is required.

The flue arrangements should be such that air can be passed over or through the fire at will, so that hot free oxygen can be supplied to the cores when desired and so that the temperature can be quickly raised, when required, by blowing air through the fire.

The core oven may be heated by coke, gas, oil or electricity, each fuel having its own advantages and disadvantages.

Temperature control, with gas or oil is easily effected, but, generally speaking, cost of fuel per hundredweight of cores baked is in excess of coke when burnt in a modern stove. It must also be remembered that with town's gas or oil, the combustion of the hydrogen results in a high moisture content in the hot gases; this moisture may condense in a cold stove and have to be re-evaporated subsequently. The gases from the combustion of coke, on the other hand, contain only a negligible amount of moisture.

Apart from the cost of current, which in the majority of cases is prohibitive, electric core baking has distinct points in its favour. It is clean and under complete control; it is essential, however, to provide some means for exhausting the moist air from the stove during the drying period and circulating hot fresh air during the oxidation period.

Personally, the writer is in favour of a coke-fired stove working under forced draught, and so arranged that the air can be passed either through or over the fuel bed.

The principal exhaust flues should be under the floor of the stove, and the flues should be so arranged that hot gases may be by-passed from firebox to chimney stack, so that this may be heated and capable of lifting the moist gases from the exhaust flues.

VI.—THE FINISHED CORE.

The finished core consists essentially of sand grains, a resinous bond, and air spaces. When properly made and baked, an oil-sand core combines high strength with maximum permeability, or, in practical terms, very good venting properties. Provided that a good oil has been used, the core will also have the added advantages of requiring less core-irons, whilst it will not absorb moisture from the mould; this is a highly important point where light intricate castings are moulded in green sand.

Now, before considering the effect of the heat of the molten metal upon the core, it may be of assistance to consider the reason why oil-sand cores are less liable than the general run of cores to produce blown castings, together with the principles underlying "core-blows."

When molten metal is run around a core—any kind of core—the air in the core expands at once and seeks an outlet; at the same time, any moisture in the core is converted into steam, and in doing so expands considerably, whilst simultaneously the binder, whether clay in a dry-sand core or resin in an oil-sand core, decomposes and generates gas.

This generation of gas commences at the surface of the core and extends inwards as the heat penetrates to the centre. It naturally creates a greater pressure in the core than the external pressure of the atmosphere, and the gases seek an outlet. Two outlets are available: the first is through the air spaces between the grains of sand, possibly into an artificial vent and out into the air at the print end of the core; the other outlet, as is well known, being through the metal. This latter course may result in a blown casting or it may not; as a matter of fact, far more cores blow than many foundrymen care to believe, but owing to the fact that *hot* molten cast iron is an accommodating sort of metal with a considerable range of fluidity or semi-fluidity, it often remains molten until after the blow has subsided, and a sound casting results.

Should anyone doubt the above statement, let them cast a few of their moulds fully cored up but leaving off the copes; a dry-sand core of large bulk in relation to the area of the prints should be chosen for preference, and the mould should be slowly filled, so that the various stages may be more closely watched. The determining factors as to whether the gases will travel through the core or through the metal are these:—(1) The volume of gases generated at any time; (2) the resistance offered by the core to the flow of these gases; and (3) the head of molten metal above the core.

Now, the molten metal exerts a pressure of 4 ozs. per sq. in. for each inch of depth, so that if there is a core with half an inch of molten metal above it, the back pressure of the gas in the core has only to exceed 2 ozs. per sq. in. pressure to lift the metal and blow through it. If the height of metal above the core were six inches, the pressure inside the core could rise to 1.5 lbs. per sq. in. before trouble occurred.

However, the height of metal above the core is often either beyond normal control or expensive to control, so that foundrymen should turn their attention rather to the production of cores that will generate as little gas as possible together with the best possible venting properties, so as to allow this gas to escape. As has been explained, the properly-made oil-sand core combines these properties in a marked degree.

Turning now to the influence of heat upon the core, the progress of the core from the weak green condition to the strong state after baking, in which the grains are securely held together by a strong resinous substance, has already been detailed. This resinous bond breaks down when it is heated by the molten metal into water vapour; a mixture of gases containing carbon; a residue consisting mainly of carbon, and a certain amount of soot produced by the decomposition of some of the gases.

Several things will be noticed on watching metal cast around an oil-sand core; in the first place, at the moment the vent fires the flame will be blue, but will change rapidly to a white, smoky flame. The blue flame denotes complete combustion, the air for which is provided by that existing in the pores of the core; so soon as this is exhausted, the white, smoky flame appears, denoting that the pores of the core are now filled with escaping gas.

Another interesting fact is that oil-sand cores may, in many cases, be used without having been blacked and yet the casting shows a good skin; whereas, had a dry-sand core been used under similar circumstances, it would almost certainly have burnt-on. The reason for this lies in the fact that the residue from the oil behaves something after the manner of coal dust; it evolves tarry matter and gases which are known as "unsaturated hydro-carbons"; these bodies break up under the intense heat of the metal and deposit soot (a form of carbon), which not only acts as a lubricant to the flow of metal on the core face, but also acts as a splendid refractory material, preventing the burning on of sand to sand or sand to metal.

Very few people appear to appreciate the important service which carbon performs in the two functions described above.

Conclusions.

When the sand is removed from the casting during fettling it is seen that it is black owing to deposited soot and the carbonaceous residue; if, however, the projecting print end of a core, where the gases have ignited as they escaped from the vent is examined, it is seen that the grains are no longer black, but white. The carbon coating (almost inconceivably thin) has been burnt off, and the sand has reverted to its original condition.

Having traced the sand and the oil from the beginning to the end of the cycle, little remains to be said, and it is the writer's wish that his explanations have been lucid and efficient; there are, however, one or two practical points which might be usefully dealt with before concluding.

It is commonly believed by those who have not attempted it that oil-sand cores cannot be used successfully in heavy castings; this is *not* the case, however, as the writer has castings in the floor at the moment of writing 3 tons in weight, and completely cored-out with oil-sand cores.

There is, however, a limit, and this limit is reached when the resinous bond in the core is burnt out before the metal has solidified. When this occurs, the core is either distorted to a more or less shapeless mass by the pressure of the metal or crumbles and floats up under the cope. When it is borne in mind that each foot in the height of the molten metal exerts a pressure of 3 lbs. per sq. in., it is obviously unwise to set a core with any chance of crumbling at the bottom of a deep mould unless the metal thicknesses are so small as to permit of rapid setting of the metal.

When working close to this limit, it is important that the cores must not be over-baked.

At the other end of the scale is the case of the light casting containing a bulky core. Here there may not be sufficient heat given out during the cooling of the metal to break down the resinous bond, and the writer has seen cases where the centres of such cores were extremely hard and difficult to remove.

In such cases, where the core is practically surrounded by the metal, ashes may be used to fill in the centre, whilst if a large flat print surface is available it is sometimes possible to fill the centre with moist sea sand, which, after holding up the core during baking, falls out readily and leaves a more or less shell-like core.

When this type of problem is encountered it is advisable slightly to overbake the cores, as they are then rendered friable more easily by the limited heat available from the casting.

Steel Shot Cores.

The writer has developed and patented a modification of the usual oil-sand core, the sand being replaced by fine steel shot.

Whilst this type of core is more difficult to make than the usual type of core, and is too costly to use indiscriminately, yet it has proved its utility in places where solid denseners or chills could not be employed owing to the impossibility of extracting them from the finished casting.

In one particular casting the frequently occurring blow-holes, once attributed vaguely to "bad metal," have entirely disappeared since oil-shot cores were used in its production.

Which fact seems to indicate that there is still something to be learnt, both about "bad metal" and good cores.

DISCUSSION.

Mr. W. T. Evans said that, as one with experience of oil-sand cores, he was of opinion that this Paper was one of the best on the subject that he had so far encountered, and he was in accordance with the whole of it. At the same time, he asked for information on steel-shot cores, which Mr. Holmes, in his modesty, had left out.

Steel-Shot Cores.

Mr. Holmes said he had not dwelt upon steel-shot cores because he did not wish to waste time. There was nothing more to say about them, except that they were fairly difficult to make, and would not "stand up" readily. The weight of the steel-shot made them tend to "sit down," and it was a question of either making them on a flat-plate, which had to be machined, or making them in a drier. He had found them very useful in castings where there was a big boss, and the designer had seen fit to put a 1-in. hole through, and there was about 4 in. of metal all round it. He did not say that that was a perfect way of getting over the trouble; there were other ways, but in a foundry which was casting different types of work they could not run a different kind of metal down every five minutes, and sometimes they had to run thick sections with metal which was hardly suitable for it. In such cases it paid, in his opinion, to use a device of this sort rather than to use a special grade of metal, unless, of course, the output warranted it. But he would certainly not recommend them for indiscriminate use, on account of the cost. Of course, the steel-shot was more expensive than sand, and unless they had a magnetic separator they did not completely recover the shot. He had not found it doing any harm in the sand, but he had found that the new shot which had to be put in to make up for the old shot which was lost was just about the amount they had got to use to make a strong core. One had to use a fair amount of gum to hold them together, apart from core oil, and apparently there was a tendency to get a different type of coating on the shot than on the sand grains when they had been used more than once; after the shot had been used three or four times it had not a very good surface.

Mr. J. Longden referred to the question of whether it was better to add the emulsified oil to the sand after drying, in preference to adding it to a green sand. It seemed to him that a great deal too much was made of that. He was of opinion that, when a green sand was used and oil added, the mixing of the oil which was added to the water already present, induced a sort of emulsification during the mixing process. He had never found the necessity for drying the sand before adding oil. Finally, he asked Mr. Holmes what, in his opinion, was the maximum thickness of section which it was safe to use round an oil-sand core, because he had heard of cases where oil-sand cores had collapsed when used for very heavy castings.

Mr. Holmes, dealing with the amount of grains in a given quantity of wet or dry sand, said that a cubic foot, or any other measure, of wet sand did not contain so many grains as a cubic foot of dry sand. He illustrated what happened in two containers of, say, 1 cub. ft. capacity, filled with wet and dry sand respectively, by means of a sketch. If the sand were dry, he said, there was nothing at all to stop the grains touching each other, but, if the sand were damp, the water would collect at the points of grain contact. There was a certain amount of surface tension which became quite appreciable when one considered the large number of grains contained in a cubic foot of sand. If the grains were pushed together the water would push them apart again. Another thing which stopped the sand grains settling down perfectly was the fact that there was, to a certain extent. more friction.

Emulsification of Oil Through Mixing.

With regard to the emulsification of core oil, he did not say that they could not make a perfectly good oil-sand core without emulsifying; they could do so, and he had seen many. But, if they did emulsify it, they could do it better in a proper apparatus, and he had such an apparatus. The ordinary method of mixing oil and sand was designed simply for mixing oil and sand, and not for emulsifying oil and water. It was quite possible to make oil-sand cores in the oven in the kitchen, but the oven was not designed for the job and would not do it so well as a specially designed stove. In his opinion it was much better to break the job up into two operations. If they were making a lot of cores, and wished to get the best possible results with regularity day in and day out, his advice was to dry the sand.

Maximum Size for Oil-Sand Cores.

He could not give any definite information on the subject of the thickness of section which it was safe to use round an oil-sand core. The largest thickness of metal he had run round such a core was 2½ in. The job was a fairly heavy wheel, with a rim about 2½ in. thick, but it would be rather thicker in the boss. That was as far as he would care to go. They should not have a greater height of metal than they could possibly help for an oil-sand core, because, if it started to collapse before the metal had set, they would get the core distorted.

Mr. Oliver Stubbs said that a member of the Institute, a few days previously, had made a casting 22 tons in weight, with a mixture of 1 in 40, oil-sand cores, with a 9-in. thickness of metal. Asked what was the size of the core, Mr. Stubbs said he should think it was possibly about 7 ft. 9 in. long. It was oblong in shape.

Mr. E. Longden asked the conditions under which it existed in the mould—vertical or horizontal.

Mr. Stubbs said he would be glad to get information about that. He had mentioned the fact merely because Mr. Holmes did not go beyond a thickness of 2½ in. His own firm were regularly casting up to 4 and 5 in. thickness of metal with no trouble whatever.

Mr. Holmes said he meant that he had only gone up to 2½ in., but he could see that they could go further. He had said in the Paper that oil-sand cores could be used for heavy castings, but, in the fourth paragraph of the last section, he had pointed out that there was a limit, which was reached when the resinous bond in the core was burnt out before the metal had solidified. He went on to quote: "When this occurs, the core is either distorted to a more or less shapeless mass by the pressure of the metal, or crumbles and floats up under the cope. When it is borne in mind that each foot in the height of the molten metal experts a pressure of 3 lbs. per sq. in., it is obviously unwise to set a core with any chance of crumbling at the bottom of a deep mould unless the metal thicknesses are so small as to permit of rapid setting of the metal. When working close to this limit, it is important that the cores must not be over-baked." However thick or however thin anybody happened to make castings from oil-sand cores, he said, that was the practical limit, and those were the considerations underlying it.

Mr. A. Marks, dealing with the size of the castings which could be turned out with oil-sand cores, said that those with practical experience of oil-sand core-making knew that they could have an oil-sand core of any size if they could persuade the foreman to make it. One met with a good many old foremen who had vast practical experience and who liked to go gradually. The standing up of a core to the metal was a question of the consistency. Even for small automobile work he had three or four oil-sand mixtures which he used for different purposes. For example, he could not make, say, a jacket core of the same consistency as a core to be used for a 36-in. diameter pipe, and anyone who was familiar with walking round a foundry and testing cores could see at a glance whether the mixture was made correctly. No limit had yet been reached with regard to the use of oil-sand cores, but they ought to get down to the essential underlying principles. Mr. Holmes had given a very good practical Paper, but, if progress were to be made in this matter, they should understand the principles underlying oil-sand cores more thoroughly. In regard to binding, Mr. Marks was not at all convinced that it was necessary to have a perfectly clean sand, as Mr. Holmes had termed it. He was not convinced that oil and an absolutely free pure silica would give a perfect core. In sea sand there was something besides free silica; there was ferric oxide, and two or three other minor constituents. Also, there was a considerable proportion of sodium chloride present in any dry sea sand, and the influence of that had not been taken into consideration in connection with these oil-sand cores. From the practical point of view, they had taken this into consideration by rule-of-thumb methods, and had gradually gained experience, but they would have to look at it scientifically as well as practically. At present they were in the hands of the core-oil maker. He submits a certain brand of oil, and, by experience, the users get to know its idiosyncrasies. It might be right or wrong; frequently it was wrong. Perhaps Mr. Holmes had been up against that difficulty and had, therefore, failed to make castings of larger sizes than those he had mentioned. The question of the minor constituents in the sand would be well worth investigation, followed by an investigation of the binding powers of the different varieties of oil.

Mr. Holmes asked whether it paid to use an inferior sand and a greater quantity of oil. As to the minor constituents of sand, he had made perfectly good oil-sand cores with sea sand, river sand, and dune sand. He had not found anything in sea sand that one would not expect to find, and had not found, from practical experience, that salt made any difference. It might do, but he considered it most unlikely. As to Mr. Marks' point that these things had to be looked at from a scientific point of view, Mr. Holmes said he had only had a week in which to write the Paper, and could not do much scientific research in that time. He also pointed out that he hoped, at a later date, to go into the question more thoroughly, and, instead of giving a descriptive paper, to give one which would be simply a mass of facts—the sort of paper that could not be read, but which would have to be given to people for them to digest at leisure.

Shell in Sea Sand.

Mr. B. Hird asked if small shells in sea sand affected oil-sand cores, and whether they were responsible for some oil-sand cores made from sea-sand blowing occasionally. He had had difficulties with that kind of sand, and had attributed them to shells. Mr. Hird added that, when he was short of sand for oil-sand cores, he had found that a fairly good substitute was the ash gathered from the top of the cupola.

Mr. Holmes, dealing with the possibility of cores blowing through the presence of pieces of shell, said that the only case he could see in which that was likely to occur was where the pieces of shell were fairly large, but he did not think that, apart from the mechanical obstruction caused by the pieces of shell, there was much risk of blowing. In the case of sand which had been knocked in the fettling and used again, with shells in it, they might, through heating, get the shells rather porous, so that they absorbed oil; if they made the mixture fairly rich, with the sand on the wet side, they might get a good deal of oil collecting in the shell, and, if it were near the surface, blowing might occur. But, speaking generally, by taking out the larger pieces of shell in sea sand, he had not found any trouble, though there was just a possibility that there might be trouble in a very narrow core. He was quite interested to hear Mr. Hird's reference to cupola ash, which was quite a new material for making oil-sand cores.

Binders Other than Oil.

Mr. E. H. Brown asked the lecturer whether he disagreed entirely with the use of binders of the nature of glucose. With regard to the baking of cores, he would like to know whether Mr. Holmes considered that oil-sand cores should be dried in a separate stove, or whether, if oil-sand and the naturally-bonded core sand had to be dried in the same stove, there must be separate heats. Even to-day there were a large number of foundries which were anything but up-to-date, and the foreman had to make the best of a bad job. Mr. Brown then referred to a recent experience which might interest members. In the last three weeks he had seen some very thin oil-sand cores, the section being between ⅜ and ½-in. thick, built into a very thick section of metal. The total thickness of metal, including the core, was practically 6 in., right at the bottom of a fairly heavy mould. The cores were made in oil-sand, using a very fine sea sand as a base. After being dried, they were further spread with oil and baked again, and when the cores were knocked out they were found to be perfect.

Mr. Holmes, replying, said that he was speaking generally of drying oils in the Paper, and "drying oils" meant something with a linseed or similar base, but he had no objection to the use of glucose. They could use all sorts of things, but he was not dealing with that question at the moment. There were a large number of imitation core oils on the market, consisting of wood extract, pulp extracts, and similar materials, as well as gums; as a matter of fact, they could call anything a core oil nowadays, when it was not an oil at all. It was not so much a question of baking with other materials, but, in the case of the linseed base oil or a similar product, they had to oxidise the material; that was a distinct baking action, and not a drying action. It was not merely a question of drying out the moisture and leaving something that was sufficiently strong; they had to dry out the moisture and make something fairly weak, and then act on it further by hot air and strengthen it, not by drying but by oxidising. If a glucose binder happened to suit the particular type of work for which it was used, and it was an economical proposition, his advice was to stick to it. As to the baking of cores, he had found that if they wanted the very best from oil-sand cores they had to have their own heat treatment, and that did not fit in with the proper conditions for drying a naturally-bonded core. Reverting to the question of core oils, he said that some of the oils on the market appeared to contain two constituents which required quite different thermal treatment in order to get the best out of them. That was a point which some makers of core oils did not appreciate. Dealing again with the question of separate stoves, Mr. Holmes said that if the volume of work justified the use of separate stoves, well and good, but there were so many factors entering into the question that it was quite impossible to say whether it was a more economical proposition to get a slightly worse core through giving it the incorrect heat treatment, or to spend more money in order to get good cores.

Mr. Stubbs asked if Mr. Holmes would give information in writing with regard to testing oils for specific gravity, flash points, and other tests that he had made, because there was nothing that had been so much exploited in the foundry trade during the last two or three years as core binders and oils had been, and to his mind there was either a real good thing in it or else foundrymen did not know what they were doing. If Mr. Holmes would give that information, it would help them to come to a conclusion as to which was the best binder they could use.

In reply to Mr. Stubbs, Mr. Holmes said he did not feel in a position to discuss this as he had very little knowledge of organic chemistry in general or the testing of oils in particular.

In any case, it seemed doubtful if the laboratory testing of core oils, other than by an expert using exhaustive methods of investigation, would throw any light on such complex properties as those which render the handling of the core in the foundry possible or not.

Much time and money is spent each year on conducting rather futile tests on lubricating oils, and probably the same thing would happen in the testing of core oils.

The problem was one that might well be attacked by the British Cast Iron Research Association (after the present urgently-needed researches are completed), together with one or more experts on the subject; but so far as the foundry laboratory was concerned, the subject was almost beyond its scope.

The President, in bringing the discussion to a close, said that that was information which they were all looking for. He also expressed indebtedness to Mr. Holmes for his Paper.

DILATOMETRIC ANALYSIS OF ALLOYS, WITH SPECIAL REFERENCE TO CAST IRON.

By Professor Pierre Chevenard.

[*Translated by V. C. Faulkner.*]

INTRODUCTION.

The Industrial Importance of Thermal Analysis.

The principal methods of metallography comprise, apart from chemical analysis, micrography and thermal analysis. Micrography reveals the physico-chemical and structural state of a sample at ordinary temperature; it determines the entire effect of any treatment, but it gives no information, at least directly, as to the mechanism of this treatment. Thermal analysis, on the other hand, allows of the visualisation and registering of the transformation of an alloy during the period concerned, and to envisage the temperature, the speed and the intensity; this information is essential for the carrying out of thermal treatments.

Diverse Methods of Thermal Analysis.

Methods for thermal analysis may be divided into two groups:—Thermal methods (the chronographical methods, as used by Roberts-Austen and Dejean) relate to the calorific properties of alloys. Their use is very general, because a change of state is invariably accompanied by thermal phenomena, more or less intense and more or less defined; they are equally applicable to both solid and liquid bodies. Their sensitiveness, however, depends very largely upon the speed of heating and cooling.

They are useless for the study of very slow reactions. Moreover, they do not allow of the quantitative comparison of observed phenomena when the speed varies between large limits. This inconvenience is very serious when related to the study of thermal treatment, a subject which has for one of its objects the rendering more clear of the effect of speed of heating and cooling.

Physical methods, based upon the study of expansion, electrical properties, magnetism, etc., do not exhibit this fault. They allow of the study of slow reactions and a quantitative characterisation of transformations.

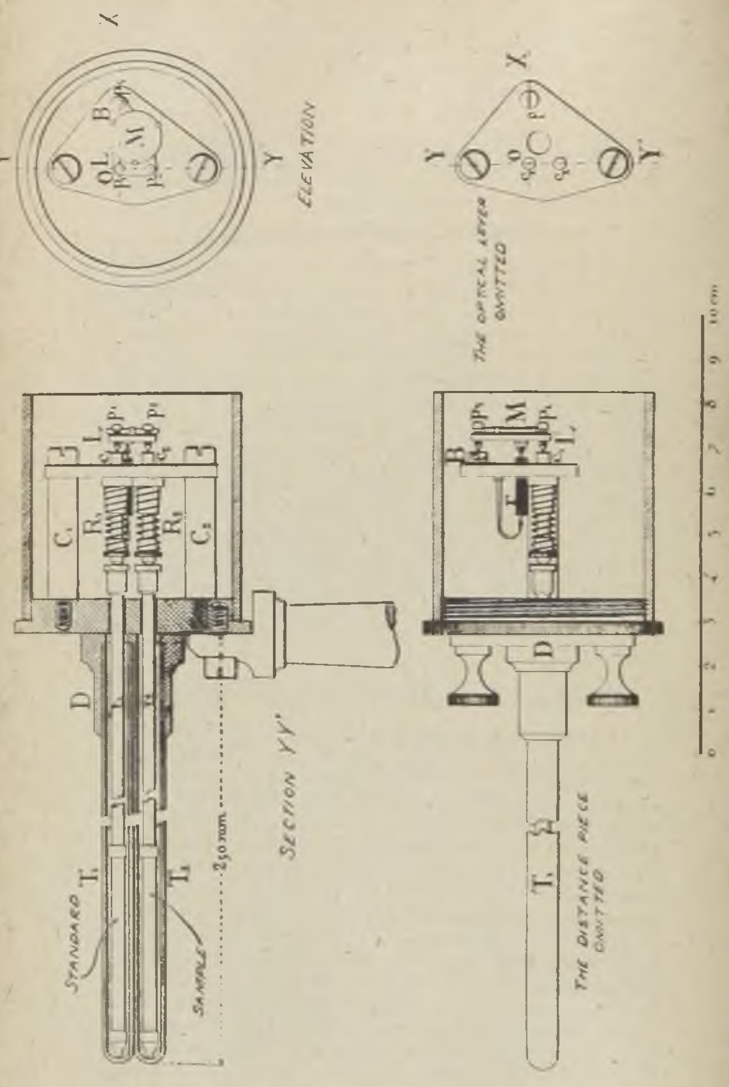
Principles Underlying Physical Analysis.

The observed manifestations during the heating and cooling of alloys show up:—(1) The *specific transformation* of the constituents. (a) *Allotropic* transformations with change of phase; (b) *abnormal* transformations without change of phase; (c) *decomposition* of a phase out of balance. (2) *Reactions between phases.*

The close study of these phenomena therefore show, (1) followed in all its details, the mechanism of the reaction during the time of operation, and to receive from it an appreciation of the importance of the phenomenon to which it refers. (2) To control, after trial, the results of a reaction, because, according to the amplitude of the physical properties of the constituents and to the intensity of their specific directional change, one can approximately evaluate the proportion of each.

Advantages Shown by the Dilatometric Method.

Amongst the methods used for the physical analysis of solid bodies, that which is based upon the observation of the phenomenon of dilatation appears to be the most rational, the easiest, and the most precise. However, changes of state of substances are always accompanied by a variation of volume. The amplitude of the phenomenon is remarkable, on account of it being so easy to measure in a large number of industrial products, such as the alloys of iron, bronzes, silica bricks, etc., but even in a case where the dilatometric phenomenon is quite small, as in Duralumin, it is always possible to make an analysis even when the manifestation is quite small, if a suitable apparatus is available. However, the results of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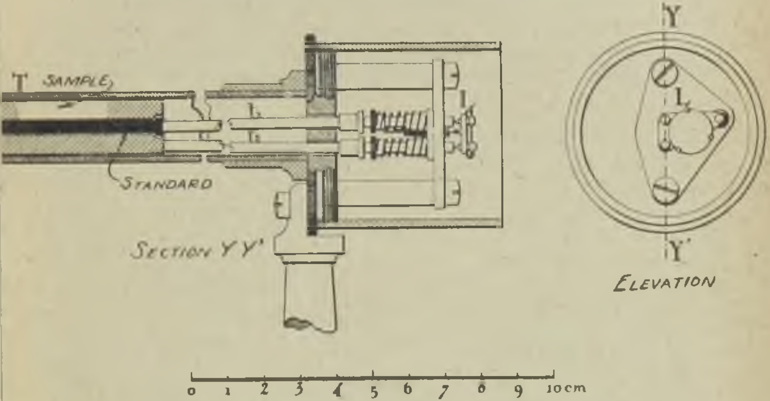
dilatometric analysis are easy to interpret; the dilatation of an aggregate does not differ radically from that which can be anticipated from the law of mixtures. The dilatometric method presents, unlike the electrical and magnetic methods, the advantage of distinct sensitiveness to secondary reaction, such as impurities, thermal history, and allied parasitical phenomena which are unable to mask the essential facts. It is proposed to expose the technique of dilatometric analysis, such as has been developed in the laboratories of the Imphy Works of the Commentry-Fourchambault-Decazeville concern, by taking steel and cast iron as examples, and it is proposed to pass in review some of the results which have been obtained.



IG. 2.—Differential Dilatometer. The Standard is Enclosed in the Sample.

Technique of Dilatometric Analysis.

*The Differential Dilatometer**.—(1) The apparatus used for the determination of the dilatation of a sample utilises a suitable standard sample which is heated to the sample temperature. From the play of the single mirror (Fig. 1) moving around two rectangular axes, OX, OY, the apparatus photographically makes a curve, of

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* For detailed description see "Rev. de Met. Mem.," 1917, vol. XIV, page 610.

which the co-ordinates are (1) the expansion of the standard sample which acts as the axis of the abscissae, and which has reference to the temperature communicated to the two samples. (2) The difference in expansion of the two samples.

The Standard Sample.

In order to play the double rôle of being able to compare samples, and as an indicating pyrometer, the standard sample must possess the following properties:—(1) Inoxidysability and rigidity in the region of the temperature where it is used; (2) it must definitely fulfil the law of reversible and regular expansion. In some cases, such as iron, copper, aluminium, it is often possible to utilise a nickel-chrome-tungsten alloy, known as Pyros, which possesses to a high degree the necessary qualities. It is possible to use an apparatus employing Pyros up to 1,100 deg. C., or even 1,200 deg. C.

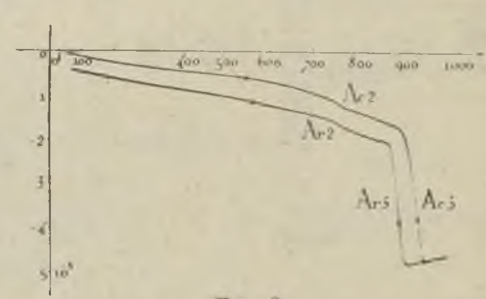

Fig. 3.

Swedish Iron C. 0.035; Pyros standard used. Ac2-Ar2, transformation without change of phase; Ac3-Ar3, Allotropic change with change of phase.

Details of the Apparatus.

The standard chosen should possess an average and similar expansion to that of the sample, so that one can, without giving inconvenient dimensions to the diagrams, admit of a high range as regards the ordinates. Thus, the differential apparatus is sensitive. It shows up directional changes, from the normal thermal expansions, and also the very small jogs which are liable to be masked through the rapid rise of the true dilatation curves. Another quality shown from the use of an expansion pyrometer is that the apparatus is robust, reliable, and is completely fool-proof. The curves are entirely free from accidental variations. It is possible, by a graphic elaboration, to trace the curves obtained, which will accentuate the slightest abnormality in

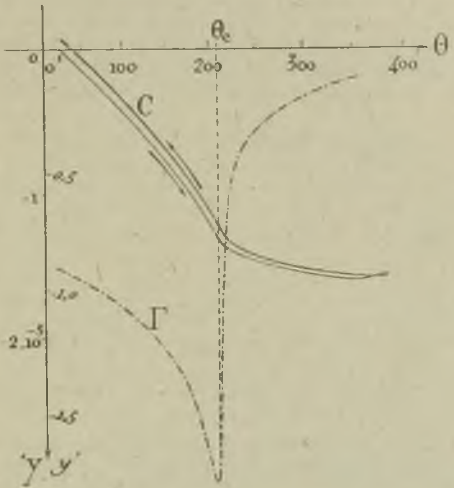

FIG. 4.

Reversible transformation of Cementite directional change. Standard used was electrolytic iron. C = Registered Curve; Γ = Derived Curve; θc = Curie's Point.

the curve. The clearness of the curve is a great help to rational conclusions. From this point of view, the differential dilatometric apparatus appears to present a definite advantage over apparati giving direct readings which rely upon the construction of a curve by a series of points, and incorporates the enregistering by a galvanometer, which latter is always liable to be affected by outside conditions.

Uniformity of Temperature.

The working of the dilatometer presupposes that the two samples are kept constantly at the same temperature. To what extent is this condition realised? Many experiments have been carried out to determine this. In order to ensure this thermal uniformity, samples of the same mass as the standard are used, whilst their calorific capacities should have but small differences. The apparatus is centred in an electric furnace which is provided with a nickel copper muffle. Because of these precautions, equality in temperature is established within two or three degrees, except when the sample is outside its thermal stability as a result of a transformation. It would appear in this case to give a parasitic jog, of which examples will be given.

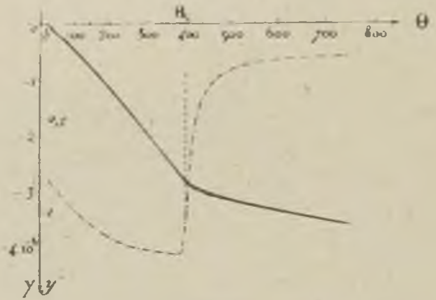

Fig. 5.

Reversible transformation of 45 per cent. ferro-nickel, Pyros being used as standard. The dot and dash line is the derived curve. θc. Curie's point.

In order to eliminate them, it is sufficient to place the standard sample in the inside of the sample to be tested. In the apparatus shown in Fig. 2 the pyrometer needles very lightly touch the sample, and experiences the same differentiation in temperature. When reading a diagram, it is easy to distinguish true manifestation, as parasitic jogs are always localised in a straight temperature interval, and of which the direction can be regularly visualised. Also, as the sample is hollow, it is more difficult to prepare than a cylindrical sample, such as used for the first apparatus. This latter is principally used, and is to be recommended.

Calculation of the Co-efficient of Expansion.

The differential dilatometer is not apparatus simply for thermal analysis, as it also allows of the measuring of the expansion of bodies of all temperatures less than 1,100 to 1,200 deg. C. This evaluation is derived from the graphic determination of the results. The operation gives clear diagrams, which is an aid to clear interpretation. The true co-efficients calculated from this method are obtained with a precision amply sufficient for practice. The true error rarely exceeds $0,2.10^{-6}$.

Cast Iron.

Ordinary cast iron is essentially formed by the association of ferrite, cementite, and graphite. When the cooling from the liquid state is rapid, the constituents to be associated with steel are found. These are austenite and martensite. It is proposed to deal with first of all the dilatometric properties of these constituents, then directional changes and mutual reactions. As this is a *résume,* it will suffice to deal with the features of the dilatation diagrams and their physiochemical signification. The interpretation of these features will be discussed in detail in the finished memoir.

Constituents of Cast Iron.

Iron (Fig. 3).—This diagram relates to a sample of Swedish iron practically free from carbon (C = 0.035 per cent.).

The magnetic transformation is marked by a dilatation directional change Ac2 – Ar2, at 770 deg. C., which is reversible, and which consists of a rapid variation in the dilatometric properties in the region where magnetisation disappears. (Curie's point.)

The radiographic analysis by Westgren and Phragmen confirm the previous conclusions of Grenet and Weiss, showing that these transformations are carried out without change of phase. The region of the stable alpha state at cold extends from the absolute zero to 920 deg. There is not sufficient space available to deal with beta iron.

On the contrary, the transformation Ac3 – Ar3 definitely corresponds to a change of phase: Alpha → gamma. Stable gamma iron when hot possesses a crystalline system (cubic with centred facets) and physical properties quite distinct from this system and the properties of alpha iron. This allotropic transformation is sometimes thought to be brought about by a contraction of Ac3, which is small when the iron is pure, but extended when the iron contains carbon, oxygen, etc. The existence of a bend at the start of the point Ac3 of the dilatometric curve is thus characteristic of the impurities of iron.

Cementite has been isolated by Professor Arnold, who used a dilute hydrochloric acid solution, which was electrolysed by taking as the cathode a sheet of lead, and for the anode a sheet of carbon steel. The iron in this steel alone is attacked, and the insoluble cementite is precipitated as a black powder. This powder titrated with a few drops of silicate of soda and when compressed in a mould supplies a sample sufficiently solid for dilatation tests.

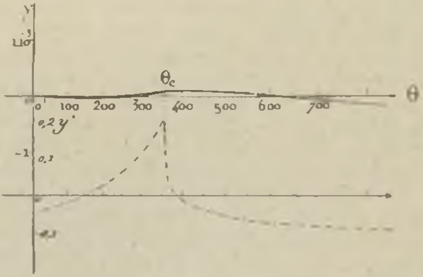

Fig. 6.

Reversible transformation of pure nickel. Pyros standard used. θc, Curie's point. The derived curve is shown dotted.

Cementite, having ferro-magnetic properties, possesses a dilatation directional change which is definitely pronounced (Fig. 4). Curie's point is found about 210 deg. C. This point corresponds with the peak in the derived curve.

All ferro-magnetic bodies and alloys such as alpha iron, cementite, magnetite, ferro-nickel, ferro-cobalt, etc., present a directional change of this character. But the direction and intensity of the phenomenon varies from one substance to the other. (1) In a 45 per cent. ferro-nickel shown in Fig. 5 the dilatation directional change which accompanies the magnetic transformation is definitely comparable with that of cementite. The curve for pure nickel (Fig. 6) symmetrically coincides with the preceding ones, so far as the horizontal axis is concerned, but in every case the bending point in the resulting curve coincides with Curie's point, as revealed by thermo-magnetic methods. It should be noticed that the reversible directional change in dilatation is not only met with in ferro-magnetic bodies. Thus

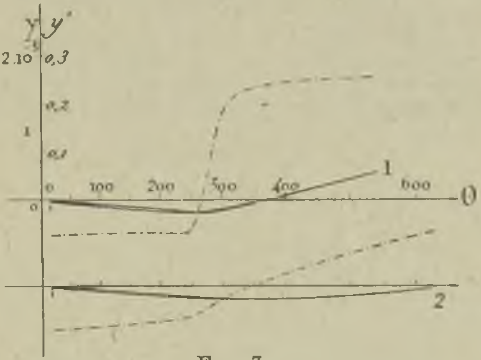

Fig. 7.

Reversible directional change of a Cu-Al solid solution. The full line is the registered curve, and the dotted one the derived curve. Curve 1 contains 8.64, and Curve 2 3.92 per cent. Al.

solid solutions, such as copper-aluminium alloys (Fig. 7), show it up very clearly about 250 deg. C.

Diagram 2 of Fig. 7 calls for another remark. The resulting curve shows a bend which the appearance of the first curve would not pre-suppose. This result shows the superiority of an apparatus giving continuous registration, associated with clear tracing and devoid of outside interferences. The directional change of cementite is shown in all aggregates where it exists in the free state, such as *carbon steels* (Figs. 8 and

10) and *white irons.* A quantity of cementite corresponding to a carbon content of 0.05 per cent. only appears on the dilatation diagram when the derived curve is traced. This phenomenon of iron carbide constitutes a pointer, and even contains something of an element of quantitative approximation.

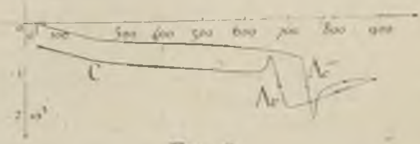

FIG. 8.

A Eutectoid Carbon Steel. (C. 0.85). Pyros standard used.

Graphite.—Fig. 9 has reference to a sample cut from an Acheson electrode. A sample of agglomerated Ceylon graphite mixed with silicate of soda has given a similar diagram. Graphite is only slightly expandable, and is free from thermal perturbations. This small expandability brings about the rupture of the lamellæ of graphite when cast iron is subject to a transformation incorporating important changes of length. It results in swelling and in porosity

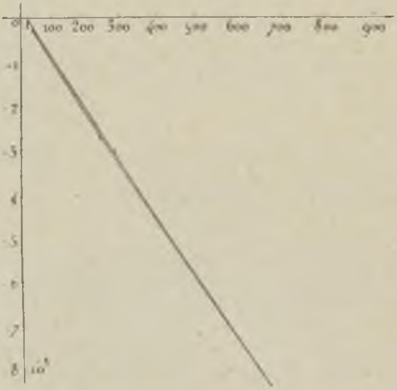

FIG. 9.

Graphite Electrode. Pyros standard used.

Complex Cementite.—Manganese, chromium, vanadium, tungsten, etc., also form definite compounds with carbon. These carbides associate themselves with the cementite in cast iron and special steels. Fig. 11 is a group of diagrams obtained from cast irons all carrying about 4.5 per cent. of combined carbon and manganese contents ranging from 0; 0.75; 1.6; 2.9; 4.0; to 8.1 per cent. Curie's point is seen to be retrograde, and this continuously, which proves that manganese carbide forms a solid solution with Fe_3C.

A similar conclusion is to be drawn from Fig. 12, which relates to chromium cast iron. In these special cast irons, of which the combined carbon contents is practically the same (4.5 per cent.), the lowering of Curie's point is due to the cementite, and is proportionate to the manganese or chrome content (Fig. 13). Thus, according to the position of Curie's point, which corresponds, as regards cementite, it is possible to appreciate whether this latter is pure, or if it contains an element such as manganese, chrome, etc. By this method the changes of the carbide in a steel during the course of heat treatment can be followed.

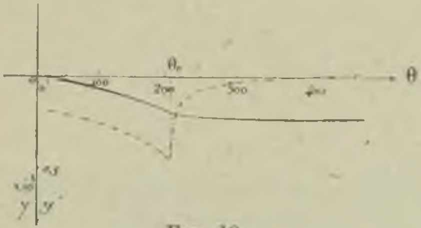

FIG. 10.

Cementite directional change in 1.15 per cent. Carbon Steel. Electrolytic Iron used as standard.

Pearlite-Eutectoid Steel.—Pearlite or the iron cementite eutectoid is encountered in all iron-carbon alloys in the instable state. In order to study these properties, a steel containing 0.85 per cent. carbon, which practically consists of pure pearlite (Fig. 8) was taken. About 730 deg. C. iron and cementite react in order to produce austenite, a solid solution of the carbon in gamma iron. This reaction, which is isothermic, according to the phase rule, is accompanied by a contraction. The thermal phenomenon which accompanies this creates a difference of temperature between the standard sample and the steel sample. This difference tends to be narrowed as soon as the reaction finishes. That is why the normal contraction is prolonged by a parasitic bend, but it is easy to make an abstract from it, and attention being drawn to this accessory phenomenon any false interpretation of the bends, will be avoided.

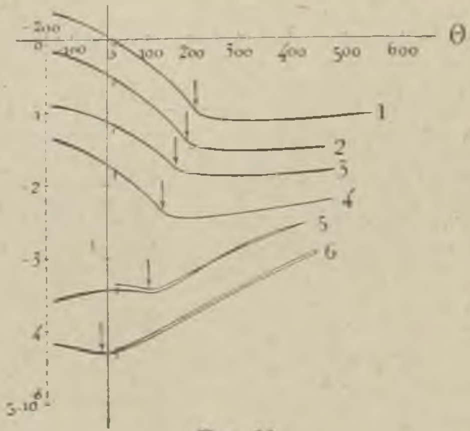

Fig. 11.

Cementite directional changes in complex Cementites in manganiferous Cast Irons. Electrolytic iron used as standard. The carbons averaged 4.5 per cent, and the manganese ranged from nil in Curve I to 8.1 per cent. in Curve 5.

The curve C is nothing else but a directional change of the cementite.

Austenite.—Pure austenite—that is, a solid solution of the carbon in gamma iron—is only stable above 700 deg. C., but it exists partially unaltered at closely approximating temperatures, when it is subjected to a quick cooling from high temperature (super-quenching). By such a treatment, pure austenite is never obtained, even when starting with an alloy consisting solely of iron and carbon. It thus becomes necessary to utilise a steel carrying an addition, such as manganese, which allows one to take into consideration this foreign body in the quantitative interpretation of the results.

Fig. 14 refers to a manganese steel containing carbon 1.5 and manganese 2.05 per cent. quenched from 1,150 deg. C. in water, and tested beside a standard sample consisting of electrolytic iron. At the beginning of the experiment the alloy is magnetic, and the microscope shows up austenite free from martensite. This austenite is very dilatable, as it shows a clear inclination in curves 1, 2, and 3. Moreover, it is stable when re-heated until the temperature exceeds 325 deg. C. Then the curves 1, 2, and 3 are almost reversible.

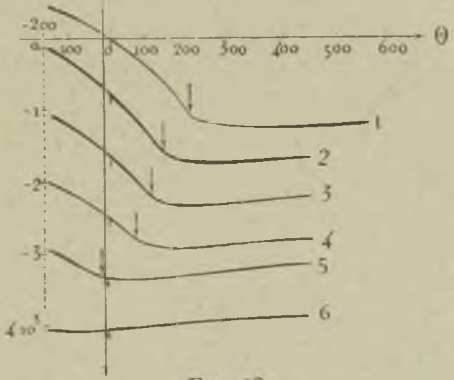

Fig. 12.

Cementite directional changes in chrome cast iron. The carbon averages 4.45 per cent., and the chromium ranges from nil. in Curve 1 up to 8.78 per cent. in Curve 6.

At 350 deg. C. (Cycle No. 4) the austenite rapidly decomposes with the generation of heat, which creates parasitic bend (A), which is well defined. The return curve of Cycle 4 is almost horizontal. It shows that the iron has returned to the alpha state. Moreover, it shows a directional change of the carbide C1, and proves that the Austenite decomposes into ferrite and carbide.

But the point C is below 210 deg.; the carbides liberated by the decomposition of the Austenite contain manganese, this element being divided between the complex cementite and the ferrite.

As the heating progresses, phenomenon C decreases, and in a steel heated to 850 deg. C. (Curve 8) the temperature C_2 is clearly lower than that of C_1. Thus the co-efficient of the division of the manganese between the carbide and the ferrite varies according to the temperature to which the sample has been raised. Dilatometric analysis shows this change of composition.

Martensite.—Martensite—a constituent associated with quenching—cannot be obtained in a pure state. The transformation which gives rise to its production is effective at low temperature, and is never complete. Martensite is always accompanied by an excess of Austenite. Also, the dilatation directional changes characteristic of the decomposition of these two constituents will superpose themselves in the return curve (cooling).

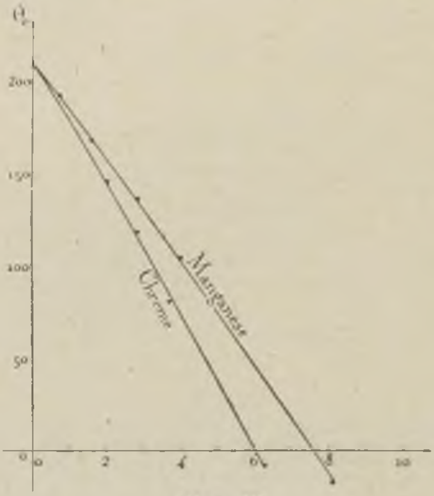

FIG. 13.

Variation of the temperature of Curie's point with the chrome or manganese content in cast iron, carrying about 4.5 per cent. of combined carbon.

If a eutectoid steel is quenched from very high temperature so as to obtain, in the Martensite, a considerable percentage of Austenite, then on reheating (Fig. 15) an important contraction is noticed, but the speed is very variable according to the temperature. One is thus led to believe that this curve is the resultant of two phenomena —(1) a continuous contraction, which corresponds to the decomposition of the Martensite, and (2) a localised expansion, with a parasitic jog A, which more or less neutralises the preceding contraction and which has reference to the decomposition of the Austenite. On the return curve, after reheating to 700 deg., the cementite directional change (C) has exactly the same value as in a steel heated to 800 deg. C. The Sorbite is therefore an aggregate of iron and cementite, and is of the same composition as pearlite.

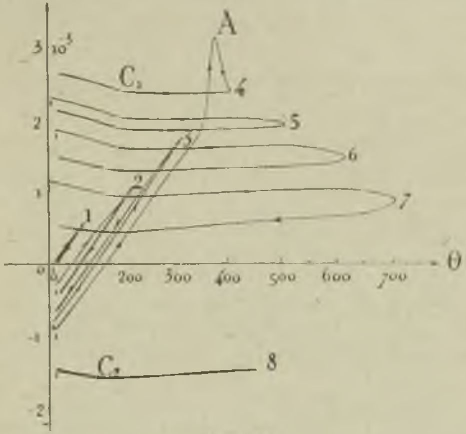

FIG. 14.

Cycles of heat treating of Austenite, obtained by superquenching a manganese steel. C = 1.50; mn. 2.05 per cent. electrolytic iron used as standard. A = Parasitic gob. C_1-C_2 = Directional change of the manganiferous Cementite.

In a second experiment the steel was quenched at 800 deg. C. in order to ensure a small excess of Austenite, and gave the curve shown in Fig. 16, in which (1) the cementite directional change does not exist in the quenched steel re-heated to 250 deg. C. This shows that in Martensite the carbon is in a state below and not in the form of cementite invisible under the microscope. (2) The directional change C. appeared progressively, and the rate of this is definitely parallel to the decrease in the hardness.

The Graphitisation of Cementite.

In order to throw light upon the rôle of silicon and manganese, the author prepared a series of synthetic cast irons in an electric laboratory furnace, using pure raw materials consisting of electrolytic iron, graphite, ferro-silicon, and alumino thermic manganese. The alloys were cast at 1,400 deg. C. into cast-iron ingot moulds so as to form rods of 4 mm. diameter. Under such conditions solidification becomes extremely rapid, and the irons usually turn out white. Moreover, one can definitely associate with it a true martensitic quench. In all the experiments to be described the speed of heating was kept practically constant at about 250 deg. per hour.

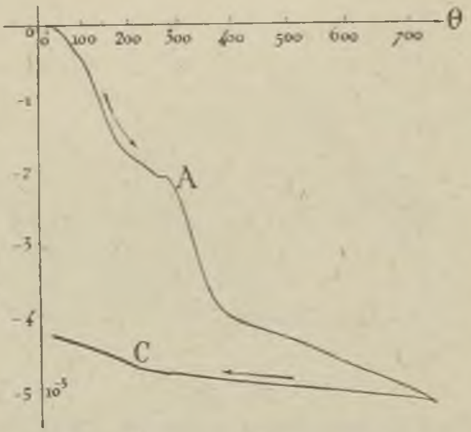

Fig. 15.

Thermal history of a 0.85 per cent Carbon Steel quenched in water, from 1,150 deg. C. Pyros was used as standard. A = Parasitic jog relating to the decomposition of the Austenite. C = Cementite directional change.

Very Pure White Iron A.—This iron showed the following composition:—C.C., 4.44; Gr, nil; Si, 0.14 per cent.; and Mn, trace. The first cycle,

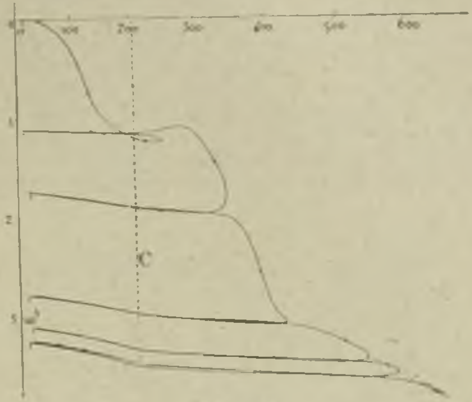

FIG. 16.

Reheating cycles from .85 Carbon Steel quenched in water from 800 deg. Cent. Electrolytic Iron standard used. C = Progressive appearance of Cementite directional change.

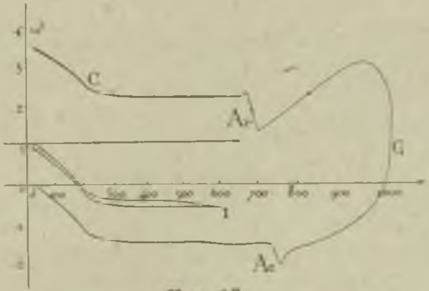

FIG. 17.

Synthetic Cast Iron after casting. C. 4.44; Si 0.14; Mn. Tr.; Pyros standard used. C, Cementite directional change; G, Graphitisation; Ac-Ar, Allotropic transformation.

shown in Fig. 17, shows in a striking manner the reversible cementite directional change C. On curve 2 there is recorded, on heating up the directional change C, the jog, given by the transformation of the pearlite Ac, and above 1,000 deg. C., an ascension G. Then on cooling the formation of the pearlite Ar and the directional change given by the cementite.

On careful examination the return curve shows that the directional change of the cementite is less intense than on heating. This result is confirmed by micrographic observation, which shows graphite particles after cycle 2. Thus the phenomenon G relates to the graphitisation of the cementite. It is thus shown that the reaction starts at high temperature and that its speed is slow.

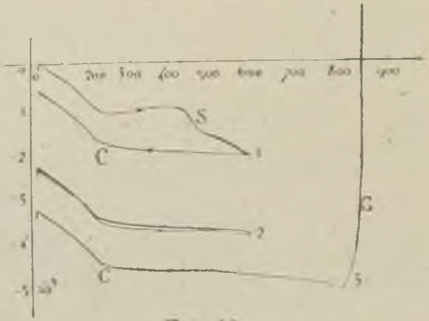

Fig. 18.

Synthetic Cast Iron B, after casting. C. 4.8; Si 0.85; Mn. Tr.; Pyros standard used. C, Cementite directional change; S, Reheating bend from Martensite and doubtless Austenite. G, Graphitisation of Cementite.

The Influence of Silicon.

Table I shows the composition of the samples experimented upon.

Table I, showing composition of samples used for ascertaining the influence of silicon.

Sample.	Tot. C.	Si.	Mn.
B.	4.80	0.85	Tr.
C.	4.85	1.70	,,
D.	4.42	2.38	,,
E.	4.36	4.78	,,

It is well known that silicon is an energetic accelerator of graphitisation. With 0.85 per cent.

Si, the graphitisation of sample B started at 800 deg. (curve 3 of Fig. 18), and the phenomenon is rapid. If the temperature is taken to 1,050 deg. C. the cementite is totally decomposed. Proof of this is given by referring to the novel dilation cycles after the phenomenon G (cycles 4 and 5 of Fig. 19). This aspect of the diagram is profoundly different. The directional change of the cementite has practically disappeared, and the jogs Ac and Ar correspond to the stable iron-graphite system.

The diagrams of the samples C, D and E, of which the silicon contents are in increasing amounts, call forth the same observations. As silicon is added so the temperature of graphitisation (G) decreases, and this practically continuously until it stabilises itself at 600 to 650 deg. C., when the silicon content will have reached 4.0 per cent.

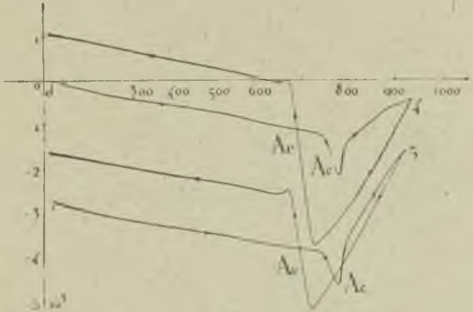

FIG. 19.

Synthetic Cast Iron B, after graphitisation. Same sample as Fig. 18.

Graphitisation is independent of the Ac transformation. According to silicon content, the ascending curve G starts either above or below the Ac point. In Fig. 20 the Ac point is seen to be right in the middle of the graphitisation period.

In all these diagrams the first thermal cycle shows a bend S on heating analogous to that exhibited by quenched steels. Thus casting in chills sets up two quite distinct phenomena, though both are referred to under the name of "chilled" (quenched). The first is the production of the unstable system, iron—cementite, and the second a true martensitic quench, similar to that of steel.

Influence of Carbon.

The cast iron samples just outlined have a carbon content of about 4.5 per cent. It is now proposed to consider one containing much less carbon, sample F. Its analysis is C, 1.68; Si, 1.20 per cent.; and Mn, trace. (Fig. 23).

The intensity of the jog S on heating is very pronounced. The graphitisation (G) scarcely commences until 875 deg. C., whereas in an iron carrying the same silicon contents and 4.5 per cent. C., it would occur from 650 deg. C. This confirms the well-known fact that silicon and carbon help graphitisation. Above G the dilatation curve experiences a change of direction P, and beyond becomes sensibly reversible. Whereas on cooling the graphitisation characterised by the ascension of the curve returns at temperatures lower than that of P. The temperature of the phenomenon P corresponds to the line of Roozeboom's diagram—the limit of the solubility of

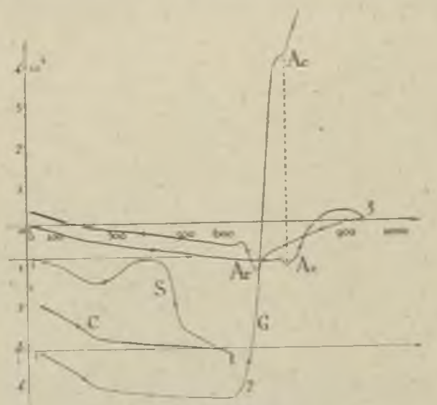

FIG. 20.

Synthetic Cast Iron. C. after casting. C. 4.85; Si 1,70; Mn. Tr.; Pyros used as standard. C. Cementite directional change; S, Reheating bend; G, Graphitisation; Ac-Ar, Allotropic transformation.

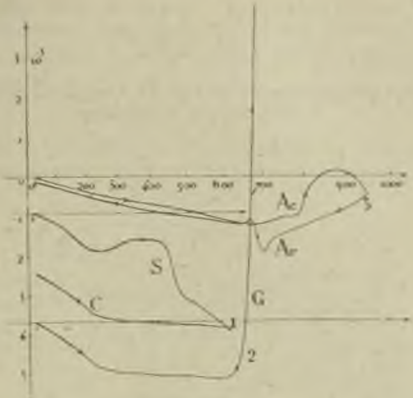

Fig. 21.

Synthetic Cast Iron. D, after casting; C. 4.42; Si 2.39; Mn. Tr.; Pyros used as standard. C, directional change of the Cementite; S, bend on reheating; G, Graphitisation; Ac-Ar, Allotropic transformation.

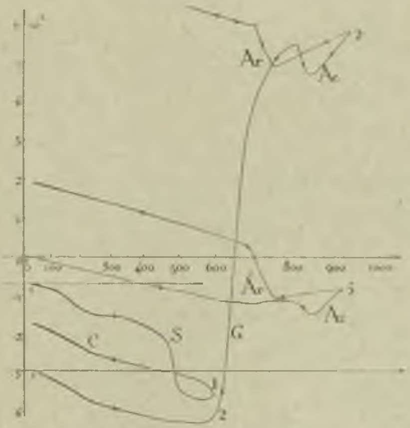

Fig. 22.

Synthetic Cast Iron. E, after casting. $C = 4.36$, Si 4.78; Mn. Tr.; Pyros standard used. C, Cementite directional change; S, Reheating bend; $G =$ Total graphitisation. Ac-Ar, Allotropic transformation in the Iron-Graphite system.

graphite in austenite. Above P the alloy is a homogeneous solid solution, and graphitisation ceases, to re-occur again below.

Complex Phenomena Observed in Cast Iron Contained in Silicon and Manganese.

The iron used contained C, 4.20; Si, 1.34; and Mn, 4.06 per cent (Fig. 24). The manganese tends to counteract the action of the silicon on graphitisation. It enters into the constitution of complex cementites, and renders the iron-carbon alloys self hard. Complex phenomena are thus to be expected in the course of reheating and iron containing both silicon and manganese which has been chill cast. It is proposed to show by an example that it is possible to clear up these obscure phenomena.

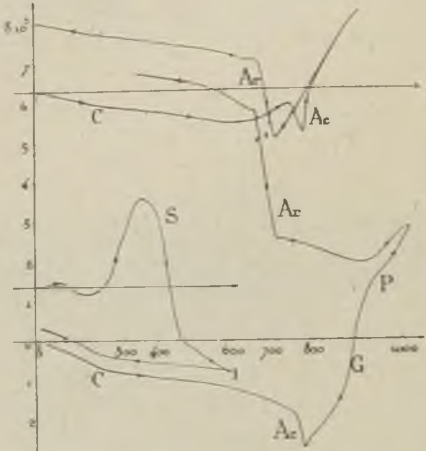

FIG. 23.

Synthetic Iron F. after casting. C = 1.18; Si 1.20; Mn. Tr. Pyros standard used. C = directional change of the Cementite; S. Reheating Bend. G = Graphitisation. Ac-Ar, Allotropic modification. P = Total solubility of the carbon.

Cycle 1 of Fig. 24 shows first of all about 125 deg. C., the directional change of the complex carbide, then the curve takes an ascending course.

After a jog S, it returns to nearly horizontal, and the directional change of the carbide again appears with an added intensity. The explanation is simple. The cast iron cast in 4 mm. rods was partially super-quenched; that is to say, it contains a certain quantity of austenite with the martensite, which induces high dilatability. This austenite and martensite retains some carbon in

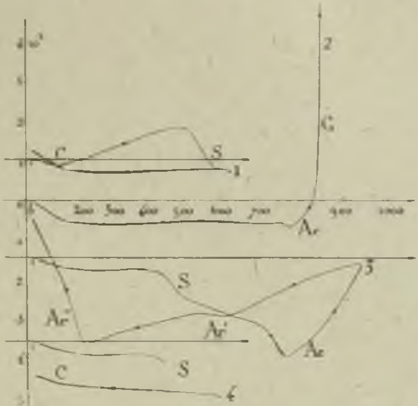

FIG. 24.

Synthetic Cast Iron after casting. Pyros standard used. C. 4.20; Si 1.34; Mn. 4.05. C, Cementite directional change; S, Reheating bend; Ac, Allotropic transformation on heating; Ar'-Ar'', Allotropic transformation on cooling; G, Graphitisation.

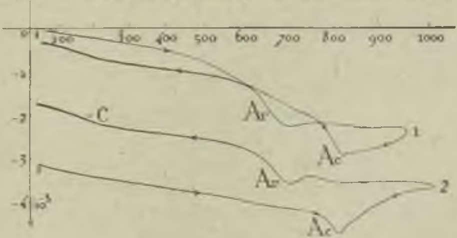

FIG. 25.

Very grey impure Cast iron. C. 3.30; Si 3.00; Mn 3.25; S. 0.011; P. 0.082. Pyros standard used.

solution. The heating S precipitates the carbon, which increases the directional change of the latter.

From curve 2 the graphitisation (G) is seen to appear about 800 deg. C.; that is to say, about 150 deg. higher than if no manganese was present. The stabilising action of the manganese on the cementite is again apparent. The return of this cycle No. 2 has not been registered, but as the manganese renders the alloy self-hardening a quench during the course of cooling is foreseen.

It is this which appears on cycle No. 3, the jog S of heating proves the existence of a previous quench. Besides, on the cooling portion of this cycle (3) the transformation Ar is doubled into two manifestations Ar_1 and Ar_2, and this aspect corresponds precisely to a self-hardening, confirmed in its turn by the jog S of cycle 4.

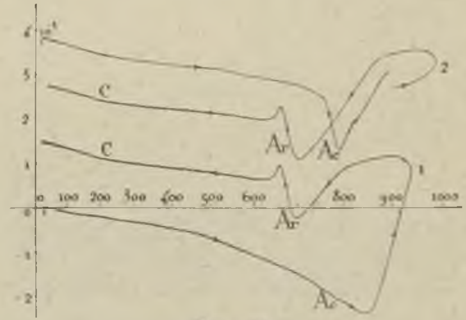

FIG. 26.

Black Heart Malleable Iron. C. 1.1; Si 0.77; Mn. 0.16; S. 0.05; P. 0.16. Pyros standard used.

Industrial Cast Irons.

Impure grey cast iron was used containing C, 3.30; Si, 3.00; Mn, 3.25; S, 0.011; and **P**, 0.082 per cent. (Fig. 25). The graphite was in very large flakes, and because of its size the transformation Ac and Ar is very spread out.

Blackheart Malleable.—This sample contained C, 1.10; Si, 0.77; Mn, 0.16; S, 0.05; and P, 0.162 per cent. (Fig. 26). The microscope showed the graphite to exist as nodules in the ferrite.

From curve 1 on heating there is no directional change C, and the transformation Ac is scarcely apparent, or very spread out. The ascending portion doubtlessly corresponds to the solution of the graphite in gamma iron, a very progressive action because of the form of the condition of the graphite. On cooling the directional change C and the transformation Ar are to be noted.

On curve 2, beyond the transformation Ac—Ar, the directional change (C) of the cementite is noticeable both on heating and cooling. Thus the metal tends to return to the unstable system, which is without doubt because of the low carbon content.

Cast Iron Roll (fragment from the chill).—This sample contained C, 2.6; Mn, 0.25; S, 0.075; Si, 0.95; and P, 0.49 (Fig. 27). The successive cycles between 550 and 950 deg. C show a progressive expansion, which relates to a gradual graphitisation of the cementite. This cementite, which is slightly manganiferous and of a relatively small quantity (the proportion of carbon is less than the normal cast iron content) in contact with a ferrite containing 0.95 per cent. Si, is found in a condition of average stability and decomposes slowly.

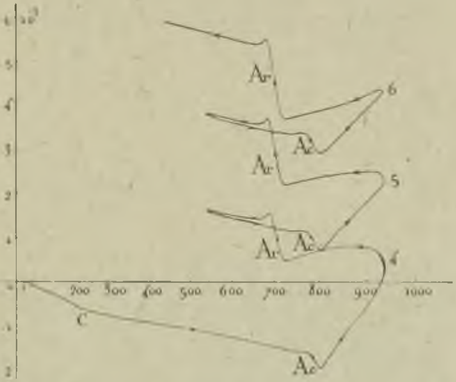

FIG. 27.

Chilled portion of a roll. Pyros standard used.
C. 2.60; Si 0.95; Mn. 0.25; S. 0.75; P. 49.

Phosphoric Cast Iron.

This sample contained C, 3.30; Si, 2.10; Mn, 0.40; S, 0.06; and P, 1.35 per cent. The curve derived from the first heating (Fig. 28) shows a sharp jog and ends by a sharp drop F. However, the cycles allow of the elucidation of the phenomena. The directional change C shows that the iron initially contains about 1 per cent. of combined carbon. The silicon content being increased side by side with the proportion of manganese, the graphitisation starts at from 600 deg.

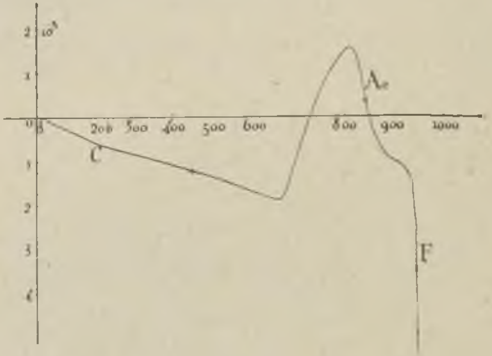

Fig. 28.

Phosphoric Iron. sample cast in bar form. Pyros standard used. C. 3.30; Si 2.10; Mn. .40; S .06; P. 1.35.

C, as is shown in curve 3 (Fig. 29), which is practically free from the directional change C. But this curve 3 shows about 730 deg. C, the directional change Ac_2 of the silicoferrite. It is known that the silicon lowers Curie's point of alpha iron. The jog Ac is next shown, and it relates to the transformation of the stable system. However, the temperature of the drop coincides with the melting point of Stead's phosphide eutectic ($Fe - Fe_3C - Fe_3P$), at about 950 deg. C. This drop therefore corresponds with the release of the sample under the small pressure of the springs of the dilatometer.

Conclusions.

(1) It has been shown that all the phenomena actually known of cast iron have their counterpart

in dilatometric curves. Actually it has confirmed the principle results of Charpy and Grenet relative to graphitisation, and obtained by micrography after quenching. But the dilatometric method is much more rapid, easy and sensitive. It allows of continuous measurement, and this continuity appears to be necessary to clear up the phenomena, which are masked, such as those which have been observed in manganiferous cast iron. It is reasonable to hope to obtain, for the graphitisation of cast iron, results comparable

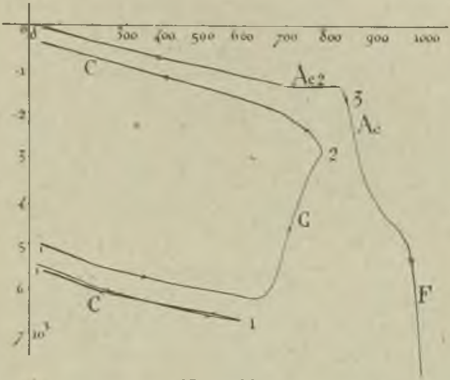

FIG. 29.

Phosphoric Cast Iron. Same sample as Fig. 28. Pyros standard used.

with those which are actually obtained for the quenching of steel. Undoubtedly, dilatometric analysis permits of the characterisation of the tendency to graphitisation in a cast iron in the same way as one can set forth the quenching properties of steel. The practical importance of such results should have a strong bearing upon the scientific manufacture of malleable iron.

(2) *Dilatometric analysis* possesses, as does chemical analysis, a dual aspect (*a*) qualitative analysis. The specific directional changes at definite temperatures, as that of cementite, characterise the presence of phases, definite aggregates or solid solutions of which the chemical composition is known. But, though chemical analysis indicates the mass composition of an aggre-

gate, dilatometric analysis gives information as to the nature of the aggregate, and thus constitutes a process of immediate analysis. (*b*) *Quantitative Analysis.*—The size of the directional changes, of which finishes a process capable of quantitative evaluation of the constituent of which the presence is revealed.

(3) Dilatometric analysis is applied not only to large samples obtained by casting or machining, but also from rods prepared by the agglomeration of powdered material as was done in Bilasco's experiment on varieties of silica and in Chaudron's work on iron oxide. Thus it is now possible to study industrial reactions which exist in the solid slate such as roasting, cementation, etc.

(4) Finally, independent of dilatometrical analysis, the differential dilatometrical allows of the measuring of expansions in an extended temperature interval, such as the working of a part in machines operating at high temperatures, the choice of foundry enamels, optical glass apparatus, glass soldered electrodes, etc.

DISCUSSION.

The President, after expressing his regret that time did not permit of the discussion of this valuable Paper, said that the members of the Institute were very deeply thankful to Mons. Chevenard for the immense amount of work that he must have put into his subject. It was one of the most valuable Papers which the Institute had had the pleasure of listening to. Also he expressed thanks to Mr. Faulkner for having translated it, a task which must have been stupendous.

The vote of thanks was carried with acclamation.

Mons. Chevenard, addressing the meeting in French, returned thanks for the kind manner in which his Paper had been received, and expressed appreciation of the help which Mr. Faulkner had given him.

Mr. F. J. Cook, on behalf of the British Cast Iron Research Association (of which he is a Vice-Chairman), said that the Association looked upon the Paper as one of the most valuable that had been presented for a long time, and assured the Institute that there would be a good discussion of the Paper in writing.

AMERICAN FOUNDRY PRACTICE.

By Dr. Richard Moldenke.

As a preface to his remarks, Dr. Moldenke said he had had so much correspondence with his English friends that he had really got to know them all before he met them. He proposed to give them a rambling talk about American foundry practice, and then his hearers could make their own comparisons. They would probably recognise a good many things that were done in this country. He hoped there would be a discussion afterwards, as he had always found that the discussions were the best part of the evening.

The position as they were facing it in the United States and in the foundry was that their prime requirement was to try to do something to justify the enormous wages they were paying over there. During the war he was called on by the Secretary of Labour at Washington after the wages had gone up by bounds, and he said, "What can we do to justify these so that the men may keep these high wages?" He (Dr. Moldenke) said that education was the only thing to do it. They laid their programme to get the men more information so that they could do their work with a little more brain, get better results, and justify these wages.

Recruiting Labour.

With the high rates of wages that were now being paid in the United States they could understand how it was that their whole export trade had gone smash, and that it was hopeless to trade with the world at the present figures which the people insisted on keeping. Their prime requisite was to get more moulds per man, and also to make a bar of iron go further than ever before. He

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* Delivered before the Sheffield and Lancashire Branches.

was very much pleased in going through some of the works in Sheffield, especially at Hadfields, to see so many young men in the shops. In the United States the young men would not go into the foundry. They wanted collar and tie jobs. The ratio used to be that out of 100 boys 9 went to the high school. On an average to-day about 70 went to the high school. They would not go into the shops; they would not work on appliances, and the works had had to put in machinery to take the place of those boys who ought to go in. It was a pity, but that was the situation.

Pittsburgh Castings.

The customer in the United States was after higher quality work. He wanted better castings, stronger castings, and yet wanted them to be able to machine like cheese just the same. The customer also wanted greater accuracy in the dimensions and greater uniformity in the weight of castings, as well as greater freedom from inherent defects and castings with less blemishes upon them. If they ever saw Pittsburgh castings they would be ashamed of them. They were good castings, but they looked very bad because the sand round that region was very poor. So to-day they were at work on the sand problem, trying to get a small-grained sand. Formerly they had to use sand that was almost gravel. The castings were now coming a little better.

Nomenclature of Semi-Steel

Referring to specifications, Dr. Moldenke said that they had heard, of course, of this so-called semi-steel. It was very fine, but the name was poor. They should do away with it if possible, because the name as used in the United States practically meant the swindling of the customer. It was said, "I have got something better than common iron; it is semi-steel." He made it out of steel scrap, which was cheaper than pig-iron. That was the result, and it was not fair. They had been working to find a better distinctive name for this material. It was being called high-test cast iron, but they hoped someone would suggest another and better name.

The situation the foundryman had to meet was to look for more moulds and better moulds. The thing was to make every single mould count. They wanted to make as many moulds as they could, and make every one right. The next point was the application of metallurgical principles to the moulding process. The foundryman should not be haphazard in his work, but should work the mould and charge his cupolas systematically. After detailing several instances where some slight alteration in the method of charging had resulted in the saving of vast sums of money—in one case £20,000 a year—Dr. Moldenke said they had to study the metallurgy of their processes in addition to the mechanical arrangements in order to get those perfections for which they were looking.

Cost Systems.

Dealing next with a uniform cost system, Dr. Moldenke said that if foundrymen among themselves had a system which would enable them to work on the same lines they would have accomplished a good deal. The first time this question of costing was raised by the American Association was during the time when he was secretary of it, and a number of men were asked to estimate certain costs. One man gave 2½ cents, another 6 cents, and indeed all the figures given were different. This showed the importance of bringing down the element of cost finding to a point where all could work on the same lines, and have the same methods of keeping costs.

Research Work.

Foundrymen should encourage the work of foundry research. In England they were doing some splendid work, and now they were doing the same in the United States. They were working in committees on special lines of their own, and then there was general work by men from all those committees. He remembered during the war getting in contact with a gentleman who told him of a system practised in Germany. An investigation was made into the coal results at works. The results were sent out in tabulated form, and a man could see whether anyone else using the same kind of coal was getting better results than he was He would then visit the other man's place or would have the information sent to him. In that way he was able to improve his method of using coal, and could save, as was shown in one instance, about one-third of the coal. Such things as that could be worked out by foundrymen. It was being done in this country, and they were doing it to a certain extent in the United States. The electric foundrymen there had got together to carry out research work. They had voted £7,800 a year to elucidate the details of the electric steel foundries, and they found it paid magnificently. Standardisation was an excellent thing to help running in these industries. They had learned by sad experience that it was a good thing to save at the beginning.

Sulphur in Cast-Iron.

Their greatest menace in the foundry business was the effect of sulphur. He had made a good many analyses of the scrap used. About 0.05 per cent. was the average for five years. Afterwards it rose to 0.08 per cent., and during the war they had 0.14 per cent. in their scrap. At the close of the war it was at least 0.18 per cent., and he remembered being in a foundry in Cleveland looking over the analyses day after day, and found as high as 0.21 and 0.26 per cent. of sulphur in the regular work. They had not yet begun to get the castings from the war in their scrap. When they did come in they would be appalling, because they made castings for the American navy from 90 parts scrap and 10 of pig. They made some in which the sulphur was 0.32, and that had yet to come back.

Critical Factors.

His own life experience in foundry work had shown him that there were three critical points. First the materials. The best materials ought to be obtained for the purpose. Secondly, they must see that the good materials with which they started were put through the processes properly and rightly so as to bring out good results so far as the processes were concerned. Then the third great cardinal point was the propagating of the moulds to take good material, melted properly and put into the moulds so that it did its work correctly and made good castings. If they obtained those three things right they were on the road to make good castings.

Pig-Iron by Fracture and Analyses.

On the subject of pig-iron, he would like to say that on the previous day in Sheffield he was shown the finest collection of fractures that he had ever seen in pig-iron. But on this point he would point out that in this country they had entirely different problems, and rather more serious than they had in the United States. In this country they had furnaces making foundry iron which made small tonnages, and if they made 80 tons to-day and 80 tons to-morrow that was quite a different thing to the American practice of making 450 tons, 600 tons and 850 tons a day out of one furnace. The British iron was all good, but some of it was better; all the American iron was bad; but some of it was worse.

He believed in educating the workmen to understand analyses and to work by analyses. They could figure out each item of their loss and see how they came out, and they sometimes found that by paying higher prices for scrap, by getting a better grade, they got fuller value in the metal.

Foundry Coke.

On the question of coke, Dr. Moldenke said he did not know much about British coke, but he had always maintained in the United States that if the coke makers would mix their coals so that those very refined coals running to about 8 per cent. in ash were mixed with those running a little higher, giving an average of 10 per cent., it would be very good for the foundryman. They used a good deal of by-product coke. He always liked it, if they would only take the precaution of making it under very high temperatures.

Question of Sand.

On the question of sand, Dr. Moldenke said that if they kept a record of the amount of castings they obtained from the sand they would sometimes find that the more expensive sand was the cheaper in the end. He divided the processes under three heads. The first was mechanical, which had to do with mechanical engineering; the second was metallurgical; and the third the humane standpoint. He was glad to see that in this country they were perpetuating the art of the moulder, which in the United States was getting lost. At

Mr. Ford's big plant in Detroit everything came to the man. He had to get nothing at all. There was a case where everything was pushed to the utmost limit. In one large American motor car works he would undertake to say that they would find that 25 per cent. of his castings were no good, because just some little things were lacking. There was more mechanical skill coming into the foundry in the United States every day. The 28,000 idle men in Sheffield would be a boon to the United States if their legislators were wise enough to allow them to go in.

The metallurgical standpoint was either unknown or not appreciated by the majority of foundry engineers. In the United States they had many chemists who were metallurgists, but taking results and translating them into the works was quite another thing. Many things were done with them, which, if they merely called in a metallurgist to go over the plants they could immediately show some weaknesses which meant indifferent results.

Safety First Considerations.

With regard to the humane standpoint they wanted to increase the number of moulds per man. They could always consider the interest of the workman in this way; the more money a man could get the better he liked it, but he must give results. He (Dr. Moldenke) would give him two or three times as much money if he turned him out two or three times the amount of good work. The next thing was to deal with the question of danger in the foundry. This question of safety was one which their legislators were taking up more and more. In his experience he had found that if they were to get safety in the foundry they had got to make every man think in terms of safety. Whenever a man did anything he should be trained to say to himself, "Is this safe?" The majority of their losses were borne by regular insurance, and at the present time the insurance companies were spreading a lot of information among the foundries as regards safety devices.

Co-operative Research.

The tendency in the United States was to go more and more for top pouring. The whole thing would appear to him to look something like this: the foundryman, beset by all the difficulties he had, was up to the necessity of keeping abreast with the whole line of information. There were few industries which required so much information as the foundry industry did. The next thing was the necessity for studying each problem as it came along—to consider what were the principles involved. When making tests, said Dr. Moldenke, it was a good thing to take their men into their confidence, for it would be found that they could be of great assistance, and he illustrated an instance of this in his own experience. He would like to get the United States Government to spend 10,000 dollars on trying to find out what happened inside the cupola, and to find what they had to do to get good iron. If they melted on too low a bed or in any way got oxygen in they were going to pay for it in lost castings or in castings which were full of "shrinks," and in castings which were full of little fine blow holes, the result of oxidation in the cupola.

The two places in the foundry where they needed to have the best men were on the cupola platform and in the sorting room. Science was a good thing, but they had to apply practice with it. When they applied the two things together they obtained results. The cupola was the easiest thing to run if they knew how to run it.

Testing Cast Iron.

When a man bought a casting he wanted to know that it was going to do its work. The only way was to break it. That was out of the question, and so the next thing was to test a few pieces. Another way, of course, was to take each casting and put it under pressure. In that way they tested so as to be sure that it was going to be safe. With reference to the test bar, most of them in the United States had come to the conclusion that a test bar, after all, was only the test of the quality of the metal as put into the castings, and the foundryman could still spoil it if he wanted to. But if the quality of the metal was good, and the foundryman knew his business, that was the best the customer could expect. The test bar was used very little in the United States:

The customer was satisfied if he knew that the foundryman had a good reputation.

DISCUSSION.

Dr. Longmuir, in opening the discussion, said that Dr. Moldenke had given them a most excellent survey of American foundry practice. He had told them that they ought in all sincerity to admire the foundry cupola. All he could say was that they did admire Dr. Moldenke and the work that he had done so consistently for so many years for the advancement of foundry practice. Dr. Moldenke and he were old friends by correspondence. Dr. Moldenke was one of the first to encourage him, and three of his early Papers were published under the doctor's editorship. The use of a casting was best determined by a test which approximated service conditions as near as possible. He was extremely interested in Dr. Moldenke's reference to body. In Sheffield, particularly on the steel-making side, body was thought a good deal of. This was equally so in the foundries of Britain, as Dr. Moldenke would realise before he went back. Body, something that perhaps chemists could not define and metallurgists could only guess at, was recognised in what had been referred to as the low-output blast furnaces. There was a great field for research in a study of something that certain irons, whether cast or wrought, do not possess apart from what is known by their ordinary chemical composition. He wished to express his thanks for the treat that branch of the Institute had had that night. He would especially thank Dr. Moldenke for his very clear definitions of what research should be and of the need for research.

Principles Underlying Quantity Production.

Dr. Hatfield said it was perfectly clear that Dr. Moldenke had made a masterly study of foundry practice, and he could only agree with the bulk of what he had said. As an American, they naturally welcomed him among them, and they were a little relieved to hear that the cost of labour had gone up as much in the United States as it had in this country. That rather equalised things, because it was of world effect.

A good deal of the trouble which we thought we alone were experiencing was really being experienced by all the countries, and therefore if the various populations really put their backs into the work he had no hesitation in saying that probably a better world would arise in a few years time than existed before the war. The most important thing that Dr. Moldenke said was said inadvertently, when he spoke of orders for 40,000 and 100,000 castings. That, of course, was the key to the dissimilarity in the methods of production in America and in this country. America was a newer country, and they had learned the value of the centralisation of capital and industry earlier than was done over in this country. He also thought that there were not so many constructive minds in America as here, and by here he did not mean in this country but in European countries. The type of mind such as Dr. Moldenke and Mr. Ford possessed could be found in this country, not in such a high standard of excellence but in greater numbers. That meant that there were more attempts at development over on this side. This country had many small firms; in the United States they had fewer but larger firms, and of course larger firms could give larger orders to the foundry industry. What they wanted to see on this side was more of that system in operation. Personally he thought that the tendency to higher education in America was a very good feature, and he believed it could be said that the same tendency was in operation here. It had been very definitely in operation in Germany, and in the Scandinavian countries, and in other countries, it had been extremely well developed from the industrial point of view and likely to give the Anglo-Saxons a very good run for their money in the next few years. With reference to test bars, there was only one possible ruling, and that was that the test bar was entitled to give to the consumer, to the engineer who was using the casting, a definite idea of the properties of his casting. The engineer was not interested in the fact that the iron in the casting was good iron. He wanted to know what his casting was like, and therefore it was necessary that the test bar should represent the casting. That was the attitude of mind of the British engineer, and if they simply submitted a test piece of the iron they could not expect the engineer to have a sufficient knowledge of the details of the foundry industry to be able to weigh up the various influences at work which in the casting might produce a different result from that which was found in the test piece. As regarded the balance of coke and pig-iron he agreed with Dr. Moldenke, and he might be interested to know that in Sheffield foundries they worked on 1.7 cwts. of coke per ton of iron, which, of course, was quite in line with the best American practice. He agreed that the term "semi-steel" should be discarded. A unified costing system, of course, was really necessary in any industry where there was competition, because otherwise there was very foolish competition. He thought all industries should at any rate exchange ideas sufficiently to have a common basis of calculation. He personally heartily endorsed the truly American sentiment which Dr. Moldenke had put before them, that payment should be by results. In these days when there was so much politics mixed up with industrialism, there were false ideas abroad. It was necessary that if they were to eat they must work. That was a fundamental. He did not know that among Sheffield manufacturers there was a strong desire that payments should be limited. If a worker would only do good work and put the right kind of energy into his work he might very largely indeed enhance the earnings which he could take home. There were difficulties in the way of translating an idea of that kind into practice. but by the friendly and liberal exchange of thought which was going on between the employers on the one side and labour on the other, there was every appearance that equitable conditions would be arrived at compatible for both the worker and the employer, and the net result would be that production would attain a standard which it had not attained before. Then, just as in Pittsburgh, the British workmen would come to their work in motor cars. On the question of testing Dr. Hatfield said that the thing to do, was to cast the test bar on to the casting. The reason for that was that if they cast their test bar on to the casting the speed of cooling of the test bar was determined by the size of the casting, and it was the speed of the cooling which largely determined the strength of the test bar. That particularly applied to cast iron. If the designer was to satisfy the man who was ultimately to use the device he had to show what the strength of the material in his casting was. He had no other way of getting it other than by cutting a test piece from the casting or having a test piece of dimensions similar to the casting cast on. This idea of casting test-bars separately did not appeal to him at all. There was such a thing as confidence between the producer and the consumer, and what they had to achieve and maintain was that confidence. If the principle which he had been suggesting was carried out they would thereby gain the confidence of the consumers who knew something about the business.

Mr. Upton said that if the works managers, foremen, and others in control of foundries in this country would only look after their men and see that a moulder was a moulder and not a labourer, they would get results equal to America or any other country in the world. He did not think that there was a finer man than the British working man to be found anywhere. If he was properly looked after those results would be forthcoming. A large number of cupolas were often in difficulties. The cupola was the basic of all foundry practice, if that went wrong it did not matter what they did elsewhere.

Mr. Ambrose Firth proposed, and Commander Jackson seconded, a resolution of thanks to Dr. Moldenke for his address. This was carried, and the Doctor briefly replied.

LANCASHIRE BRANCH DISCUSSION.

Mr. S. G. Smith said he did not think there was a foundryman present who had not read, in some shape or another, part of what Dr. Moldenke had written, and it was a great privilege to have the opportunity of listening to this address.

Sulphur Reduction by Soda Ash.

One very important point was the increased proportion of sulphur in scrap iron. In England it was gradually rising towards the end of the war and just about a year after the Armistice it reached its highest point, and some of them were puzzled how to remove that sulphur. Dr. Moldenke had mentioned a method which was new to most of them —the use of soda cakes—and he would like more information to be given regarding that. If a soda cake was put on the top of the iron how was that going to draw the sulphur from the bottom of the ladle? Was there some particular way of applying?

Dr. Moldenke had touched upon an immense number of subjects, some of which, each by itself, would have been sufficient for one afternoon's discussion. He himself had had much experience with the question of shrinkage. Those who had read his articles dealing with the problem of the foundry, which had appeared in the FOUNDRY TRADE JOURNAL during the last two years, would see what a variety of matters came into this question of shrinkage. Dr. Moldenke truly said that every important casting had its problem, and what applied to one might not apply to another.

He would not venture at that moment to deal with the question of the test bars, but his view was that a test bar should represent the metal not the casting. He firmly believed that a test-bar could never represent a casting, no matter what its thickness was.

DR. MOLDENKE said in America the percentage of sulphur rose to the highest point after the war, when the foundries were also suffering from the effect of bad iron and inferior coke. In those respects the English foundries were better off than the Americans, who had enormous furnaces producing enormous tonnages. When the soda cake was thrown on the molten iron there was an immediate action throughout. That was proved by the fact that whether a sample was taken from the top iron, the middle iron, or the bottom iron, it was found to be identical in composition.

MR. SMITH: Is it the ordinary raw material?

DR. MOLDENKE: Soda ash, the cheapest.

MR. H. SHERBURN said this was a very proud moment for the members of the Lancashire Branch. Many of them had read the contributions of Dr. Moldenke to the technical journals for many years, and also that wonderful book of his. Contact having been established in that way, they had now the privilege of amplifying it by seeing him and listening to his words.

He thought it was a difficulty with all of them that somehow the problems they were up against often led them to hold pet theories about different experiences, to cherish certain prejudices, and it was very good to have the corrective of Dr. Moldenke's contribution to their knowledge and practice.

The question of sulphur was a very serious one, although there were people who said that sulphur was actually a good thing within limits and under certain conditions. One of the difficulties was that in the first melting in the cupola some foundrymen used a very small amount of flux. What did Dr. Moldenke consider a good average amount of limestone to use, say for a ton of iron? His own practice was rather unorthodox in that he used a considerably greater amount of limestone than any of the friends with whom he had discussed this question. It seemed to him that if the sulphur was kept as low as possible in the first melting, the problem would not be so acute as it otherwise tended to become later on.

He understood Dr. Moldenke to say that he would not use shot iron in the cupola. In foundries which produced very light castings, where there was a lot of hand-ladle work, a considerable amount of shot would accumulate, and this presented a problem. He wondered whether Dr. Moldenke could suggest a better wav of dealing with it than simply putting it into the cupola.

Height of Coke Bed.

Another question he wished to ask had reference to the height of the bed charge of the cupola. If Dr. Moldenke would give them some idea what the height in inches should be, say above the top of the tuyeres, that would be very helpful. Personally he always commenced melting operations with the coke bed up to a certain level. Quite apart from any question of the weight of the coke charged, the bed must be maintained at a certain spot. He had tried lowering the bed, and certainly the metal would come down quicker in the first instance, but at the end of a period there was a tendency for trouble to occur with the tuyeres. The question then always arose whether it was wiser to increase the height of the bed in the first place or to increase the weight of the subsequent coke charges. His own observations led him to the conclusion that it was better to keep the bed well up at the outset, but he would appreciate Dr. Moldenke's views on the matter.

Dr. Moldenke said the height of the bed was not governed by the weight, but it was necessary to consume the proper amount of air in order to get the necessary reaction, and that would be influenced by the height of the bed. The volume of air put into the cupola must never be slackened, as that would affect the position of the bed, but if it became necessary, for instance if the cupola was found to be furnishing too much iron, it could be shut off for a time and resumed afterwards. One could shut off or run the blast as he pleased provided the volume when running was not changed.

Dealing with the question of fluxes, Dr. Moldenke said with very clean metal only 1 per cent. of limestone would be needed. For sprues that had not been cleaned it was necessary to take about 3 per cent.; for very dirty scrap and iron one might have to go as high as 4 per cent. When running continuously, 4 per cent. was necessary in any case, in order that the slag might run below the tuyeres quickly.

Tuyere Ratios.

Mr. Key asked what Dr. Moldenke would consider the correct tuyere ratio for a 40-in. cupola assuming that the blower was of sufficient capacity to deliver the necessary amount of air. Also what blast pressure in inches or ounces would he reckon on for such a cupola?

Dr. Moldenke: Forty inches—that would be about 5½-tons capacity per hour.

Mr. Key: We have melted 7 tons per hour, but we melt 5 tons per hour because with the smaller quantity we get an improved iron.

Dr. Moldenke said the proportion ranged from 1 in 5 for small cupolas to 1 in 10 for large cupolas. The situation was regulated by the volume of the blast. If the proportion of the blast to the size of the cupola was correct, the blast pressure would run from about 7 ozs. up to 16 ozs., depending upon the resistance afforded by the charges to the passage of the air. If they were very slaggy they would naturally resist more.

Mr. Key: Assuming you have got the correct tuyere ratio, what would you recommend as the permanent pressure?

Dr. Moldenke replied that really one could hardly say there was a permanent pressure, because it varied. It would run low at the beginning, and at the end it would run high. The volume gauge was more important than the pressure gauge, because in order to get the proper combustion it was necessary to have a fixed volume of air blown into the cupola.

Bottom Shrinkage.

Mr. Markland asked whether Dr. Moldenke had come across a case where the shrinkage, or the drawing as it was called here, of the iron was at the bottom instead of at the top. In the case of a 3-16ths section with a rib on the top of it he found it was quite hollow underneath. It came right from the surface. He had been much troubled with that, and he thought the reason was that the iron was too soft, but he would like to have the benefit of Dr. Moldenke's experience.

Dr. Moldenke said he was of the same opinion, and he could give one instance of a very long table which had spots. The reason was that they used iron that was too good for the purpose. It would not happen if a lot of scrap was put in.

Mr. J. Hogg said Dr. Moldenke spoke like a Britisher on what was described as the "humane" side, which included the elimination of hand labour and accident prevention. He had been led to believe that America only cared for production, but apparently that was a misapprehension.

Dr. Moldenke's observations about the cupola agreed with the views he had expressed many times. In his opinion, especially where the diameter was small, a simple cupola with a straight shell was the best form, provided one kept the correct height above the tuyeres. If the foundryman followed the directions for determining the height of the bed, there was no need for the elaborate forms of tuyeres which were sometimes seen. As regards the height of the tuyeres from the bottom of the cupola, in his own practice he had raised that to 6 in., but it was done simply in order to hold more metal in the bottom of the cupola. Unless that object was in view it was really a waste of coke to place the tuyeres too high.

Dr. Moldenke said it was important to mix the charges carefully, so that all the ingredients—the pig-iron and the scrap—would mix together properly in every part, so that when melted they obtained iron of the same character throughout.

Vote of Thanks.

Mr. Smith, in proposing a vote of thanks to Dr. Moldenke, said there seemed to be a similarity between him and Mr. Thomas D. West, but there was this difference that the latter was a practical foreman and foundry manager, whereas Dr. Moldenke was a highly skilled technical and scientific man. If Thomas D. West were now living he would be near the same age as Dr. Moldenke. At the "Welcome" dinner given by the National Ironfounding Employers' Federation to the American visitors on the previous evening he (Mr. Smith) had the pleasure of sitting near Mr. R. West, the son of Thomas D. West, who, on this his first visit to England, had been able to procure a copy of the birth certificate of his father, who was born in Manchester. So although he was a great American, he was primarily a Britisher. Indeed, American foundry practice sprang more or less from English foundry practice. Some thirty or forty years ago one could hardly go into a foundry in the United States and not find a Britisher as foreman there.

He wished they could have Dr. Moldenke with them once a year. Amongst themselves they had thoroughly discussed almost threadbare some of the matters which had been touched upon in the address, and they fully appreciated the importance of Dr. Moldenke's remarks. In the matter of moulding sands he quite agreed with what was said about the size of the grains. If they were all large it was good for heavy work, if they were all small it was good for light work, but a mixture of the two was bad for both large and small castings.

Mr. W. H. Sherburn, in seconding the vote of thanks, said it was not a stranger from a foreign land whom they were welcoming, but a man whom many a foundryman knew better than he did his next door neighbour. Looking through some old foundry technical literature of 25 to 27 years ago, he came across one of Dr. Moldenke's letters, which he read with special interest, because it stated what the foundryman would do in the future, and experience had shown that Dr. Moldenke was right. Prophecy helped to bring about the things predicted when it inspired people with confidence to attempt them. Not every prophet lived to see his prophecies verified, and Dr. Moldenke was fortunate in that respect, nor was he without honour in his own country. For more than a quarter of a century, he had been an inspiration to British foundrymen, and had set them reading and thinking. He had let light into the dark corners of the industry. Twenty-five years ago there were many dark corners, and some people tried to keep them dark; if they learned anything, they wanted to keep it to themselves. Dr. Moldenke had done more than any other man to dispel that view, and they wished him success in his future efforts in that direction.

The vote of thanks was carried with acclamation. In replying, Dr. Moldenke remarked that Thomas D. West was one of his best friends, and they worked together. He was an ideal worker; no man could make experiments better, and they co-operated at a time when they had to grope in the dark and work things out for themselves.

OIL SAND CORES.

A Discussion Opened by Mr. W. T. Evans.*

Mr. Evans explained that he proposed to deal with the subject under the following headings:—Sands used, binders, methods of mixing, drying and driers, methods and reasons for using oil-sand cores.

Sands Used.

There are many mixtures of sand used, and each foundryman seems to have his own particular favourite which is no doubt suitable for the work in hand. Obviously some would be mentioned which are not suitable for all classes of castings; it has to be left to the individual to choose the most suitable.

There was no reason for drying sea sand, which everyone is familiar. This can be used wet or dry. Mixtures of sea sand with the ordinary red or new moulding sand of the locality are used, preferably after both sands have been dried to get an even mixture. Sand from the fettling shops, old cores which are gathered up in the foundry and reground, are the classes of mixture with which he was most familiar.

There was no reason for drying sea-sand, which is used with linseed oil and water, but the other sands are better dried before mixing, as this shortens the period of time in the core ovens.

It is not intended to say much about binders; there are now so many on the market, of which some are quite good, but there are few which are an improvement on linseed oil by itself or with molasses. Personally, he had had very little experience with the proprietary binders.

There are several mixing machines which are suitable, those similar to machines used for dough mixing being most familiar.

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*Before the Birmingham Branch, Mr. J. B. Johnson presiding.

The ordinary machine used for mixing and aerating facing sands, either vertical or horizontal, with the double cage, is thought to be the best. The chief difficulty with this class of mixer is that the pegs in the cages get clogged with the binder. The best method of dealing with this is to dismantle the machine periodically and sandblast the cages, which quickly cleans the sticky mess from the pegs.

The machine he had used chiefly for mixing is one with a half-round bottom like a basin with a centre shaft on which is keyed a casting carrying a series of round or square pegs. The worst feature is its simplicity. It will turn out a new mix every five minutes, the quantity obviously varying with the size. It is cheap to drive and costs very little for repairs, and empties itself into barrow, etc.

Drying Sand Cores.

The chief feature of drying oil-sand cores is that they do not require the temperature used for ordinary sand cores, which implies that many more cores can be produced from the same core ovens. Additionally, when dry, they can be handled without fear of breaking. They are more or less impervious to moisture and can be safely left in moulds for much longer periods than ordinary cores, and can be stored for indefinite periods.

For the successful production of this class of core, "driers" are definitely necessary, as the worst feature of some mixtures of sand is that the cores are so easily distorted and broken before drying, and provision has to be made for carrying cores which are not flat by making plates or "sand driers" of the same contour as the cores. This is a matter of experience, and when carried out successfully, first-class cores true to shape are made.

Necessity for Varying Sand Mixtures.

First, as to the ordinary undried sea sand, if this is mixed with linseed oil, emulsified with water, it is suitable for most cores, but chiefly those for light castings; also, such cores as have good "driers" retain their shape, for this class of sand mixture has practically no bond when green and the least touch is sufficient to break a core, and cores cannot be made true to shape unless some special methods are adopted. This mixture is free venting and easily rammed; in fact, it only needs pressing in the boxes with the fingers, but some core-irons or wire are necessary.

To overcome this lack of bond when green, the use of mixtures containing red or other moulding sands up to 50 per cent. are successful. This class of sand can be used with very few core-irons, and in many cases core-irons are unnecessary.

It is better to dry all sand used in this mixture; also to increase the moulding sand the heavier the castings for which the cores are required.

This class of sand will require more binder in proportion to the moulding sand used, and it also requires more ramming. Where cores are under pressure at the bottom of the moulds, there should be no soft places in the cores, but they should be evenly rammed.

This mixture is suitable for relatively heavy castings, such as locomotive, gas and oil engine cores, as it will leave a clean face on the castings. It is easily removed and, being used with few or no core-irons, though rather expensive in the quantity of binder used, it will pay for itself ultimately.

The chief reason for adding red sand to sea-sand is to overcome the risk of distortion and the use of "driers," which are an expensive item for large cores. Additionally, it obviates the use of core-irons and, in most cases, where this mixture is used, cores will have sufficient bond to hold up when green and keep their shape with the minimum of support. Another feature is that cores made with sea sand alone cannot, in many cases, be successfully mended, whereas, when an addition of moulding sand is made, they can be patched up without much trouble. These cores, when dry, will be very hard, and will stand somewhat rough usage. The skin is exceptionally smooth, and there is not the rough finish on the inside of the castings that is often found with ordinary sea sand.

Another feature which recommends this mixture is that, where loose pieces have to be withdrawn.

they will leave without much fear of rough edges, which are not conducive to clean castings.

A good mixture can be made from the dry sand from the fettling shop, which is quite good for light castings, such as small piston heads, etc., or any core which has not to be chapleted, for this mixture will not be strong enough to use without supports or core-irons. All old cores should be collected and returned to core-shop and reground for further use. This makes a core a little stronger than that from the fettling shop sand, and is very useful, and economical, as it uses otherwise waste material. From experience, he felt sure that foundrymen could not produce the intricate cored castings, such as motor cylinders, now called for in large quantities, without using cores made by methods under discussion. There are many snags to overcome by foundrymen commencing to use this type of material.

One great drawback is that, with some binders, there are large quantities of noxious fumes from the cores when casting, and good ventilation is essential. There would be a market for a binder at a price which would overcome to some extent this trouble.

"Driers" made from Sand.

The Branch-President said that, going through some of the local foundries recently with the American visitors, he noticed that at one foundry they had adopted a splendid idea for "driers" or plates to hold the cores when they were in the stove and to prevent distortion. They appeared to have made a sand mould of the bottom end of the core box, which they used over and over again. It was made out of waste sand and broken cores ground up, with the addition of extra linseed oil, and these "driers" were as hard as a brick, and no doubt would last a long time.

Mr. F. Dubberley said he had had over ten years' experience with sea-sand, and he found it was little use explaining its peculiarities to those who were to use it. They had to be found out from actual practice. So far as linseed oil and red sand were concerned, he had never been impressed by their use. It was a cheap method and a quick method, because there was no ramming, but they had to put up with scabs and dirt.

Mr. H. Field said that, in considering whether oil-sand cores were or were not difficult things to make, everything depended upon whether they had standardised processes. Where did the difficulties arise? If they were making their cores from sea-sand, they could not ask for a more uniform material than that. It did not vary anything like so much as red sand, although the latter always came from the same bed. As to the mixing of the sand with the oil, he admitted that they were far from being standardised In mixing sand with oil, it was necessary, if they were to get an effective bond, that every particle of the sand should be coated. It was not sufficient that the materials should be roughly mixed up. As to the drying, there was only one correct temperature, and any variation causes trouble. He agreed that the market was being flooded with core oils. There was a rush of people on the market to-day selling core oils, who thought it was as easy to manufacture and sell core oil as to deal in coal or foundry shovels. These people were not supplying oils which were suitable for making high-class cores.

Mixing Considerations.

Mr. A. J. Marks thought it was essential to look at the scientific principles underlying the process in order to get rid of the difficulties to which reference had been made. There were two practical points which had a scientific basis. The first was the mixing. In mixing a substance like oil, which was usually of high viscosity compared with water, it was necessary to bring each particle of the sand in contact, because the capillary force between the particles of sand was not of so high an order as in the case of water and sand. Any machine for mixing sand, therefore, must have a rubbing action. Machines such as dough mixers, where they were using very different material, were essentially different in principle from machines which would be successful for oil-sand mixing. Any machine which was simply flapping about, or mixing by means of a fork or arm, was producing comparatively little rubbing action, so that that type of machine would be scientifically inefficient in mixing oil and sand. They wanted a machine which would cause the sand to be rubbed. As to the oil itself, the process was essentially one of oxidation brought about by heat. For using the minimum amount of oil it was necessary to balance the temperature with the available supply of oxygen. In purchasing oil for foundry work, it was essential to avoid the purchase of pure hydrocarbon oil, which would require some admixture such as molasses to bind up the particles of sand. In essence, such oils were not core oils at all. They must obtain vegetable or oxidisable oils in order to produce a satisfactory core without undue loss.

Mr. H. Tyson said he was sorry for any coreshop foreman who had to handle oils, because he never knew when he was going to get two barrels alike. The remark applied both to linseed oil and molasses. A man went along well for a time, and then his cores went wrong, there being no doubt the failure was due to the chemical properties of the different oils supplied. As to sea-sand, he considered it was necessary to dry it. His practice was to mix the sand in an ordinary sand mill, which, he thought, was almost as quick as any other mixer on the market.

A member stated that his firm tested oil at the working temperature of the core oven. A weighed sample was placed in the oven and heated for a definite period. It might vary from four to six hours. They placed the sample in a steam oven which could be maintained at a fairly constant temperature, and heated it for a stated time, afterwards weighing the residue. They must not burn the oil. It was purely by experiment that they found that the amount of residue had a considerable influence upon the stability of the cores.

Mr. H. Field suggested as a rough test that, if an oil when spread in a thin layer on glass did not go "gummy" within twenty-four hours it could be discharded without troubling to make cores with it. The test gives more information when compared with linseed oil similarly treated.

Replying upon the discussion, **Mr. Evans** referred to the mixing of linseed oil and water, and said it was desirable to take a square tank to hold two or three gallons, and to put in the amount of oil and water they required and turn compressed air on to it. They could see when it was emulsified, and the method was quite successful. As to drying sea-sand, he said he could not see why the sand should be dried when they were using linseed oil and water. A double-cage mixer was very successful. The speed of mixing was always the same with that type of mixer, and there was no doubt it did its work thoroughly. With regard to the different classes of oils, this was certainly a difficulty where there was no laboratory. In the case of linseed oils, where the foundryman had no one to look after the matter, he advised the use of boiled linseed oil. All his cores were dried at a temperature of about 255 deg. Fah. The question of oils containing hydrocarbons had been mentioned, and he confirmed that he was in favour of using vegetable oils.

Proposing a vote of thanks to Mr. Evans, **Mr. T. Vickers** mentioned that the Cast Iron Research Association was investigating oil-sand cores, and some months ago commenced the investigation of all the literature up to the time previous to the first core-making machine. They could find no mention of any stabilising of mixing of oil and water or oil and sand. He thought Mr. Evans would have enlightened them. He wondered why it was that the experts who told them all about oil-sand cores studiously avoided letting out the secret. He disagreed with Mr. Evans that the tank should be covered. It should be an open tank filled two-thirds with oil and water in the proportion of one-third of oil to two-thirds of water The air pipe should be six inches from the bottom, and just before the mixture was required the air should be turned on and kept going until the top third of the tank was filled with foam. That system gave a very great saving in the use of the oil, but best of all, it made a thorough mixture of the oil with the water and with the sand.

Mr. Tyson seconded the motion, which was heartily endorsed by the meeting.

Lancashire Branch

(BURNLEY SECTION).

DESULPHURISATION OF FOUNDRY COKE.

By A. D. Young (Burnley Gas Department).

A perfect coke would consist of carbon together with very small quantities of hydrogen, but in actual practice it contains a number of impurities, such as nitrogen, sulphur, phosphorus and ash. Sulphur is usually present in amounts varying from 0.5 to 1.75 per cent. To ascertain in what form these impurities exist, it becomes necessary to make an examination of the coal prior to the coking process.

The coal may be said to contain as impurities dirt, shale, iron pyrites, and the ash of the coal substance. The larger percentage of the first three are removed in the washing process, but the mineral ash remains in the coal after washing.

Looking at the occurrence of the sulphur in the original coal, it may be said to exist as four types of sulphur compounds.

Inorganic Sulphur (distributed irregularly).—(1) Pyrites and marcasite, FeS_2; (2) sulphates soluble in dilute hydrochloric acid.

Organic Sulphur.—(1) That present in those portions of the coal soluble in phenol and termed "Resinic" organic; (2) that present in the portions of coal insoluble in phenol, termed "humus organic," and shown by chemical reactions to be related to the humus compounds of the coal substance.

During the coking process the pyrites and marcasite are decomposed into ferrous sulphide, sulphur, and pyrrhotite (magnetic pyrites of composition between 5 $FeS.Fe_2S_3$ and 6 $FeS.Fe_2S_3$). The sulphur is partially retained by the coal, and partly combines with hydrogen to form sulphuretted hydrogen found in the gas. The reaction reaches a maximum between 400 and 500 deg. C.

The sulphates are reduced to sulphides during the coking process, the reaction being complete at 500 deg. C.

The resinic sulphur remains in the coke in a changed form.

The humus sulphur is partly volatilised, part of the sulphur remaining in the coke in a changed form.

Thus it can be said that whilst the coke remains in the reducing atmosphere of the oven, sulphur is present in two forms:—

(1) *Major Portion.*—As a solid solution of sulphur in carbon.

(2) *Remainder.*—As ferrous sulphide with a small quantity of calcium or magnesium sulphide.

During the quenching process the sulphur in the coke is subject to oxidation, a portion of the metallic sulphides being oxidised to sulphates and free sulphur, this free sulphur being retained in the coke, while that in solid solution remains unchanged.

If the coke can be quenched in a reducing atmosphere, no oxidation of the sulphides would take place; and also if coke quenched in the usual way is reheated in a reducing atmosphere, the sulphur existing in sulphates will revert to its original form

Having seen the forms in which the sulphur exists in the coke, the processes and proposals for its removal can be examined.

Roasting Coke.

As explained above, during the quenching process the sulphides are oxidised to sulphates and free sulphur, and fifty years ago Phillipart published the results of his work on the desulphurisation of coke by roasting in air. These results, in the light of present-day knowledge, are not of great use. It must be remembered that any roasting process will not touch the sulphur in solid solution, and only the removal of the sulphide-sulphur would be possible.

A. R. Powell, of Chicago, who has devoted much time to the desulphurisation of coke by air, has shown by his results that the processes necessary are not easy of accomplishment in practical working. Powell first determined the best temperature for the oxidation of the ferrous sulphide in the coke, with the least loss of coke by the process, by passing air over powdered coke heated to certain temperatures as shown in Table I.

TABLE I.—*Showing Result of Powell's Experiments.*

Temperature.	300° C.	400° C.	500° C.	600° C.
Oxidation of ferrous sulphide	Slow	More quickly	Completed in a few minutes	Slow'r than at 500° C.
Loss of coke ..	Nil	Practically nil	Under 1%	Appreciable.

Evidently 500 deg. C. was the temperature giving the best results. Powell's work also showed that any process for the removal of sulphur must be a two-stage one.

Firstly.—The oxidation of the ferrous sulphide into sulphate and free sulphur.

Secondly.—The removal of the free sulphur so formed, which has been absorbed on the coke surface. For the second stage of the process he tried three different methods:—

Vacuum.—Applying a vacuum to the heated coke during the roasting period. Little or no sulphur is extracted from the coke by this method.

Higher Temperature.—Raising the temperature had little added effect in the elimination of free sulphur. The industrial objection to the method is the reheating of the coke mass to a temperature higher than that necessary for the first process.

Further or Secondary Roasting.—By passing air through the coke beyond the point where the sulphides have been oxidised to free sulphur there is some added elimination of free sulphur. The objection is the excessive formation of sulphates in the coke.

He concludes that the industrial elimination of sulphur from coke by air is not practicable, due to the tenacity with which the free sulphur is held by the coke.

Admission of Air during Carbonisation.

Campbell in 1917 showed that the sulphur content of coke made in beehive ovens was not less than that of coke made in by-product ovens, as might be thought from the formation of sulphur dioxide, due to air admitted to the oven in the beehive process.

A writer in the "Gas World" last year, referring to Campbell's writings, proposed the addition of a small amount of colloidal silicic acid to the coal before coking as a means of lowering the sulphur content. The coal ash is basic in character, and, as Campbell remarked, that the sulphur from the sulphates in the coal is not driven off during coking, and, with a basic ash, a low-sulphur content is impossible.

Quenching with Water.

On quenching the coke with water at the expiration of the coking period a very small amount of sulphur is driven off in the form of sulphuretted hydrogen (H_2S).

The effect is only slight, due to the rapid decrease in temperature of the coke, the conditions being the reverse to those required for the rapid evolution of sulphuretted hydrogen. The cooling of the coke at all times must be done quickly, and the decomposition of organic sulphur to form sulphuretted hydrogen takes place only slightly below 500 deg. C.

Possibly further investigation into the quenching of coke may lead to improved results. The above phenomena leads us to consider the effect of steam and hydrogen on the elimination of sulphur.

Elimination of Sulphur by Steam.

The desulphurising action of steam requires a high temperature for the necessary reaction to take place, and, under such circumstances, water gas is formed, resulting in a lowering of the temperature of the coke. This means also a considerable loss of coke, due to the carbon in the water gas so formed.

Any process using steam as a desulphurising agent will thus require the addition of external heat to the coke under treatment to keep up the necessary temperature for the reaction.

The difficulties of keeping a large mass of coke at the correct reaction temperature, together with the capital and labour charges on the plant, will retard practice with this agent.

In all probability the coke-oven manager will give more serious attention to this question as the "steaming" of the charge of partially carbonised coal in the coke oven becomes more common, in his endeavour to obtain a larger yield of by-products.

Under such conditions the coke will be treated with steam before being expelled from the oven, but it must be understood that such treatment will not give a coke free from sulphur.

Investigation into the Question of the Gasification of Coke by Steam.

Pexton and Cobb (Inst. Gas. Eng., 1923) showed the impossibility of completely desulphurising coke unless practically all the coke under treatment is gasified, but that much of the sulphide-sulphur could be driven off in the early stages of gasification, especially when an excess of steam is present. They also remark that the maximum extent to which cokes could be desulphurised with but little gasification of the coke seemed to be governed "within limits" primarily by the proportion of sulphide-sulphur in the material.

Elimination of Sulphur by Hydrogen.

Much attention has been devoted in America to the action of hydrogen and coke-oven gas as desulphurising agents. In coke-oven gas the active desulphurising agent is hydrogen, which reacts with the organic sulphur in the coke, and at high temperatures (1,000 deg. C.) removes most of the sulphur without affecting the character of the coke. The time of treatment by hydrogen would be fairly long, and the practical difficulties many, whether the coke be treated in the oven or afterwards.

Some work has been done in this country on a laboratory scale by Monkhouse and Cobb (Trans. Inst. Gas Eng., 1922) on the liberation of nitrogen and sulphur from coal and coke. Cokes made at 500, 800 and 1,100 deg. C., corresponding to low, medium, and high temperature cokes, were subjected to the action of currents of nitrogen, hydrogen and steam at certain temperature stages. The results on the high-temperature coke are those which directly concern us, and are given in Tables II. and III.

TABLE II.—*Influence of H on the S Content of High-Temperature Coke made at* 1,100 *deg. C.*

Treated with hydrogen gas at a temperature of	Sulphur obtained as H_2S in per cent. of total sulphur of coke.
600°C.	1.8
800°C	11.4
1,000°C.	12.1
	25.3

Sulphur in Coke 1.30 per cent.

TABLE III.—*Influence of H and Steam together on the S Content of Coke made at* 1,100 *deg. C.*

Treated with hydrogen and steam at a temperature of	Sulphur obtained as H_2S in per cent. of total Sulphur of coke.
600°C.	2.3
800°C.	38.3
1,000°C.	26.6
	67.1

The above results show that there are great possibilities in the use of steam and hydrogen for the elimination of sulphur at high temperatures, but from the graphed results (Fig. 1.) the time taken to attain the results is long. This feature coupled with the large plant for practical working will not allow such a process to be a financial success at present.

Treatment of the Coke by Acids.

The treatment of the coke by certain mineral acids would remove the whole of the sulphide-sulphur, the most convenient acid for the purpose being hydrochloric. Unfortunately the commercial qualities contain sulphur in such amounts that the ultimate result would be nil. Acetic acid has been found to give better results than hydrochloric which would be beneficial in more ways than one, as hydrochloric acid, if applied to the coke in the oven, would add further troubles to the coke-oven manager's lot. The acid treatment could also be applied to the coke after discharge from, instead of when in, the oven, but the cost of pure acid renders the process prohibitive at present. Up to the present time no satisfactory solution to the problem of desulphurisation of coke has been found.

Desulphurisation in Cupola Practice.

About five years ago Vollenbruck, in "Stahl und Eisen," gave the results of his practical work in Germany on the behaviour of sulphur in the cupola, and describes a set of experiments dealing with the absorption and removal of sulphur by the different additions of lime in the cupola, as given in Table IV.

Table IV.—*Sulphur Reduction in the Cupola.*

Limestone additions in per cent. of the weight of coke. %	Sulphur content of the cast iron. %	Sulphur content of slag. %	Lime content of slag. %
0	0.124	—	--
3	0.120	0.057	10.90
6	0.118	0.057	13.04
9	0.111	0.061	14.26
12	0.087	0.062	14.74
15	0.083	0.062	16.15
18	0.084	0.062	16.40
21	0.087	0.062	18.36
24	0.084	0.078	19.15
27	0.088	0.116	23.65

The cupola practice was uniform throughout the tests, and charges 1,650 lbs. of large coke, 1,320 lbs. of iron, and 99 lbs. of fine coke were employed. Additions of lime were made, and varied as given above in the trials. The tests were taken 15 minutes after the appearance of the first metal at the receiver, and at the junction of this and the cupola.

The charge had less than 0.05 per cent. of sulphur at the most. The lowest sulphur content of the iron after melting was 0.088 per cent., and of this, 0.03 per cent. comes from the coke and cannot be prevented by the addition of lime (Figs. 2 and 3).

The slag is enriched with sulphur up to an addition of 27 per cent. of lime, but the removal of sulphur from the iron ceases when the slag contains 14.74 per cent. of lime. Further additions

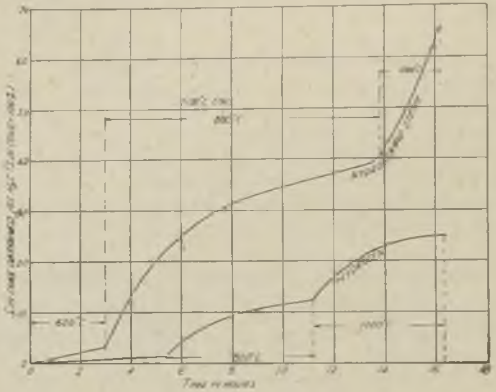


FIG. 1.

of lime are useless beyond this point, as the extra lime only takes up sulphur from the gases leaving the cupola.

Vollenbruck also gives some results of desulphurisation by varying blast pressures, and also results as to the effect of lime and manganese silicates.

DISCUSSION.

MR. PELL said Mr. Young's explanation was a very good one, but perhaps too technical for the purpose of a foundryman, who was not concerned with the production of coke in the oven, except that if the makers could manage to supply a coke with a low sulphur content his problem would be simplified and he would get better results. The practical question from his point of view was, how could he desulphurise a furnace coke which contained much sulphur. His (Mr. Pell's) own experience had been that they sometimes received very poor coke with sulphur far in excess of normal. Was there any means by which that could be removed before the coke was used in the cupola? At the Manchester meeting one member stated that he put a high sulphur coke into the furnace, heated it up, then drew it out of the furnace and quenched with water. In that way he eliminated some of the sulphur.

Another matter which had been a bone of contention for some time was the distinction between two kinds of coke, one from beehive ovens, the other the coke produced after the by-products of the coal had been taken out. Was there any material difference in the constitution of the coke so far as use in the foundry was concerned? They were told that the by-products had a commercial value. Did the removal of them affect the heating properties, or did the beehive oven produce a heavier weight of coke?

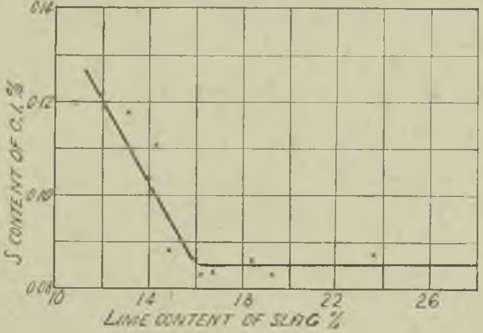


FIG. 2.

Impracticability of Vollenbruck's Work.

MR. JACKSON, referring to the table showing the results of Vollenbruck's experiments with the addition of limestone, said he did not see that they really served any good purpose in foundry practice. It was quite removed from the general practice.

MR. YOUNG, agreeing, said he had included them because he wanted to show that although nothing had been accomplished from the point of view of desulphurisation by coke-oven managers, attempts had been made to do it in the foundry itself.

A small amount of sulphur could be eliminated by heating coke in the oven and quenching with water; it was equivalent to roasting or heating in air and quenching with water. If air was admitted into the furnace for heating the coke over there would be no benefit.

Beehive and By-Product Coke.

He was not going to be drawn into making any statement as to whether the beehive or the by-product oven coke was the better. It was purely a matter of opinion and the treatment of the coal during treatment. But in this country the number of beehive ovens was not increasing, and the by-product ovens were increasing, slowly at present, but the rate of progress would become more rapid. In German practice the beehive oven was practically extinct. To some extent it depended on which type would best suit a particular case.

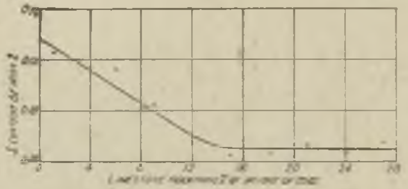


FIG. 3.

Apart from the question of purity, the coke structure was a matter for consideration. A process which left the coke too hard to burn, that is, incombustible, would be useless. A paper read before the Iron and Steel Institute this year by Messrs. Sutcliffe and Evans opened up very big possibilities, and if their statements turned out to be correct the present ideas of the combustibility of coke would have to be altered to some extent. Hitherto the demand had been for a hard quality of coke which would resist abrasion and not break down in the furnace. On the other hand, they did not want a coke which was going to take a lot of burning, because the more combustible it was the more the heat that was given off, and associated with quicker melting. Sutcliffe and Evans took an ordinary well-washed coke, ground it very finely, practically to powder, and under pressure of about 10 tons per sq. in. compressed it without a binder into small oval blocks. It was carbonised in any high temperature plant. They claimed that by so doing they eliminated some of the questions regarding the natural structure, and they obtained a fuel which would burn after the type of charcoal. The property of burning depended to a great extent upon the internal structure.

The Chairman stated that the question of the two kinds of coke was brought up at a recent Manchester meeting. One member who used all sorts of coke said he could not find that there was any difference.

Mr. Young said the smoke problem would have to be dealt with, and probably in time it would lead to the use of smokeless fuel. To a great extent that would cut out a great many beehive ovens in the future.

Mr. Pell remarked that his point was that if it was possible to get equally good coke and at the same time get by-products which had a commercial value, that process should lead to the scrapping of the beehive ovens.

Mr. Young said one could get the same chemical composition of coke, whether it was made by the beehive process or with recovery of the by-products. The difference was that in the one case the by-products helped to supply the heat for carbonisation, in the other they were led from the oven, the by-products recovered, and the gas led back to the ovens. The probabilities were that in the future the necessity for coal conservation would to a great extent force the coke-oven people to adopt the latter in the interests of national economy. The chemical composition of coke made either by the beehive or recovery oven would be about the same if the coal was from the same source and coked at the same temperature. The only real difference would be in the physical structure and its shape. The combustibility of cokes will vary, due to the differences in physical structure.

A vote of thanks to Mr. Young was passed unanimously.

Coventry Branch.

FINE LIMITS IN FOUNDRY PRACTICE.

By C. Dicken.

The foundry trade is one of the oldest and is often referred to as a trade that is never learnt, as it has so many branches. There are so many factors to control, and when everything has been done to ensure good results, batches of castings may be scrapped. The foundry trade is one in which the human element is of greater importance than in the majority of other trades. When considering castings produced years ago, most foundrymen would agree that they were really samples of fine castings of all classes, but it should be pointed out that in those days efforts were entirely centred upon quality, and little consideration given to weight or thickness. If the casting had a good appearance and possessed an ample thickness for machining operations, it was considered satisfactory. Metal was cheap and so weight was not important, but to-day foundrymen are concerned if the casting is one half millimetre out, and, in some cases, it is almost a question of a thousandth part of an inch. The motor industry, especially, calls for fine limits for its castings, and obviously Coventry, being the centre of the industry, is required to make fine intricate castings, almost works of art. The craftsmanship of the foundry is undoubtedly better than a century ago, and it is probable that the foundryman of those days would be incapable of making the sections which so often occur in the motor trade.

Of course, the machine shop too has to work to extremely fine limits. Mass production, finer limits and lower costs are aided by jigs, etc. The only method to secure best results from every point, is to conduct the foundry under strict scientific control. By this is meant the analysis of the component parts of every piece of work. Practical experience has revealed the exact contraction allowance to be given for different alloys. Metals mixed strictly to analysis and cast at a definite temperature by the aid of a pyrometer, cannot fail to produce castings of the most intricate design to within the variation of a 50th part of an inch. Moulding and coremaking machines have been introduced into the foundry to avoid excessive rapping, and yet it is not essential for all patterns to be put on moulding machines to obtain good results. This is usually decided by the number of castings required. In the automobile trade a pattern is often produced the first time for experimental purposes and is altered from time to time and castings tested from different aspects

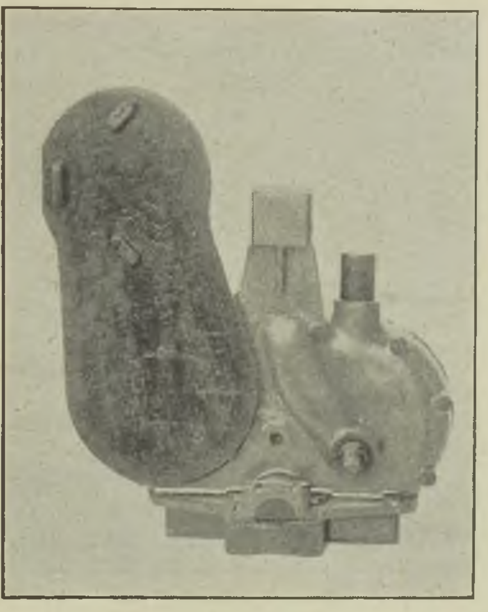


FIG. 1.—TIMING-CASE COVER PATTERN. FRONT VIEW.

until it is decided to use the improved pattern to produce a few hundreds and await results. To place some of these patterns upon a moulding machine in the first instance would mean many alterations and great expense, which would not be recovered unless the pattern was adopted as standard.

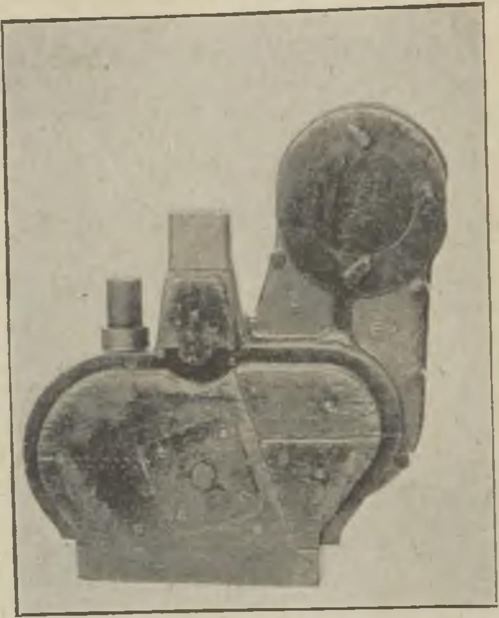


FIG. 2.—TIMING-CASE COVER PATTERN. BACK VIEW.

Sometimes difficulties arise from sand, for too much or too little binder may be present, whilst the quantity of moisture is equally important. A mechanical device has yet to be invented which will assist the foundryman to define the percentage of moisture in sand. In the laboratory and in machine shops, instruments and mechanical devices have been introduced to test the properties of metals, such as those associated with the names of Brinell, Keep, Turner, Schore, and others, but surely a fortune awaits the inventor who will assist the foundryman to test the hardness of a mould. In the case of an intricate cylinder mould it is sometimes necessary to mix several kinds of sand. Some parts require sand with a very small quantity of binder, and in another part of the mould it is necessary to use sand heavily mixed with binder and, at the same time, using mixtures that will promote the permeability of the sand so that the gases may escape freely directly the stream of metal reaches the sand.

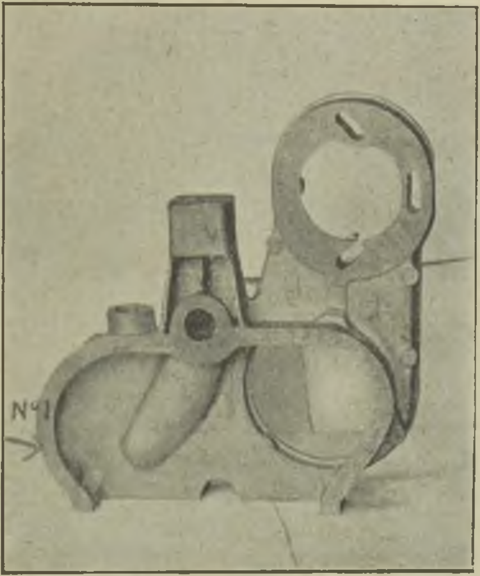


Fig. 3.—Timing-Case Cover Casting.
Back View.

Timing Case Cover.

Some time ago the author was requested to inspect a timing-case cover, the pattern for which is shown in Figs. 1 and 2. The complaint was serious, as about 25 per cent. of these castings were distorted. Aluminium does not distort, and the suggestion was made that they had been hit when hot and so become distorted. This casting had eleven machining operations. After being placed in the jig, the faces were milled to a depth gauge, shown at No. 1, Fig. 3. The casting is then turned over and placed into another jig, and the face is also milled to a depth gauge from the face (indicated at No. 1 in Fig. 4). Thus, afterwards, when the depth gauge is tried into the inside of the face (see No. 2, Fig. 4) it was found to be 2 or 3 millimetres shallow. Therefore the chain clearance was missing which caused the casting to be scrap. To investigate the case the patternshop

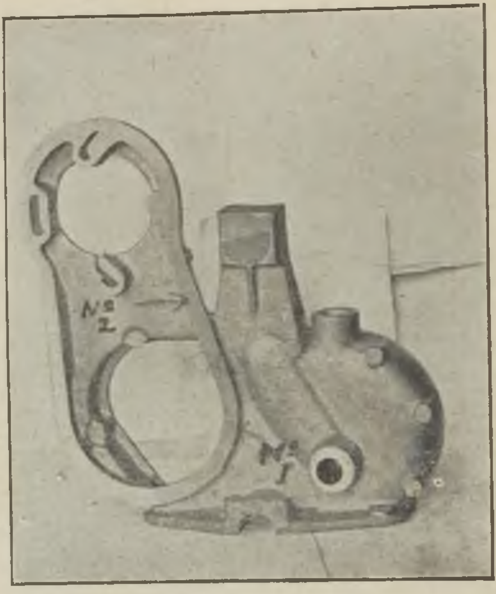


Fig. 4.—Timing-Case Cover Casting. Front View.

foreman was sent for, and the pattern and core-boxes were checked over and were found to be correct. The author supervised the making of a set of cores and also the mould. It was cast, dressed, and machined, and found to be correct. Why should there then be 25 per cent. waste? The author came to the conclusion that it must be the human element. A little later from his office the author heard what he thought to be the excessive rapping of a rapping bar in a pattern. On investigation, it was noticed that the moulder was talking and thinking little of the work he was doing, and was undoubtedly rapping excessively. This was the solution of the trouble. By excessive rapping, the pattern was kicking from 1 to 2 mm., with the result that the bottom core was laid on its print (Fig. 2) and the top core taking its bearing on core No. 1, Fig. 3, causing an extra thickness of metal on No. 1 face (Fig. 4). It is open to question as to whether this was the better way of moulding such a casting, but that, of course, is controversial. Then, too, it may be thought that a moulding machine would have prevented the 25 per cent. waste, but the number ordered would not permit the expense. The chief viewer or machine shop superintendent can point out the various troubles, but it is seldom possible for him to assist the foundryman to define the real cause of it.

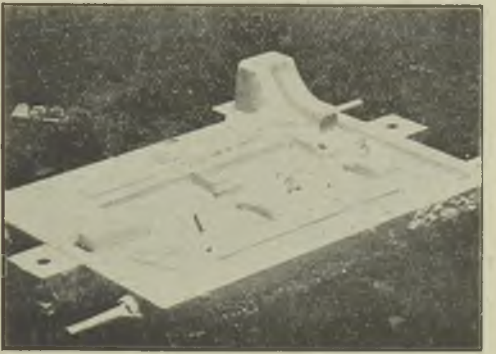


FIG. 5.—MOTOR CRANK CASE. BOTTOM PART.

Motor Crank Case Troubles.

Fig. 5 illustrates a bottom mould of a motor crank case, in which Nos. 1, 2, 3, are the flat prints where the cores are to be placed. This casting required 12 cores. Fig. 6 illustrates the bottom part of the mould with cores erected on it, and Fig. 7 depicts the casting. When these castings were sent from the foundry one could definitely say that they were of the highest quality. They pass through 24 operations. After several of the operations had been carried out, it was found that the flange, indicated by a line in Fig. 7, was 2 mm. thick instead of 5 mm., as stated on drawing. After investigation it was found that the timing end-core (No. 3, Fig. 6) was standing on its end on the flat print (No. 3, Fig. 5). This was a patternshop error, as the end of the core had but one taper put into the corebox to enable the core to leave the corebox clear. This, not being allowed for on the print of the pattern caused the core (No. 3, Fig. 6) to lean outwardly, thus causing the flange indicated in Fig. 7 to be 2 mm. thick instead of 5 after machining.

Fig. 6.—Motor Crank Case. Bottom Part of Mould, with the Cores in Position.

A Striking Fork Difficulty.

Fig. 8 illustrates a striking fork, used in a gear box of a motor. If the illustration is reversed, the fork is on the flat. This casting passes through nine machining operations, chiefly drilling. The first operation (indicated in Fig. 8) governs many more to follow. Actually this casting turned out badly all over. After an investigation it was found that the jig was made to drawing. The pattern being moulded as illustrated, it was compulsory to have a run of taper from the top arrow to the bottom arrow (marked on illustration), so that the pattern would leave the sand. This was not taken into consideration in the making of the jig on the one hand, and on the other, the casting being placed in the jig, as illustrated, the bottom would stand out 1 mm. more than at the top, and thus when drilled would come out thick and thin. Furthermore, this operation being the starting point for others to follow, caused the casting to turn out a waster.

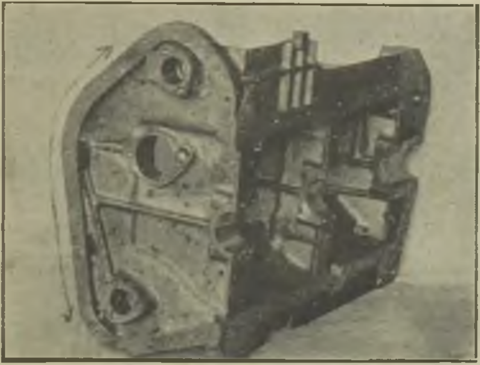


FIG. 7.—MOTOR CRANK CASE CASTING.

A few years ago it was general practice to mark out any casting of importance before machining. To-day ideas have changed, and in our most up-to-date machine shops (especially those laid out for mass production) it is considered necessary for castings to be received direct from the foundry dressing shop, and placed immediately into the jig and to be machined correctly. It is the general machine shop opinion that the small percentage of waste caused by adopting this method is far cheaper than marking out. It is recorded that castings 3 ft. 6 in. long have been scrapped because a pimple has happened to be just on the spotting face. The report was "foundry scrap," of course, although it could have been avoided had the operator seen it first. Complaints are sometimes received concerning castings that have apparently proved correct until they have reached the fifth or sixth operation, and it has been found that the first operation caused the trouble. The casting perhaps has a flange and on this flange it has been run with a spray runner. When designing the jig, the designer has forgotten the runner and made the spotting face right on the runner, of course the casting differed according to the dressing. In many cases, it is foundry scrap made at the expense of the improvements of the machine shop. In the United States it is the general practice to make jigs for the foundry, similar to those used in the machine shop so that each casting may be tried in the jig before leaving the foundry.

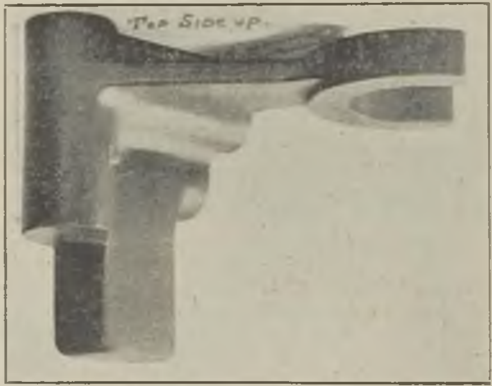


FIG. 8.—MOTOR GEAR BOX STRIKING FORK CASTING.

The Importance of Jig Making.

If made from drawings, the designer is apt to place spotting faces to come just where the joints

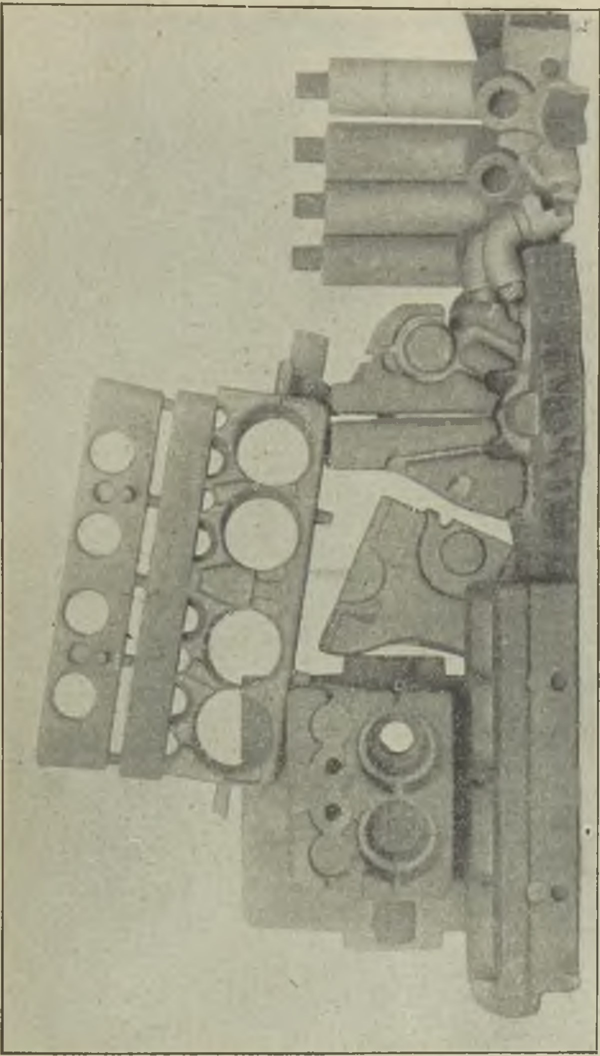


Fig. 9.—Set of Cores for a Four-Bore Water-Cooled Motor Cylinder.

of the casting are. This causes trouble. The dresser on the one hand taking a millimetre off, or leaving one on, will often cause wasters. It is always advisable, as far as possible, to avoid spotting from a position made by a loose core. Jig designers would be well advised, if at all possible, to design their jigs from the actual casting and co-operate with the foundry manager.

Water-cooled Cylinder.

Fig. 9 shows a set of cores for a water-cooled cylinder with crankcase combined. They are the 17 cores used in the making of the cylinder illustrated in Fig. 10. The position of this cylinder crankcase gives a full view of the bores. The end of these bores stand about 2 in. in length above the bottom of the crankcase, so that there are, when machined, 4 bores with webs about 6 mm thick and standing above the crankcase about 2 in. in length, just webbed together. It is most important that these cores fit accurately. Every core when placed into the mould is gauged, to make doubly sure that it is in its exact position. If one of these cores, say the barrel core, should be out of position one-fiftieth part of an inch in No. 1 barrel, it would, when machined, cause No. 4 barrel to be 2 mm. out, so that it would result in the walls being 8 mm. thick on one side and 4 mm. on the other; thus, in the end resulting in a waster. An alteration in a core box of 0.5 mm. has been known to change a waster into a good result.

Many years ago, on receipt of an order for 100 cylinders for the motor repair department, the author sent for the pattern and after making inquiries he gave instructions to a moulder, who had previously made these castings, and told him to execute this order. It was ascertained that there had previously been a great deal of trouble in the machine shop. After having one made, and marked off, it was found to be a complete waster. Upon investigation it was ascertained that the prints of the pattern were a few millimetres large, so that the moulder could place the cores into the centre of the print. When the rough casting was cut up, of course, the thicknesses were fine and regular, but when machined they were out alto-

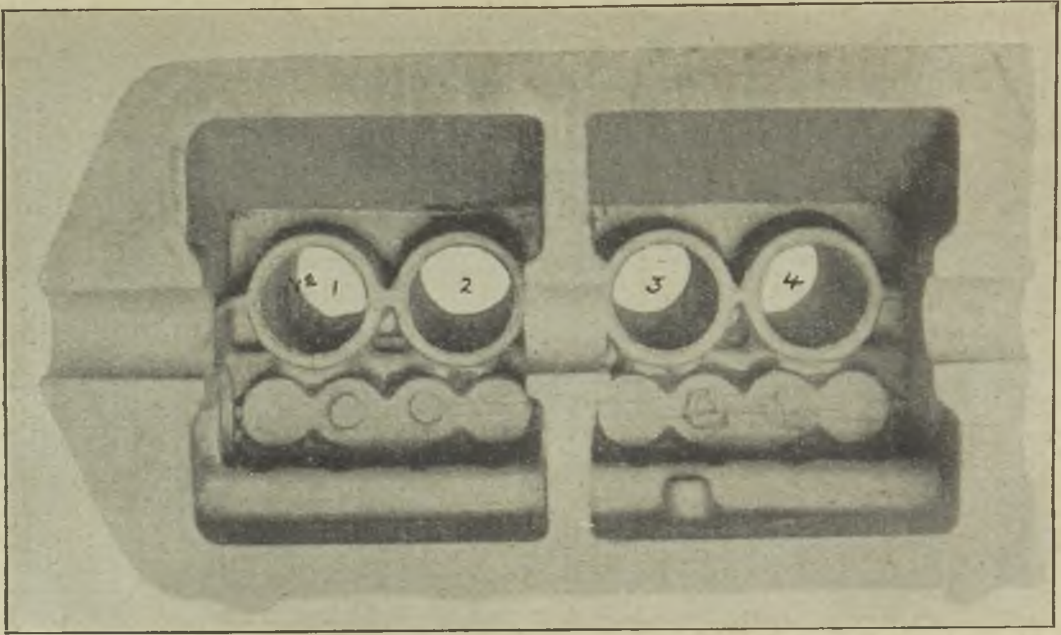


Fig. 10.—Motor Water-Cooled Cylinder.

gether. The prints were then made exactly to size so that the cores should fit quite tightly. After this alteration the pattern proved to be wrong. Finally, 2 mm. had to be taken from one side of the pattern and 2 mm. added to the other side. After this had been done the percentage of good castings increased by large numbers. The slightest oversight, such as a particle of sand the size of a pin's head in a bore, or between a valve, will cause a waste cylinder, yet is it not wonderful that these castings after passing through 29 machining operations and tested up to 80 lbs. water pressure will come out at 90 per cent. good results? There is no doubt that after considering the complaints from the machine shop, and thoroughly investigating, a good percentage of the cause of the trouble can be traced to the foundry.

In the motor industry specifications are usually forwarded with the order, and test bars are requested in the case of ferrous and non-ferrous metals. So far no one has been successful in producing a formula for casting temperature to suit different castings; as the casting differs in design so does the casting temperature need to differ, especially in non-ferrous castings.

Cupola Practice.

Fig. 11 depicts the half-section of a charged cupola, and is an illustration of an American cupola taken from West's text book. The bed of coke should be from 18 to 24 in. above the tuyeres, after which is the melting zone. A few years ago, having charge of a class of students, one evening the author was requested by a student to be enlightened concerning furnace trouble. The moulders had finished work, but the iron was unusually late, and a long time in coming down. The foreman had intended to cast early that day and had given instructions for an extra barrow and half of coke to be put into the cupola, but it is obvious that the melting zone of the furnace is definite, and it does not matter how much coke is placed on above the zone, for it must all burn away, and allow the iron to come into that zone before it is melted. It is not to be assumed that the iron would not be hotter, because the extra coke taking so long to burn away allows the metal

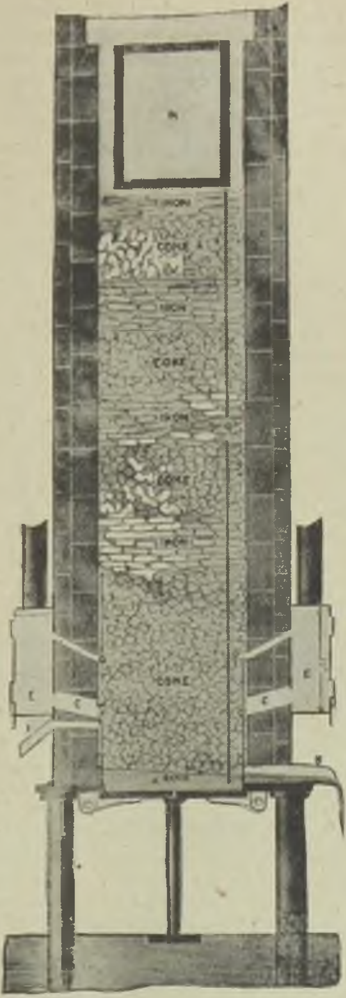


FIG. 11.—HALF SECTION OF CHARGED CUPOLA.

to get very hot before reaching the melting zone. On the other hand, if the bed of coke is not sufficiently high, or is hollow, then the pig-iron would drop in front of the tuyeres and the result would be disastrous. But the most important part of melting is the accurate time of the melting of the charges, and the correct amount of blast. For instance, in two charges, the silicon content of which has been taken in each case, it is well to consider the different brands of pig-iron and steel constituting it, and yet it is essential that all should be melted, no more and no less, and yet there are charges to follow. If these charges are not timed even to half a minute, the test will fail. The author has timed his furnaces for years and taken test bars from every charge and runners from important castings, such as automobile cylinders, and yet he has not erred more than 0.002 per cent.

This method is just as essential for malleable iron foundry as for grey, and, of course, the time it takes to melt a charge is only learned by experience.

A suitable mixture for cylinder iron is as follows :—

Silicon.	*Cwts.*	
1.45 per cent. Scotch	2	2.90
2.74 per cent. Lincolnshire	3	8.22
.25 per cent. Steel Scrap	2	0.50
1.6 per cent. Cylinder Scrap	3	4.80
	10	16.42

1.642 per cent. Silicon.

DISCUSSION.

Mr. Player remarked that Mr. Dicken had touched very widely on foundry practice as carried on in Coventry. He had found the human element very complex. Large percentages of machine shop wasters were very often due to their waiting until after large deliveries had been made before anything was done with the castings. Foundries often received urgent notes from the machine shops intimating that they were so many behind on schedule, and that the machines were held up, and then the foundry worked too quickly and created more scrap. He was afraid that Institute meetings there had little influence on the powerful men in the designing office, the jig and tool shops and the machine shops. If by any fortuitous chance any remarks of his could reach those people what he would like to emphasise most strongly was that there was no greater handicap placed on the foundry in repetition work than the policy on the part of the machine shop of not letting the foundryman have very early information relative to the castings.

Mr. Broughall remarking that hitherto it had been the custom not to discuss the Presidential address, humorously observed that this occasion gave the President an opportunity to say anything he felt disposed without fear of being criticised.

As Mr. Dicken had intimated that he preferred discussion, **Mr. Broughall** said that he thought a better title for the Paper would have been "Defective Castings and How to Palm Them Off on Another Department." They would probably have noticed that whenever Mr. Dicken described some fault in the casting it was either put down to the designer, the pattern shop, the machine shop, or the jig and tool draughtsman, but it was apparently very rarely the foundryman's fault.

Mr. Dicken: I beg pardon. I showed several castings on the screen illustrating defects concerning the machine shop, pattern shop, jig and tool design, and also faults connected with the foundry.

Mr. Broughall, continuing, said that as one who had to supervise both machine shops and foundries, he felt a strong sympathy for both departments. If there would be encouraged a real spirit of co-operation between the various departments, much wastage could be avoided, and he was confident that if they could secure such a desirable thing as a co-operation between the drawing office, pattern shop, machine shop and foundry, the results would be surprising. In fact, no foundry could run smoothly unless this arrangement existed.

As regards accurate castings, they know that the whole secret of obtaining these lay with the class of pattern and core-box from which they had to work. If moulders and core-makers were supplied with good patterns and good core-boxes there should be no difficulty in working within fine limits.

He was rather sorry that Mr. Dicken had touched on cupola practice in the way he had, because he disagreed with much that Mr. Dicken had said. However, perhaps Mr. Dicken would give a paper on this subject at a later period when the matter could be fully discussed.

In conclusion, MR. BROUGHALL congratulated the President on his address, acknowledging that Mr. Dicken had given a lot of thought to his Paper,

Importance of Gauges.

MR. MORGAN WILLIAMS observed that he had of late come across several of the difficulties mentioned by Mr. Dicken which could be traced to the source in accordance with what had been said. It was found that the machine shop was partly responsible, and he had come to a conclusion which entirely supported Mr. Broughall's advocacy of co-operation between the machine shop and the foundry. Going through a mass-production machine shop recently he realised how important it was from the machine-shop view that castings should be as regular in dimensions as possible, because a shop with large quantities being machined in rotation must, to be economical and profitable in production, avoid every source of loss of time. If there were any dimensional defects in castings they straight away increased their overhead charges. Machinists undoubtedly had their difficulties, and foundrymen should do all they could to help them. He had in mind a particular casting for a crank-case of a pleasure car. For the first machining operations, of the four locating points three were formed by cores, and the previous day four castings came back out of a large number delivered which rocked on the supporting pins. There was nothing very much wrong with the casting, but they happened to know from previous trouble how these castings were jigged, and what they arranged for the cores to be set in the moulds by means of gauges. He might say that the intelligent use of gauges had helped them a great deal in difficulties of that nature. Another case he mentioned was also a four-cylinder crank-case, this time for a commercial vehicle. It was a particularly difficult casting to make, as the cores were very heavy to handle, and it was as much as the assembler could do to lift one of the main body cores and place it into its print in the mould. However, the machinist jigged these castings from the core joints on the inside; and he pointed out that in order to get such long castings machined correctly it was of the utmost importance for the cores to be accurately placed. The only way of overcoming the difficulty appeared to be first to check the cores with suitable gauges before insertion into the moulds, and then to check the position of the cores in the assembled mould with further gauges and templates. This arrangement enabled that casting to be machined correctly and provided for due contraction, and in that way they had really been able to overcome many of the difficulties which seemed to be inherent in foundry work. Obviously the machine shops must have accurate castings to work upon, and therefore it was for the foundrymen to use every ingenuity to supply them.

Mr. Judd observed that there was one limit which Mr. Dicken had not touched upon in connection with mass production. They required sound castings which could be machined as easily as possible. In this respect the foundry was up against a difficult problem, especially in Coventry, where it was necessary to get very sound bores in cylinders of various descriptions. It was not an easy matter to do this with soft iron, and it would be a good thing if that could be driven home to some of the superintendents of machine shops. In reference to the mixture to which Mr. Broughall had referred, did Mr. Dicken mean that he had no difficulty in obtaining from these cupola charges a variation in silicon content of only 0.002 per cent?

Mr. Houghton remarked that, seeing the character of the work required to-day, they could not overstress the supervision and care necessary for the production of sound castings. Referring to the human element, he quoted an instance of a large casting being made for which the men were engaged several hours in building their moulds. On examination of the castings, it was found that in each case there was a crack in a thin wall, which was discovered to be due to rapping and the temperature of the metal. Thus three-quarters of a day was wasted for a simple cause.

The Author's Reply.

The President, in reply, admitted that he was rather more fortunate than some people, inasmuch as he was on the spot if anything did go wrong. However, he had similar experiences to Mr. Player in having 200 or 300 castings in the shop before the men started machining, and when owing to defects there was delay. He heartily agreed with Mr. Broughall as to co-operation between departments, and said it would certainly make for efficiency and economy. Regarding the limit Mr. Broughall quoted, they would not obtain this on a cylinder casting or a soft casting. Mr. Broughall explained that it was a carburettor casting, not from a metal pattern, but a mahogany pattern, and thousands of them were made.

Mr. Dicken, replying to Mr. Broughall, recalled that he had shown different slides for different purposes: the first one illustrating the human element and excessive rapping, the second a pattern shop error, the third a jig and tool design matter, the fourth dealt with a cylinder, and then he took up the cupola charge. Now this particular charge represented nothing except to point out that different pig-irons went with the steel to bring up the charge. As to pig-iron with 2.74 silicon and steel with 0.50 per cent., he said that the proportion reached 25 per cent. of steel in automobile work for cylinders, and the result was that they obtained a good wearing material, which has to be machined with a maximum limit of 1.6 per cent. silicon. The minimum is unimportant, it should be as low as machining will allow. Replying to Mr. Broughall's next point that semi-steel was totally different in cupola practice from grey iron, Mr. Dicken said it was so far, but the Americans put steel in all their cylinders for automobiles. Ford put in 33 per cent. (Mr. Broughall: Maclain educated him up to that.) Mr. Dicken next remarked that he averaged 19.16 per cent. Touching on semi-steel, 18 years ago by adding steel bolt heads, say 20 per cent. But as to the differences in the silicon content of the mixture shown, he might point out that pig-irons suitable for automobile work were limited in number. He himself believed in blending, and he had obtained good schedule automobile cylinders at 1.35 per cent. silicon day in and day out. However. supposing he altered his pig-iron and used a brand containing, say, 2 per cent. of silicon, the resultant casting would be such that castings would be as hard to machine at 1.65 per cent. They could use pig-iron of the same analysis and obtain a good, useful casting at 1.4 per cent. silicon. (Mr. Broughall: The point I raised was why make it difficult to get 1.6 per cent.) Mr. Dicken replied that his reasons for showing the mixture were to illustrate the different positions of pig-iron which was put into the furnace every day. There was a high silicon metal and a low one, and the mixture showed the importance of time in charging. As he had indicated, in the automobile trade they could not obtain pig-iron, except in one or two brands, which would bring out silicon at 1.4 or 1.3. Accurate timing of charges, as well as accurate mixing, was necessary if one was to secure reliable and regular results, and, of course, the steel scrap should be put in first, seeing that the pig-iron would melt the more readily. To revert to cylinders, he did not think it possible to get automobile cylinders much within a limit of half a millimetre. He fully agreed with Mr. Williams' remarks relative to every core being placed in the mould accurately, and every department required careful watching. It was so easy to get $\frac{1}{4}$ millimetre difference between the core maker and the pattern. As the mixtures of sand differed, so did the resultant contraction. Sand cores differed in contraction according to the temperature, and they would contract more with ordinary red sand. Replying to Mr. Judd, he might explain that his figure of 0.002 referred to scrap from the charges, but as regards the cupola charges the variation he had obtained was 0.2 per cent. silicon.

Coventry Branch.

TEST BARS.

By Robert Buchanan (Past President).

In considering the function of test bars only those relating to grey cast iron will be dealt with. In doing so it may be profitable to consider how far test bars convey an idea of the strength of the castings to which the test bars belong. It used to be doubted in many cases whether test bars were cast from the same iron as the castings, or the test bars specially treated to give better results than they would give otherwise. However much this practice may have obtained in the past, it is thought with the advance of scientific ironfounding, and a better understanding of the function of the various constituents of cast iron, so far as my knowledge goes these practices have almost, if not wholly, ceased. Engineers had a very suspicious frame of mind as regards the honesty of test bars. The time has now come when they may dismiss these doubtful thoughts. The advance in foundry knowledge permits the foundryman, who knows his business, to produce test bars of any reasonable strength by straight, honest methods.

Over twenty years ago the author wrote an article for the "Engineering Magazine" entitled "The False Witness of the Test Bar." In this article it was shown and proved that even when cast from the same metal as the casting, and when cast separately from the casting, the test bar was not a true indication of the strength of the casting. This was especially the case when the casting was much heavier in section than the test bar. This conclusion was arrived at from tests made on separately cast-test bars compared with bars cast solidly on to the casting and then machined off. Some of the results obtained from the solidly cast-on bars were so low and alarming that they were not published. The author had no cure by which these differences could be obviated or it would have been given. The differences between normal test bars and heavy sections will persist unless the test bars are cast solidly on to the casting and machined off. By doing so there will be some alarming results for the foundryman.

It is pleasing to note that the Institute of British Foundrymen has a Committee on Specifications for Grey Iron Castings, under the chairmanship of Mr. John Shaw, in which an attempt is made to reconcile these differences by having test bars of larger section where castings of weight are concerned.

The main difference in strength between test bar and casting unless they are of fairly equal section, is the development of a larger granular structure in the slower cooling casting. The inspecting engineer requires good, strong test bars, and the machine-shop foreman wants a casting which will machine freely. That means that in the test bar the particles of iron will be difficult to part, and in the casting the particles will be easy to part. The separately-cast bar provides these two conditions of close structure in the test bar and open structure in the casting. Of course, references are made to castings of a section much heavier than the test bar.

Importance of Grain Size in Test Bar and Castings.

There is no doubt that grain-size has more importance than purity of the mixture of iron from a chemical point of view when strength of casting or test bar is a consideration. The rotary casting of pipes and other castings is a proof of this. In the case of pipes made by this process thicknesses have been reduced as compared with sand-cast pipes and yet the centrifugally cast pipes are stronger. This reduction of thickness and increase of strength is simply due to the smaller grain-size which results from the more rapid cooling.

More than 20 years ago the author carried out a number of experiments with test bars separately cast but of varying thickness. The tests were made on transverse test bars 2 in. by 1 in. to be tested at 36-in. centre. Four plates, 2 in. by $\frac{3}{8}$ in. by 42 in. long were cast and then machined to $\frac{1}{4}$ in. thick. From the same ladle the usual test bar 2 in. by 1 in. by 42 in. long was cast. The four $\frac{1}{4}$-in. plates were chained together and broken in the testing machine. They proved to be 40 per cent. stronger than the solid bar cast separately.

A bar 2 in. by 1 in. was cast solidly on to a heavy casting and then was machined off. That bar broke transversely at approximately 20 cwts.

Tensile Test Bars.

Two tensile test bars run from the heaviest part of the casting, one near the casting and the other as far away as was available. The test bar near the casting broke at 5 tons per sq. in. The other broke at 14 tons. When analysed the principal difference between the two bars was the combined carbon. This was lowest in the weak bar as might be expected. The slowly-cooled bar next the casting was the weak bar. In other words, its grain-size was larger than the other. With large grains, rupture readily takes place along the junction of the grains or crystals. In casting a ship's propeller should the test bar be put on the boss or the blade?

I.B.F. Tentative Specification for Grey Iron Castings.

This is a well-timed publication with which everybody should be acquainted. The names of the members of Committee, of whom Mr. F. H. Hurren is one, are sufficient guarantee that the subject has been treated in a competent way by a very able and experienced body of foundrymen and metallurgists. It is not proposed to review in detail the whole specification. The agreement to have a round bar 1.2 in. diameter by 21 in. long, recognised as an International Arbitration Bar, is of importance. It is better than having test bars of all kinds. In one case a transverse test bar 1-in. square-tested at 36-in. centres, is being used. Such a bar is instructive to those using it, but forms no comparison with other tests. In another case a tensile test was made on a bar $\frac{1}{4}$ in. dia. and was taken as representing a heavy casting of 2 tons weight.

The suggestion that the test bars should have diameters approximating somewhat to the thickness of the castings they represent is an important step in the right direction. That a round bar will give a truer representation of the casting than a bar with corners is doubtful. It is certain that a round bar will have fewer internal strains than one which is rectangular. Oughterbridge proved many years ago that the barrelling of rectangular test bars for a few hours eliminated these strains and sent up the transverse tests by a couple of cwts. on bars 2 in. by 1 in. The author proved that for himself by following Oughterbridge's advice. One has to admit that *all* test bars are only approximations to the real character and strength of the casting. Whether one applies physical tests—analytic tests—or microscopic tests, applied to test bars and castings, one can get nothing absolute, but only approximate.

The full details of the proposed specification have been published. Foundrymen will agree that it is a worthy attempt to put the casting and testing of test bars on a surer foundation. Probably there will be some considerable anxiety amongst foundrymen how they are to produce the thicker type of test bar when cast on the casting. However, with the advance in scientific iron founding, these difficulties will be successfully overcome.

Grey Iron Castings for Automobiles.

The author had the honour of being Chairman of the Sub-Committee of the British Engineering Standards Association dealing with that subject, and has pleasure in introducing for discussion the proposed specification for dealing with that subject. The British Engineering Standards Association, and the author, personally, will be glad to receive criticism and advice. In dealing with the relation of test bar and casting, one can get a nearer approximate of test bar to motor casting than is readily obtainable when castings are so much thicker in section than the bars representing them. It is particularly desired to have views as to whether the transverse test bars should be $\frac{1}{2}$ in. or 1 in. sq. The author favours the $\frac{1}{2}$-in. sq. bar at 12-in. centres as it is a nearer approximation to the thickness of a cylinder than is a 1-in. sq. bar.

PROPOSED SPECIFICATION.

Air-cooled and Jacketed Cylinders for Automobiles and Motor Cycles.

The iron to be of British manufacture. No heat treatment to be given after the castings are removed from the mould.

Tensile Test Bars.—With every 10 cylinders which are cast there shall be three test bars cast ⅞ in. dia. These are to be turned down to 0.564 in. dia.—equal ¼ sq. in. in section. To break at not less than 12 tons per sq. in.

Transverse Test Bars.—Also with each 10 cylinders three transverse test bars ½ in. sq. shall be cast and tested on knife edges 12 in. apart, and shall sustain a load of 400 lbs. applied at the centre, and shall show before fracture a deflection of not less than 0.12 in.

Iron Castings for Piston and Valve Guides for Automobiles and Motor Cycles (B. E. S. A. Specification).

Heat Treatment.—Pistons may be subjected to heat treatment at a temperature not exceeding 500 deg. C. after they are removed from the mould.

Tensile Test.—A test piece cast ⅞ in. dia. and turned to 0.564 in. dia., equal ¼ sq. in., shall show an ultimate tensile strength of not less than 12 tons per sq. in.

Transverse Test.—This is similar to that given for cylinders, that is, ½ in. sq. bar, to break at not less than 400 lbs., and give a deflection of not less than 0.12 in.

Provision of Test Bars.—With every 100 pistons, and every 1,000 valve guides, three tensile test bars and three transverse test bars, ½ in. square, shall be cast from the same ladle either in green- or dry-sand according as the castings are cast in green- or dry-sand. The test bars shall be cast as an integral part of the castings when practicable.

Fly Wheels.

Tensile Tests.—With every 100 flywheels which are cast three tensile test bars ⅞ in. dia. are to be provided. These are to be turned down to 0.564 in. The tensile strength not to be less than 13 tons per sq. in.

Transverse Test.—Transverse test bars shall be 1-in. sq. tested on knife edges 12 in. apart, and shall sustain a load of not less than 24 cwt. applied at the centre, and also show before fracture a deflection of not less than 0.075 in. The test bars to be cast in green- or dry-sand if the castings are cast in green- or dry-sand, and to be integral parts of the castings when practicable.

Analytic Limit.

The only chemical limits, and they apply to all the castings under consideration, are sulphur and phosphorus.

The iron shall contain not more than 0.12 per cent. sulphur and 1.20 per cent. phosphorus.

Testing Machines.

The author is of opinion that insufficient attention is given to testing machines to ascertain if they give a correct result when in use. They go too long without being calibrated, sometimes for many years. Some time ago a case came under the author's notice where rejection took place of very important heavy castings owing to the failure of the test bars. On a duplicate set of bars being sent to a University they proved amply strong, and the castings were accepted. This proved that the engineer's testing machine was wrong. Only for this proof a very serious loss would have accrued to the ironfounder.

The British Engineering Standards Association and the author personally will be glad of constructive criticism. He would specially direct attention to the proposed size of the tensile test bars as cast, and the diameter to which they are to be turned down. Also to the size of the respective transverse test bars as related to the castings they represent.

DISCUSSION.

Case of Small Foundries.

Mr. G. E. Roberts said he wished to point out, at the risk of being charged with riding an old horse, that these test-bar analyses always seemed to press more heavily on the smaller firms who had no organisation or facilities for making such tests. Yet these tests appeared to become more and more essential to the larger buyers with a corresponding effect adverse to the small foundries. Now there were many firms who could deal with piston castings and other castings of a similar character—he would not go so far as to say cylinder castings, which he looked upon as a much more intricate job—who by reason of the smallness of their output in the aggregate could hardly acquire facilities which would ensure that their castings should be up to the requirements of the specifications. At the same time there was a tendency nowadays towards the elimination of the smaller foundry in the direction of producing repetition work. Further, while many small foundries were able to secure the output by reason of the tests which were demanded by firms to-day, they seemed rather to be ruled out of the bigger jobs, and were thereby pressed into jobbing work. This was obviously a somewhat grave position for some of the smaller shops, though it would certainly tend to assist other shops where mass production was the order. He thought that the commercial aspect of these chemical and physical tests as they affected the small foundries deserved consideration. However, his experience had proved the necessity for the smaller shops to expend, as far as they possibly could, an adequate sum in order to obtain information as to what they were actually producing, rather than to continue the making of castings, the constituent elements of which they had no exact knowledge.

Tests thought Reasonable.

Mr. G. H. Judd endorsed the point made by Mr. Roberts, saying that it was particularly noticeable when firms were sending out orders to the foundry that they also gave their specifications. And as Mr. Buchanan pointed out, the majority sent in analytical specifications, and he must confess that he had heard very little about mechanical tests. He agreed that the position should be reversed, and that mechanical tests should have the preference. As generally in Coventry the castings were machined to produce a very small thickness, it was necessary that a fairly strong iron should be utilised. He thought that Mr. Buchanan had been largely instrumental in introducing this ½-in. sq. section bar and testing at 12-in. centres in connection with automobile work, and so far as his experience of this class of casting went, he was confident it was on right lines. For many types of castings he certainly thought that an ½-in. square-section bar was much more comparable than one of 1-in. The test laid down by the British Engineering Standards Association of a 400-lb. load to the bar appeared to be reasonable, and should be attained with an ordinarily good iron. Could Mr. Buchanan give any figures of his experience of test bars cast from the same ladle in hot iron and cold iron?

Mr. F. H. N. Lane, B.Sc., A.I.C., remarked that Mr Buchanan and his Committee seemed to have done their work very well, and as Mr. Judd had said, the tests put forward were nothing but what should be obtainable by good work and using good iron. The Committee had cut down the number of tests to a reasonable figure, and although suggestions had been made that they should have a multiplicity of test bars to suit different size castings, he thought that here they had struck the happy medium. Indeed, he did not see that any serious criticism could be offered on the subject.

Mr. Twigger considered that the Committee of the Institute had brought out a very fair specification for test bars. No doubt they had been inclined to cut the number down almost to the minimum, but in his opinion one more at least might have been allowed. Mr. Buchanan had pointed out very explicitly that test bars could never be more than approximate to the strength of the casting concerned, and it did seem to him that in using a 1.2-in. bar for a casting which was mainly 2-in. in section they would get a very much better result than they would by machining a test bar out of a casting. The remarks of Mr. Buchanan on the effect of the grain-size would be appreciated by everybody, but there was another point which occurred to him in connection with this matter. This was that in certain cases it might be desirable in order to obtain a very close grain in their metal to use either denseners or chills, and in that case, if they were to cast the proposed test bar in sand, they certainly would not obtain one which represented the structure of their metal, because their densener metal would be much stronger than the test bar. He regarded the Committee's specification as an honest attempt to place the question of test bars on a much sounder foundation. An interesting point was the effect of temperature. It was possible, he thought, that in casting a test bar, unless they were very careful as to the position of the casting, they might actually cast their test bar with a much cooler metal than they would be using for the bulk of the casting. Referring to chemical specifications, he would like to know whether it was proposed to make any alteration to these specifications in the case of castings which were subjected to a good deal of frictional wear, because he believed that combined carbon was the chief element affected when anti-frictional qualities were concerned. He wondered whether there was any desire on the part of the Committee to insist on this in certain exceptional cases. (Mr. Buchanan: No; there is no clause dealing with that.)

Running the Test Bar.

Mr. Morgan asked was there any mention in the specifications about the size of the runner of the test bar, and was there any direction as to test bars being cast horizontally or vertically. If vertically, should any definite head of metal be used, because if cast vertically in dry sand with, say, 12 in. of head of metal, the density and soundness of the bar could be more easily effected than in horizontal sand moulds.

Chemical Test Conditions.

Mr. F. Hill inquired what the Committee suggested for persuading customers to adopt their ideas on the subject when specifications were sent along for a chemical test rather than a mechanical one. How were they going to enforce a mechanical test if their customers would not accept it. Further, why did the lecturer think that a test bar made in loam was a rather difficult matter to deal with. He himself should have thought it was quite a simple operation.

The President (Mr. C. Dicken, M.I.M.) said the ½ in. bar rather appealed to him in regard to the automobile trade, and he supposed Mr.

Buchanan agreed that it should be cast in dry sand moulds. (Mr. Buchanan: "If it is a dry sand casting."). Did Mr. Buchanan think that a ½ in. test bar with 0.12 sulphur, 1.2 phosphorus and, say, 2 per cent. silicon would come out har on the machine? (Mr. Buchanan: "No.")

THE AUTHOR'S REPLY.

Mr Buchanan, in reply to the discussion, remarked that as to the squeezing of little foundries to the wall which Mr. Roberts had mentioned, it was a singular thing that it was the people engaged in the large foundries who attended those meetings and gatherings of a similar character. The small man who had not the required technical knowledge and skill was the one who ought to attend these meetings more than anyone else. Moreover, his experience of these gatherings was that the personal contact of members was of the greatest possible value, for if a man had a difficulty his brother foundrymen were always willing and anxious to help him, and this quite apart from the lecturer who happened to be giving a paper. If a man was not up to date then it was only a question of time before the economic law forced him out of the business. As to analytical specifications being preferred by engineers, to physical tests, as mentioned by Mr. Judd, he must confess that he was rather surprised at this, because they presumed the engineer knew something about physical tests, while in many cases they did not know all that an analysis conveyed. When they were reading an analysis they had to conjure up a mental picture of what all these combinations of elements meant in the final product, and therefore he repeated that it was a presumption on the part of people to put down an analysis and yet could not indicate to them exactly what was meant by it. As regards the temperature of castings, there was no doubt but that a hot-cast test bar was stronger than one which was cast dull. He was sometimes rather puzzled why this should be so, and he was largely guessing when he stated that it was probably due in a great measure to the condition of the carbon. In casting cast iron at a certain temperature the carbon readily came out of solution, and most of them would have noticed the kish, which was carbon, it always threw off when the metal was dull; he had never seen it do so when the metal was hot; and this fact showed that the metal was ready to give up its carbon when the temperature became lower. It was this dullness which appeared to affect the structure of the iron. Hot metal certainly gave them the best results in the structure of their test bars or their castings, and also afforded the cleanest test. Mr. Twigger had been inclined to criticise the diameter size of test bars mainly 2 in. thick, but this point brought them back to the difficulty which he had mentioned, and with which he understood Mr. Twigger agreed. Test bars after all were only relatively correct, and not absolutely so. They were all seeking for the absolute in various directions, but he thought they were never likely to get it. His view was that the main value of test bars lay in the fact that it induced them to put better metal into their castings than they otherwise would do.

Use of Denseners.

As to the use of denseners, they were only of limited application, and they had still to face the old difficulty of the slow cooling, heavy casting and the quicker cooling test bar. Mr. Twigger had also referred to his query in respect to the casting of the test bar on the casting itself. While truly representative of the casting, whether the result would be conducive to the happiness of the foundryman was another matter. There was no stipulation as to whether test bars should be cast horizontally or vertically. He himself always cast test bars of 42 in. on the flat, with sometimes curious results. Of two bars cast at the same moment from the same ladle one broke at 36 cwt., and the other did not break on a machine which was only good for 40-cwt. In casting a ½-in. bar he saw no objection to casting it horizontally. It certainly was very much simpler than trying to cast it on end. In regard to moulding test bars in loam he thought it was considerably more trouble to do so than in dry sand, and the cooling effect, which was really sought for, would not be any quicker or slower, and certainly not so dirty in sand as in loam. As to Mr. Hill's other query about customers giving them chemical specifications, he was hoping that the specifications issued by the B.E.S.A. would help to convert some of these people, although he was afraid that many of them would be somewhat persistent. He might say that he stuck out for a ⅛-in. bar in automobile work simply because he believed it gave a truer representation of the castings in use than would a heavier section. He would now like to ask them if they were casting a ship's propeller would they put the test bar on the boss or on the blade? That brought to a crux the difference between the effect of the cooling period on the bar. Neither physically nor analytically would they find the test bar on the boss agreeing with the test bar on the blade, which brought them up against the fact that they obtained only approximate results and not absolute ones as between the test bar and the casting. In regard to the exceptional cases mentioned by Mr. Twigger, the specifications left the matter very largely in the hands of the foundry, and the foundryman could work his tests out anyway he liked so long as he kept within those two limits for sulphur and phosphorus.

Before closing the meeting Mr. Buchanan was accorded a vote of thanks.

Coventry Branch.

THE PREPARATION AND TESTING OF MOULDING AND CORE SANDS.

By E. M. Currie, A.I.Brit.F.

There has been within the last three years a great amount of investigation carried out on the properties, occurrences and characteristics of moulding and core sands, especially artificially-bonded sharp sands for core making, and the author does not profess to be able to add much more information to that already published, but rather he has tried to set down his observations and a few results in connection with the preparation and testing of sands, with special reference to those used in the iron foundry.

It is rather unfortunate that a great many founders cannot yet overcome their antipathy to any research of this nature, especially considering that no very expensive apparatus is necessary. The improvements in the resultant castings more than compensate for any slight inconvenience this may entail.

America particularly has realised the immense gain to be derived from the systematic study of sand, and their natural resources require extensive study to prepare the best available material in the most economic way to suit peculiar requirements of the mass production of their specialised foundries, but it should be remembered that the researches of Boswell, Holmes, and others in this country have very materially increased the information on sands now possessed.

The Chemical Aspect of Sand.

Realisation of the characteristics of the various constituents of a sand is an aid to obtaining maximum efficiency from a particular sand; so that chemical analysis, although not absolutely necessary, is of importance when studying the physical properties.

Sand is the result of the natural disintegration of granite, and consists more or less of three distinct substances:—*Quartz*, practically pure silica, the main constituent, which imparts a quality of refractoriness to the sand.

Feldspars, which consist of combinations of sodium and potassium oxides, lime, magnesia, together with some silica and alumina; but these in quantity are undesirable materials, as they reduce the heat-resistance properties of the sand by forming fusible slags under the action of the molten metal.

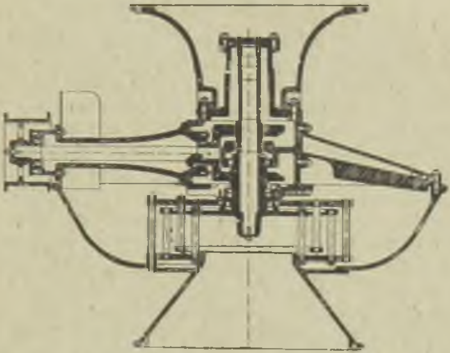


FIG. 1.—SECTION THROUGH A HERBERT CENTRIFUGAL MIXER.

Clay, responsible for the bond of the sand, consists of a combination of alumina and silica, together with hydrated oxide of iron and some organic matter.

For iron, a moulding sand usually contains from 80 to 90 per cent. silica, 4 to 10 per cent. alumina, 0.5 to 1.5 per cent. lime, approximately 0.5 per cent. magnesia, under 5 per cent. iron oxide, and the alkalies together not exceeding 3 per cent. For most non ferrous metals the sand may contain higher percentages of iron and lime without detriment. The greater the amount of silica, the more refractory is the sand, but a sand with a high percentage of silica, say over 90 per cent., is deficient in natural bond.

The main part of the bond is supplied by the alumina, the quantity of which is important, as an excess of alumina—under which conditions an excess of organic matter is also likely to be present—tends to reduce porosity, a most desirable quality in sand. It is essential also to note the percentage of iron as iron oxide, as although it aids the bond by its property of retaining moisture, in the presence of the other elements, it tends to form a slag.

The Mechanical Testing of Sand.

Mechanical analysis is probably more easily interpreted by the practical man, to whom a knowledge of the proportions of the grain sizes is of value in comparing different qualities of sand. There has been a great deal of controversy over this test, and many widely varied methods have been put forward. By this it is meant that the principle of the methods is identical, but the procedure differs. A dissertation on this would occupy too much time, but it is intended to mention the two main methods, which will be designated as the dry and wet methods.

In the latter a weighed quantity of dry sand is mechanically agitated with water for some time, and then washed through sieves of 30, 60, 90, 100 and 200 mesh with a jet of water. The contents of each sieve is then dried and weighed, and the amount retained on each is given as a percentage. The alternative method is to dry the sand at 105 deg. C. for approximately an hour, and is then graded through the sieves until no more will pass through each, and the percentages retained on each is again determined.

By this method the grain size is obtained larger than it really is, due to the coating of the larger grains by the silt and clay, *i.e.*, through 200-mesh grade, so that while there is much to be said in support of the wet method (including elutriation, for accuracy), there is no necessity from the founder's point of view to adopt these refinements, and the dry method will yield all the information necessary.

It is easy to understand that a sand of rounded grains of uniform size is far superior to one which has its permeability impaired by a large quantity of small grains packed in between the larger ones, and as the smaller grains contain relatively larger proportions of the impurities—that is, the alumina, iron oxide, lime, and the alkalies—it will be seen that refractoriness is impaired, and is liable to cause trouble due to the burning-on of the sand. Viewed from the moulders' standpoint, fine-grained sand is preferable, as it gives a good surface finish when being tooled.

Sand Mixing.

It is only within the last fifteen years that sand-mixing apparatus has had the attention it deserves. An even distribution of a thin coating of the bond on the sand grains is the aim of mixing, but the mechanical means available for doing this introduce other conditions.

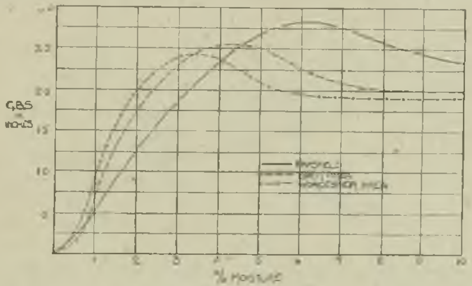


Fig. 2.—The Cohesive Power of Sands Varying Water Content.

Pan mills, once regarded as the most efficient machines for mixing, have undergone many modifications, notably the substitution of a cogged for a plain roller. This ensures a more perfect blending without exercising a crushing action on the grains, which develops the evil of loss of permeability, and which necessitates the use of more tempering agent and additional bond. The general effect of milling, as is well known, is to toughen the sand by even distribution of the bond, but a great disadvantage lies in slowness of operation; and whereas it is necessary, in the case of sands for steel or synthetic moulding sands, it can be dispensed with for iron. With the large quantities of sand dealt with in iron foundries, it has been recognised as necessary to adopt a more speedy and economical means of mixing. To attain this object the various types of centrifugal mixers, such as the Herbert centrifugal mixer, shown in Fig. 1, have found favour amongst foundrymen in general.

The Tempering of Sands.

To a less extent are used sand cutters, mechanical riddles and paddle mixers, but these find particular rather than general application. Whatever the type of apparatus used, however, in addition to the thorough mixing of all the ingredients, new sand, used floor sand, coal dust, and manure, chaff or any other materials, it is very necessary to temper the mix evenly, and one of the easiest and best ways of adding the tempering agent is by means of a spray.

Fig. 3.—Apparatus for Testing Green Bond Strength.

Unequal distribution of moisture is a cause of weakness in a mould every part of which should be equally strong to resist casting strains; in the cope especially, when it supports large hanging bodies of sand. Wet spots also do not permit the passage of gases evolved during casting, and, as is well known, are a fruitful cause of scabs and blowholes. Thus it will be seen that the manner of addition and quantity of moisture in the sand mixture are most important. As small a quantity of water as possible to obtain the desired cohesion should be used. All types of sand do not require the same amount of moisture to develop maximum cohesiveness, and the correct amount to develop the full bonding power of the clay in the particular sand in use is of importance.

The results of tests on three different types of red sands, considered from the point of view of altering the moisture content, indicated that the maximum figure is much less than each sand could absorb without losing its shape. This is shown graphically in Fig. 2 and the apparatus used in Fig. 3.

When one considers the number of different ingredients, all interdependent, forming a sand mixture, any one of which, without care in addition, is a possible cause of trouble, and the various mixtures that a progressive foundry requires, it will be seen that adequate supervision with frequent check tests is necessary in the sand-mixing department. The preparation of the various mixtures is not an inexperienced labourer's job. He cannot be expected to realise the importance of his work and its relation to the finished product.

Take for example the addition of used floor sand to the mixture. This sand should be reasonably free from shot metal, excessive coal dust, core or burnt sand, but often the mixture is made up, day after day, in the same proportions, with no regard for the continual weakening, until the trouble is forcibly brought to notice by an increasing scrap bill, of scabbed castings, drops in the mould, and excessive patching and nailing by the moulder.

Again, to the other extreme, excess of bond obtained by the use of too much new sand results in increased fettling costs and waste of new material, although it is admitted that in these days of rigid economy this is less likely to occur than the former trouble. Maintaining uniform conditions from day to day is the sole means of producing first-grade work with minimum loss. Thus it will be seen that a check on daily mixtures, or on new sand, by a simple test such as the dropping test, is of distinct value. If at first the test does not produce startling results, it must not be condemned. The greater the number of results intelligently studied, the more value the test becomes

Sharp Sand and Binders.

Although the use of sharp sand and artificial binders has been in existence for some time, conflicting results, obtained by the use of the various binders, has caused mistrust, due to their possibilities and peculiarities not being properly appreciated.

The class of sand used for this type of work differs from those described previously, as it contains very little or no natural bond, and consists mainly of pure silica grains of fairly uniform size.

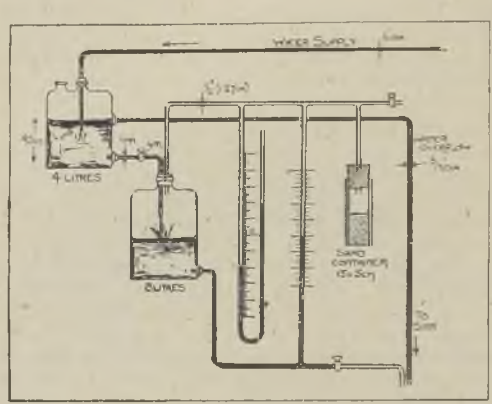


Fig. 4.—American Testing Arrangement for the Permeability of Sands.

It is not generally recognised that the aim should be to use a minimum quantity of binder, and unless the grade of sand is uniform, clean, and the grains rounded, not only will an excess of binder be necessary, but the permeability of the core will suffer. Shore sand, river sand, and pit sand form the available material. River and pit sand are liable to inclusions of earthy matter, and usually have a slight clay bond, which must be neutralised by, since it will not combine with, an excess of the binder.

Dune sand, although actually sea sand, is better than ordinary sea sand, the action of the winds tending to round and grade the sand, and to separate some of the shell, which is detrimental when in large quantities. The decomposition of the shell under the heat of the molten metal, forming carbon dioxide, together with the gas from the excess binder necessary to give strength, overtaxes the porosity of the core and results in the formation of gas holes. Sea sand also contains particles of salt in no small degree, and the decomposition of this substance during drying causes cracks to appear, distorting the finished core.

The number of different binders which have made their appearance within the present century is legion. Often a binder is sold without any attempt on the seller's part to assist the foundryman to obtain the best results from the binder in question. Practically every binder on the market can be classed under one of three headings:—(1) Oil binders; (2) water soluble; and (3) dry binders.

This classification is admittedly crude, but it is sufficient to designate the various types.

The oil binders comprise linseed, resin and other vegetable oils, and some fish oils.

The chief characteristic of the vegetable oils is their power to "dry" or assume a gelatinous form under the action of oxygen. This power is exhibited in a lesser degree in the fish oils, but practically non-existent in mineral oils; hence the inability to use these as binders. The main examples of the dry binders are resin and pitch and similar substances, which bind by simply melting and flowing between the grains. Cement has also been tried, but its use is not recommended.

Resin has a low melting point, and at 300 deg. C. forms pitch and a gas, most of which passes up the vent. Owing to this property, resin is of most use for coremaking for high-contraction metals of moderate melting point. The water-soluble binders are by far the largest class, and comprise molasses, treacle, flour, glues and the waste products from the paper industry, sulphite lyes and chemical compounds such as silicate of soda. The binding action of this class differs from that of oils. In this case, gums are formed upon evaporation of the water content, which set hard under the action of heat during drying, and, if exposed for sufficient length of time, char to a carbonaceous residue.

It is important to note that the change from the hardened gum to the charred mass is much more sudden in the case of water-soluble binders than with oils, in which the oxidised oil film is also charred. It therefore follows that the range of drying with the former binder must be given closer attention. One of the chief disadvantages of water-soluble binders is their tendency to absorb moisture if left in damp places. With this class of binder, drying of the sand prior to the admixture of the binder is more essential than with oils.

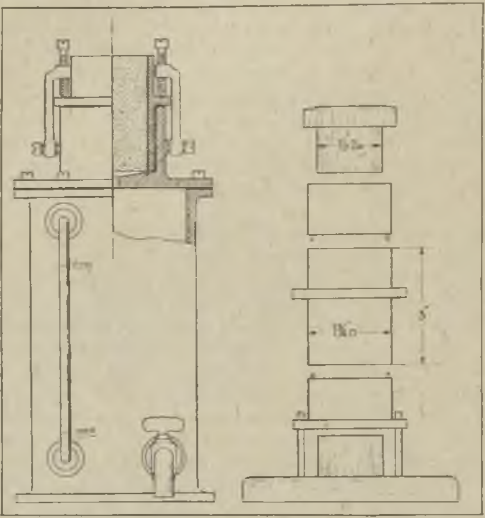


Fig. 5.—A British Apparatus for Testing the Permeability of Sands.

Emulsification of oils, undoubtedly an aid to rapid and thorough mixing, is by no means essential, and where means of drying the sand are not readily available, no trouble should be experienced if the mixing of the sand and oil is carefully controlled.

Oil Sand-Mixers.

A much better result is obtained by mixing in the correct amount of moisture, and this can only be done accurately by first drying the sand. It is not proposed to discuss the various types of oil sand-mixers on the market. Foundry technical journals have descriptions and illustrations of them, but many fall far short of producing the ideal mixture; one in which maximum cohesion is obtained with minimum quantity of binder and without detriment to the venting properties. This can only be accomplished in a machine that, by a pressing and rolling action, spreads the binder evenly and thinly over the sand grains.

The requirements of different foundries make it difficult to lay down a series of tests that would be of use to all of them, but there are one or two that everyone has in common. Usually the moulder takes a handful of sand and judges by feel and fracture, but as every moulder has his own ideas as to what is correct, it frequently happens that, when less obvious wasters occur, the sand is left out of consideration.

Apart from analysis and the dropping test previously mentioned, the only other tests worth considering in a practical way and which, although affording a great deal of information, do not occupy much time, are those of the transverse test on a dried core and permeability.

Transverse and Permeability Tests for Sand.

The transverse test finally adopted by the author after many experiments with tensile and compression tests, is carried out on a carefully-rammed core 1 in. sq. by 9 in. long, tested between 8-in. centres. Although criticised by many on account of its size, it has been found to give over a lengthy period very consistent results, and gives all the information on strength necessary when using sand in the dried state.

At the American Foundrymen's Convention of this year the committee on moulding sand research put forward a standard apparatus for the permeability test. It must be understood that permeability is distinct from porosity. By porosity is meant the volume of air space between the grains, and depends on size, shape and quality, *i.e.*, proportion of quartz to clay of the grains, moisture content and density of ramming. This is relatively unimportant compared with permeability, by which is understood the property of the sand readily to permit the passage of gas through the connected pore spaces.

The construction of this apparatus (Fig. 4) makes it a laboratory instrument, and, although testing is usually looked upon as laboratory work, for those foundries unable to maintain a department of this kind, some more substantial appliance is required. A British instrument has been designed to withstand rough usage, and has given reliable results on consecutive tests, which, it should be emphasised, is the essential factor with any test. This is illustrated in Fig. 5.

Although a systematic investigation would reveal data sufficient to offer standard results required for various classes of work, it would necessitate much time and experiment. On the other hand, the information could be collected and expanded by a group, or even foundrymen in general, and the ultimate result would be more complete in addition to its much easier application due to the groundwork being more thoroughly understood.

Available methods of testing are admittedly open to improvement, but it will be only by co-operation and fair trial to all reasonable new or improved methods that foundrymen can hope to accumulate the very necessary inside knowledge on this subject of sands.

In conclusion, the author wishes to acknowledge his indebtedness to Messrs. Alfred Herbert for some of the slides, and to Mr. E. H. Broughall for the facilities offered to enable him to prepare this Paper.

DISCUSSION.

Sand Preparation.

Mr. A. Harley, commenting first on the very gratifying attendance, said it showed what a little propaganda work among members of the foundry trade could do. He had arrived at the conclusion that defective sand preparation was responsible for a greater percentage of scrap than any other cause whatever. The proper preparation of sand presented some difficulty where there were, as in many instances in Coventry, composite foundries; that was, foundries which dealt with about four different metals, and in the case of each metal turned out a large number of different classes of castings, all practically under one roof. They were very much aware of this difficulty owing to the troubles that occurred periodically, most of which he thought could be traced to sand. Of course, in the old days every moulder was an expert in judging sand. In his old days at Coalbrookdale a moulder of high-class work would have been insulted if anybody but himself had been requested to prepare his sand. That was his own job, and a very important part of his work. While he did not put forward that this was a practice applicable to present-day mass production methods, yet it was worth noting that in those days, when the moulder knew exactly what he wanted, the result of this knowledge was that there was a very small percentage of scrap traceable to unsuitable sand. However, it was necessary nowadays, owing to the altered conditions of production, to have sand prepared for the moulder in bulk; and he was certain that the industry would be required to give a great deal more attention to the apparatus in use for this purpose. His view was that moulders of to-day should take a more intelligent interest in their work so far as the kind of sand they were using was concerned. Indeed, he might be exaggerating, but he might almost say that the average machine moulder would use mud if it were given him. Now if a moulder were able to judge sand when he felt it or after he had moulded one or two castings reported on any defect, it would form a very important check on the operations of the sand mixing department. Perhaps the most important developments during the last 15 years or so had taken place with regard to silica sand, and in his own foundry silica sand cores had been used for about that period with uniform success. He might confess that he had retained the binder with which he started, for he had tested innumerable artificial binders, and had given them up, because he had discovered on testing many of them that if they did what was claimed for them, the cost was invariably higher.

Sand Binders.

The binder he had used for years was the treacle soluble binder, and they could make all sorts of silica-sand cores with it, including a six-bore cylinder jacket, which was a fairly large cylinder. The only trouble that they had had, and eliminated years ago, was distortion. There were machines on the market which increased the ease with which these binders were mixed with silica sand, and to-day his firm used a mixer which did the work in about a tenth of the time taken by a man, and also did it better. If they were in the habit of using these sticky forms of binder mechanical means of mixing was a great advantage and ensured uniformity. He did not care for sea sand, and he noticed that Mr. Currie had remarked that Leighton Buzzard sand was not usually employed for core making. But years ago he himself found it so good that, like the man in "Punch," he had used no other. It was better than sea sand, and he had found this sand better graded and more uniform in grain than sea sand, with no lime content which might arise from broken shells. Mr. Currie had given a very practical Paper, and one that every foundryman should be interested in.

Experiences with Various Sands Detailed.

Mr. Drake observed that as regards Mansfield sand being good for moulding, his experience was that it was a little too close. Wolverhampton sand he had found excellent. For cast iron, aluminium, brass and various other mixtures of metal he had seen none to equal it. He very seldom found any scab resulting. Something might usefully be said about coal dust in the preparation of moulding sand; it was a very handy material, and they could not do much without it in many cases, for it contributed to the making of really good castings. As to Leighton Buzzard sand, it was among the best, and had the merit of being uniform. He believed it could be had in grades from No. 1 to No. 8, but the first two were more fit for sand blasting. However, Nos. 5, 6 and 7 were very fine, and quite good. Among vegetable binders, he had found treacle extremely efficacious, but he had never yet seen fish oil used for the purpose without another ingredient. Perhaps patent brands of treacle were better, but he could assure them that if they worked the fish oil with treacle or some such binder they would obtain a harder core and one quite as porous, and at the same time avoid scab and blow holes.

Mr. Williams asked what was the percentage of sand constituents for different sizes of castings and different kinds of castings, non-ferrous and ferrous. As regards binders, he thought the majority of them had heard of Glyso, which had been used in his firm's foundries for a number of years with very great success. It was a perfect binder for small cores. One feature about it was that when they came to extract the sand from the inside of the casting it disintegrated so easily that there was no trouble whatever in cleaning the casting.

Mr. Beeney wished to obtain information upon one particular point, because the lecturer had said that good porosity did not necessarily mean good permeability. At first sight it would seem that the sand which had large, well-rounded grains would possess good porosity and also the required permeability, and he did not quite see how the difference came about. Did it occur through the distribution of the binder, or was it due to some other factor?

Coal Dust and Weight of Castings.

Mr. Axby (a visitor) expressed thorough agreement with Mr. Harley as to scrap caused by sand. One firm making a very intricate casting for submarine cylinders, built up in five jackets all on top of one another, had tried to make it with several patent binders and different sorts of sands, but it was found necessary to go back to the old-fashioned core sand to avoid turning out scrap. In a shop where a good many change wheels and fly wheels in connection with gearing were made all sorts of sand were tried, and they had found nothing better than Mansfield sand. Regarding Mr. Drake's point about the use of coal dust, it was a question of the amount of metal to be poured into the mould. In castings weighing three or four tons, and also with change wheels for lathes, he had never used any coal dust.

Change wheels were cast green, and no scrap was obtained. Moreover, they had perfect teeth. His experience had shown that they could make castings easier and with better results by adopting the old-fashioned methods, and, personally, he did not lay great store by these patent binders. A person who had considerable experience in these matters recently stated that patent binder sands were detrimental to the casting, and that he would defy any moulder to turn out as good a casting as regards its condition with any artificial sand as with old-fashioned methods. He would like to know whether this was really so or not. The lecturer had raised some interesting points, but he must say that the old moulders knew how to mix their own sand, and he wished this practice were followed to-day.

Mr. Drake agreed that for making cast-iron fly wheels, coal dust had to be eliminated, but pointed out that the castings were of a very heavy type. The coal dust which was near the metal burned into the sand, and therefore scab resulted.

Mr. Axby replied that it was not mixed sand. He was against using coal dust in any sand that had to be dry and porous, because it was unnecessary. The only reason for putting in coal dust, which must be done sparingly, was because if the sand happened to be slightly wet it helped to take away the steam. He had tested it many times, and had found that it was not required in half the cases in which it was used. For if coal dust was added to sand which was dried what good could it do, seeing that it only came out again as ash. However, to face with Mansfield sand would be an expensive job.

Mr. Elson urged that much depended on the efficiency of the moulder. It did not matter what preparation of moulding sand or core sand one used if the moulder was inefficient; for as to coal dust, it was certainly useful in getting the steam away, and he asked them to think what would happen if they did not provide for this. In making cylinders in green sand they never knew what it was to get scab from one week-end to another. A great deal also depended on the material. If they had a good preparation of sand not evenly rammed or not properly blended they would not obtain a sound casting.

Sand Mills and Paddle Machines.

Mr. C. H. Judd observed that there was an interesting case that week which had come under his notice of mixing silica sand with binders: one in the old style of the pan mill and the other in the modern paddle machine. The same quantities of Leighton Buzzard sand, with linseed oil and treacle, were used. In the pan mill the sand came out perfect for core making in the sense of binding and holding in of the core box, but in the other machine the sand came out and would not bind together. In fact, if it were squeezed in the hand it fell to pieces. In the first case there was quite a good bind and a perfect core. This seemed to favour the old-fashioned method as being better to a certain extent than the modern method, but he must say that the modern machine apparently did its work satisfactorily originally. He wondered if the lecturer had had any experience of these machines in turning out core sand and of the trouble which his foundry had come across only that week.

Mr. C. Dicken, M.I.M. (Branch-President), referring to the methods of the old moulder, recalled the case of an old craftsman when he was apprenticed who made it his practice to mix his facing sand for moulding on a Saturday ready for the following week's work. That moulder always believed in letting the sand stand by for a time, and covered it with a bag, the idea being that it would then become moistened throughout equally and not be likely to fall away. So far as treacle was concerned, he mentioned that his father and grandfather used sugar before these modern improvements were introduced for coring purposes. The Wolverhampton sand which had been mentioned was really Wombourne sand, which was obtained from just outside that town, and it could well be compared with Stourbridge sand. The lecturer had placed several mixing machines on the screen, and he wondered whether any of them could take the place of the old sand mill, because he noticed that one type was a mixer and another type was a refiner, and in some instances they could not do without refining the sand. In the case of the transverse test, using a core 1 in. sq. by 8 in. long, was the object to ascertain the hardness of the core, because surely that was regulated by ramming or the moisture content? For cores made on a jolting machine, the core boxes were fastened on, and the moisture in the sand or the ramming depended on the number of jolts, which thus regulated the hardness of the core. They found that if the moisture was a little too much the core would come out heavier. Each core was weighed, and if it was over ¾ lb. they could rely upon it scabbing, but if under good results could be guaranteed. The lecturer had evidently taken great pains, and put some real hard work into his Paper.

THE AUTHOR'S REPLY.

Mr. Currie, replying to the discussion, thought that most of them would agree that the preparation of sand by a man always on the job was much better than leaving it to the moulders to make the different mixtures when they thought fit. By that method greater production was obtained, and they could scarcely expect to trouble the moulder with the job when production was so important. Their work as moulders was to make moulds, not to mix sand. With machine moulding becoming universal they were forced to find a quicker method than the old one. He agreed with Mr. Harley as to the number of faulty binders on the market. He had tested a good many, and his experience was that by doing this they could soon discover which was the best material for their particular purpose. With binders such as Mr. Harley used he found that distortion was less likely to occur, as mixtures in the green state were stronger than when using oils. He perhaps needed to qualify the statement that Leighton Buzzard sand was not usually employed for core making. For fine work they needed not the rough grain sand, but the finer material. As to Mr. Drake's point about fish oils, they were not usually used alone, but as an admixture with linseed oil. There were certain difficulties in the mixing of fish oil in water soluble binders, such as treacle, and it was far better to mix different oils than to mix two different class of binder like water soluble binders and oil. For binders for ferrous and non-ferrous metals he referred to dry binder like resin for the latter, but for iron he required one rather stronger, which would produce a core to resist strain, and this was more likely to be secured by using linseed oil or treacle. Mr. Beeney had commented on the difference between porosity and permeability; the two were similar, but a core might be very porous, indicated by the density, and yet not have a high permeability figure, as understood by resistance to free air passage of gas due to angularity, irregular grain size. Alluding to the speaker who preferred old-fashioned mixtures to new-fangled ideas, Mr. Currie pointed out that silica sand eliminated many rods and grids, etc. It was much stronger, and was an important factor in the case of rapid production. Further, it would stand more handling than the old style of mixture, and he might mention that nowadays they were not over-careful in the way in which they handled cores. The use of coal dust was not universally necessary in heavy green sand work; and he said that it only took effect just outside the mould surface. They could use a better facing sand for the purpose, but if they did it must be well vented all round. Mr. Elson had raised the question of the proper mixing of sand and the efficiency of moulders. The moulder with a shovel could not do so well in the sand mixing department as could proper machines made specially for the job. He endorsed his remarks completely. Then Mr. Judd had stated that the pan mill had been found better for mixing silica sand. Possibly they did get better results with a large grain sand like that of Leighton Buzzard. He used a paddle mixer, and with a small grain sand like sea sand there had been no difficulty in producing a very good mixture. A pan mill was much slower in its operation; that was his reason for using other mixers. It was necessary if they were making a steel moulding sand or a synthetic sand to use a pan mill; but if they were using a sand such as Mansfield in conjunction with other sands for iron, and large quantities were required, then they wanted something quicker.

Scottish Branch.

THE BRIQUETTING AND USE OF CAST-IRON BORINGS AND TURNINGS.

By J. Alex. Gardner, Member.

At a recent meeting of the Scottish Branch of the Institute of British Foundrymen, the utilisation of cast-iron borings and turnings was discussed. It was very interesting for the author, because at that time he was actively engaged upon a scheme to achieve the profitable use of what might be classified as a more or less valueless by-product of engineering shops. Usually a very small price was obtained for cast-iron borings and turnings on the scrap market; sometimes they were almost altogether valueless, and to a foundryman who has the commercial welfare of his profession really at heart, the sight of these borings and turnings being carted away, often to

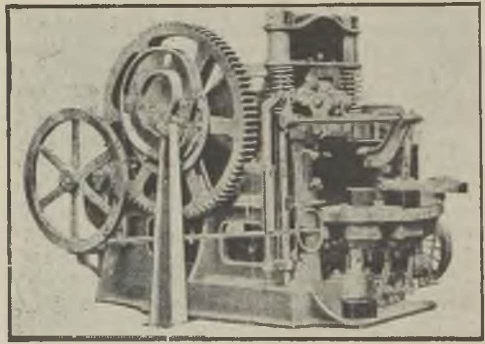


Fig. 1.—A Briquetting Machine for Borings and Turnings.

the dump heap, or to spread on the footpaths round about the works, there to rust and bond together, thus forming a means of more or less permanently filling-up puddle-holes, is disconcerting. The problems pertaining to foundry practice seem never-ending. Foundrymen apparently often have everything nicely arranged and systematised, when an important casting is scabbed, another is badly drawn, a third full of slag on the top side of a flange, a fourth has cracked before the core irons can be slackened. In the meantime the cupola has scaffolded, and seldom if ever do they get just one trouble at a time. It may be thought that this is an exaggeration, but such occurrences do happen.

FIG. 2.—CAST-IRON BRIQUETTES MADE FROM BORINGS AND BONDED WITH CLAY WASH.

Again, the machine shop staff take a true delight in commiserating with foundrymen on their misfortunes, whilst eulogising the quality of the castings turned out by our great-grandfathers. They are, however, silent when the castings are good. Meetings of the Institute of British Foundrymen never develop into mutual self admiration societies, but always have a spirit of kindly rivalry tempered with helpful camaraderie.

In this spirit, then, the author presents the particulars of what has been accomplished within his own purview concerning the briquetting and useful melting of cast-iron borings and turnings. This Paper is more or less a résumé of the evolution from a simple thought on the subject matter up to its successful practice, and it is not considered to be the last word on the subject, but it is a successful established and paying proposition.

Early Attempts.

Having examined previous attempts, it was found that various schemes have been tried from time to time, such as packing in boxes made of metal or wood, bonding by means of rusting, or again bonding by means of Portland cement. The first of these schemes entails the destruction of the container long before the mass of the borings or turnings is fritted together, with their consequent ejection from the cupola by the air blast. The second is a slow process, even when accelerated by the use of ammonium chloride, and must by its nature involve excessive stocking and handling.

Briquetting machines are on the market, and are said to work very well. Working at pressures from 100 to 150 tons, with an output of 1,000 to 1,500 briquettes per hour, when working on such material as sand, coal and coke. In a typical example, Fig. 1, the pressure is applied by toggle levers driven by gearing, and the press requires 10 to 15 h.p. to work it. On inquiry it was found that the cost was about £1,250 for a new machine and £850 for a reconditioned one.

Clay Bonding is Used.

Starting from this point experiments were conducted on the lines of compressing the borings and turnings in taper tubes with a bond, finally getting a good briquette 3.5 ins. dia. at the broad end and 3.25 ins. at the narrow end, with an overall length of 6.5 ins. The briquettes thus formed could be handled quite well, and were transported to drying stoves. After being dried, a briquette could be dropped from a height of about 20 ft. on to hard material, and may possibly break into two pieces, sometimes more, but it did not disintegrate. This briquette was obtained by filling a

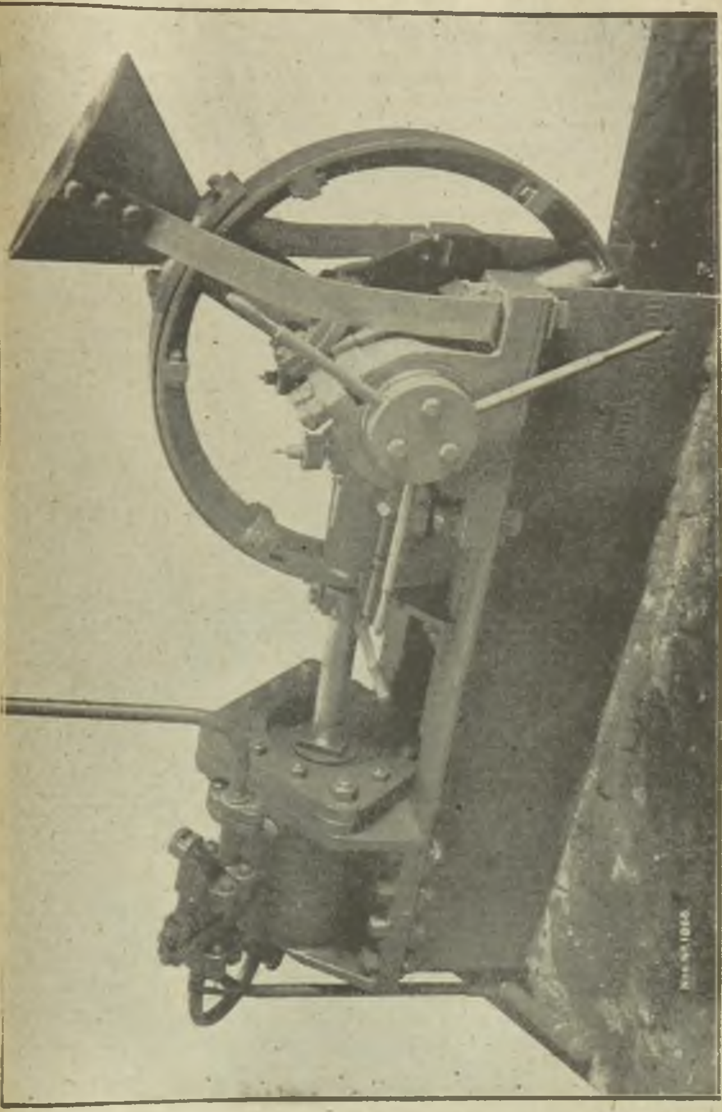


FIG. 3.—BRIQUETTING MACHINE DESIGNED SPECIALLY FOR THE PURPOSE OF BRIQUETTING CAST-IRON BORINGS.

taper tube 13.5 ins. long, the lower length of 6½ ins. conforming to the dimensions of the finished briquette. This tube was firmly packed by hand with the borings and turnings mixed with a sufficiency of clay water, the clay water being the consistency of thick cream, and the quantity of it adjusted until very little of it is squeezed out by the ramming process.

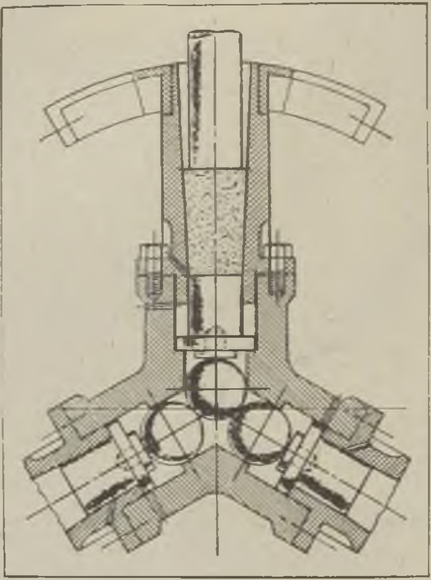


FIG. 4.—SECTIONAL ELEVATION OF THE BALL SYSTEM, WHICH EJECTS THE BRIQUETTES ON ROTATION AND DURING THE SQUEEZING OF ANOTHER.

The ramming process consisted of applying about 35 tons to the mass contained in the taper tube, by means of a ram 3 ins. dia., the other end being effectively closed against the squeezing out of the borings, but not against the surplus clay water. The briquettes thus formed were in this case dried on the floor around the carriages of the stoves

FIG. 5.—A HYDRAULIC CYLINDER CAST FROM CAST-IRON BORINGS.

used for drying the loam and dry-sand moulds, thus involving no additional outlay for this part of the process. A simple semi-automatic machine was then designed, which could effect the manufacture of these briquettes. In the meantime, 15 cwts. of mixed turnings and borings were made into 213 briquettes (Fig. 2), and the resultant weight then was 15 cwts. 3 qrs. 9.5 lbs., so that the added clay weighed 93.5 lbs., or 6.3 per cent. of the whole, and the average weight of the briquettes was therefore 8.25 lbs.

Melting Results.

These briquettes were melted in a small cupola, with a 12-in. water-pressure air-blast, and cast into pigs, the yield being 13 cwts 1 qr. 10 lbs., or a loss of 1 cwt. 2 qrs. 18 lbs., or 11.1 per cent. The borings, as usual, contained much dirt from the floors.

An average sample of the borings before briquetting showed an analysis of:—2.187 Si; 0.062 S; 0.682 P; 0.528 Mn; 0.400 CC; and 2.88 Gr per cent., and after melting the pigs showed an analysis of:—1.305 Si; 0.193 S; 0.716 P; 0.171 Mn; 2.115 CC; and 0.560 Gr per cent.

The resultant iron was white owing to what had evidently been a combination of the alumina in the clay used in briquetting with part of the silicon content of the turnings and borings, slagging off as one or more of the silicates of alumina.

Having thus obtained a reasonable return from the cupola in so far as quantity is concerned, and noting that a suitable addition of high silicon, or silky iron as it is called, would rectify matters with regard to quality, the author then concentrated upon building a machine which would turn out the briquettes at a reasonable speed. This is shown in Fig. 4, which exhibits a view of the working side of the original briquetting machine. The hopper gives direction to the borings and turnings which have already been mixed with clay water. The clay water is stored in a tank which is kept agitated and mixed by a small jet of air rising from the bottom. The succeeding cylinders are thus filled with the clay and boring mixture as they pass under the hopper. The first cylinder having been filled, the three cylinders are rotated;

the second is now filled, and the first is brought in front of the compressing ram. A pressure of about 38 tons is developed inside the hydraulic cylinder behind the ram which, allowing for frictional and other losses, will represent about 35 tons effectively applied to the borings, or about 5 tons per sq. in. of end surface of the briquette. The internal pressure on the cylinder being about 0.5 tons per sq. in. when the pressure is on.

The cylinders are locked in position during the compression period. The hydraulic supply to the machine is controlled by a "Homeyard" valve, which has given every satisfaction. The cylinders are again rotated when the third one is filled with borings, the second coming in front of ram, which when it functions, not only compresses the borings in this second cylinder, but at the same time by a system of three balls (shown in Fig. 4) acting in a wedging manner on well fitting pistons at the bottom of the cylinder, ejects the contents of the first cylinder as a formed briquette on to a suitably curved plate which slides it to the floor. Fig. 4 shows an elevation of this ball system.

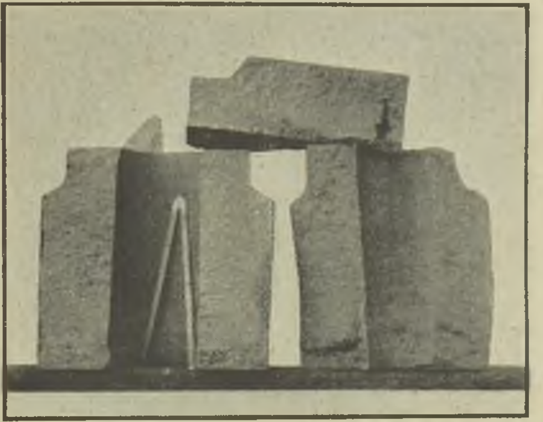


Fig. 6.—The Head of the Casting Shown in Fig. 5 Split Open.

The briquette thus obtained was a homogeneous mass about 6 ins. long, by about 3.5 ins. diam. at the broad end, tapering to about 3 ins. at the narrow end, and weighing, when dry, approximately 5.75 lbs.

Production Data.

A reasonable speed of production with three individuals when, as well as briquetting, they have to mix the borings and clay water together, is 940 briquettes per working day, weighing about 2 tons 16 cwts., but when the same individuals have to transport the briquettes to the drying stoves, the production runs about 760 briquettes per day, or a weight of 2 tons 5 cwts.

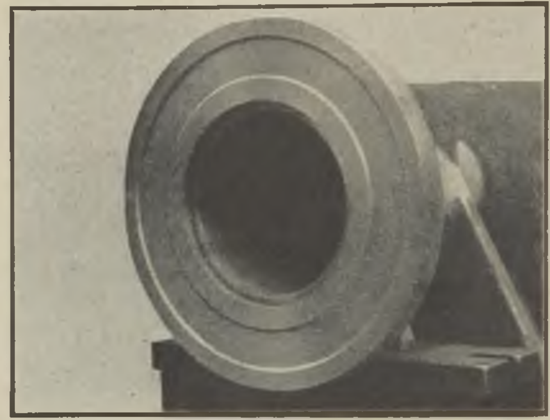


FIG. 7.—THE TURNED-UP CYLINDER HEAD.

The greatest wear in the machine is naturally located in the tubes in which the briquettes are compressed, the taper being gradually worn parallel. However, so far there has been obtained about 64 tons, or 21,582 briquettes per tube before they are useless, which means that they do not eject properly.

As the briquettes are made, and immediately upon leaving the machine, their temperature rises about 60 deg. F. above normal, the briquettes steaming slightly. Clay water is as yet the only medium with which we get this rise in temperature under the conditions stated after compression. With all other materials tried, the press " grunts " heavily during the application of the pressure, showing heavy frictional resistance to movement of the particles of the mass past one another, with the result that, the briquette is not so homogeneous, neither can it be safely handled in transport before drying. The successful functioning of the clay water is attributed to the gelatinous nature of the hydrated oxide of aluminium, its chief content, whereby it, to a certain extent, acts as a lubricant.

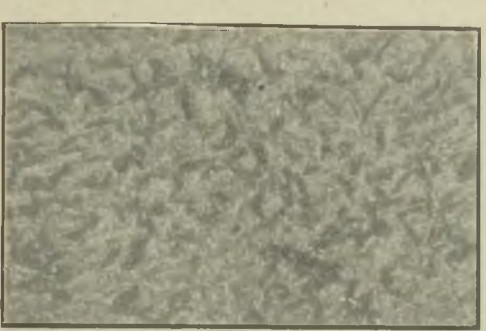


Fig. 8.—Unetched Micrograph of Cast Iron Made from Borings × 80 Dias., but Slightly Reduced on Reproduction.

Drying Process.

The formed briquettes are allowed to rest some time for the purpose of primary hardening, say about 2 to 3 hours, and are then placed on the floor round about the cores, loam and dry-sand moulds in the drying stoves. The works have ample stove capacity for this purpose. After about 12 hours' heating, the briquettes are quite dry, the clay has been dehydrated, and the whole mass is found to be reasonably hard, and quite suitable to withstand the shock of falling down the barrel of the cupola during charging, that is, they may or may not break into two pieces, but they will not be disintegrated into useless powder.

The machine was operated until 827 of these briquettes had been produced, this number when dried weighed 2 tons 2 cwts. Taking the clay content at 6.5 per cent., as in the first report, it leaves 1 ton 18 cwts. of metal borings.

Details of Working.

The author divided these into three charges and placed in the cupola, 42 cwts. of briquettes, 20 cwts. of silicon iron, and 20 cwts. of good scrap, adding at the same time a little more than the normal amount of coke and limestone.

The scrap used analysed:—2.400 Si; 0.040 S; 0.700 P; 0.800 Mn; 2.920 Gr; and 0.400 per cent. CC.

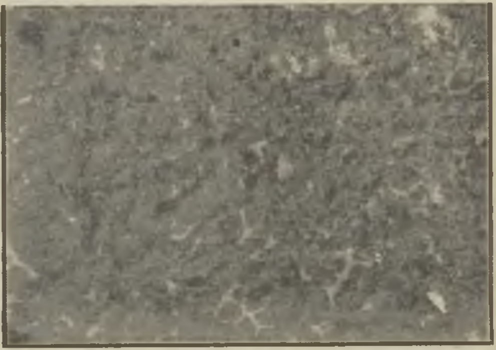


FIG. 9.—IODINE-ETCHED MICROGRAPH OF CAST IRON MADE FROM BORINGS × 80 DIAS., BUT SLIGHTLY REDUCED ON REPRODUCTION.

The high-silicon iron showed on analysis:—6.279 Si; 0.072 S; 0.375 P; 1.194 Mn; 2.380 Gr; and 0.074 per cent. CC.

Taking the borings as illustrated in Fig. 2 it is a very difficult proposition to get a representative sample from such a very heterogeneous mass, they show:—2.187 Si; 0.062 S; 0.682 P; 0.528 Mn; 2.880 Gr; and 0.400 per cent. CC.

The cupola was operated under about 12 ins. water-pressure, and the metal came down very hot and fluid, showing that the extra coke precaution was unnecessary, but, as can be antici-

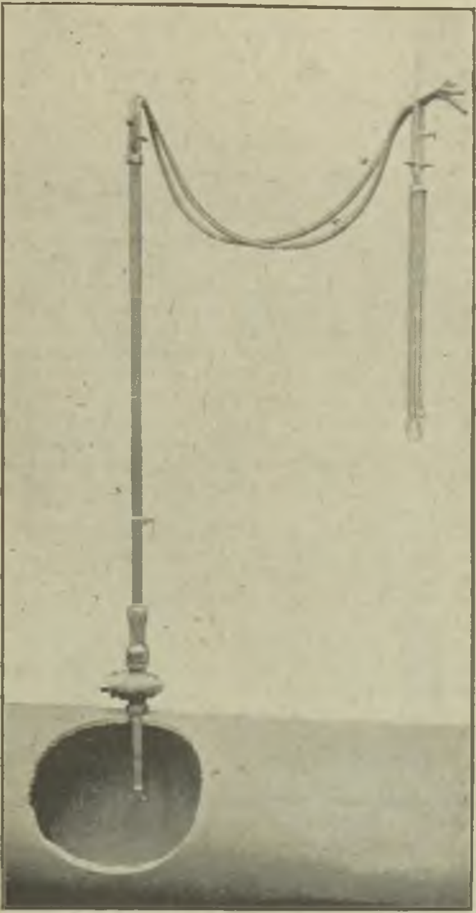


Fig. 10.—A Pitometer Tube Used in Conjunction with an Inclined Manometer for Cupola Volume Control.

pated, the melt was associated with a good quantity of slag.

An analysis made from a 40 in × 2 in × 1 in. test bar, cast about the middle of the run, showed:—2.365 Si; 0.153 S; 0.667 P; 0.457 Mn; 2.040 Gr; and 0.645 per cent. CC.

Mechanical Results.

Three test bars dimensioned as above, broken on 36 in. centres gave an average load of 37 cwt. 1 qr. 2 lbs., associated with 0.432 ins. deflection.

A hydraulic cylinder was cast from with this iron It is shown in Fig. 5 after fettling, and weighs with its head 46 cwts. Fig. 6 shows this head, which weighed 19 cwts., split open revealing the grain of the metal. As will be noted, there is the usual slag and dirt right at the top, but below that, the mass of the iron is of the very finest quality, approaching the old cold-blast iron in character, which is describable as of riven oak; it is therefore significant of a high degree of solidity and toughness. Fig. 7 shows the turned flange and bore of this cylinder all significant of iron of the highest quality.

The turner reported that he was conscious of the iron being just slightly tougher than normal, but the cutting speed was not reduced in the least, and that he would rather cut this iron than the ordinary.

A test of the cuttings taken whilst boring the cylinder showed it to contain 2.281 per cent. Si and 0.075 per cent. CC.

The low figure of the combined carbon content is of course due to the much slower rate of cooling of the cylinder mass, in comparison with the test bar.

Fig. 8 shows a micro-section cut from one of the test bars polished but unetched. It reveals a very finely divided graphite content, and comparatively very little impurity. Fig. 9 shows the same section etched with iodine, and revealing the iron phosphide as white areas, with the pearlite as halftone, and also the same small graphite plates as in No. 5. Both illustrations are under a magnification of 84 dias., and fully substantiate the analysis and results obtained from the test bars.

In the author's opinion the superior qualities of

TABLE I.—*Rough Balance Sheet assuming 25 tons of Briquettes, with clay content of about 7 per cent.*

Leaving say, 23 tons available iron:—

	£	s.	d.
23 tons Borings at 30/-	£34	10	0
2 ,, Clay at 20/-	2	0	0
12½ ,, Silky at 100/-	62	10	0
6¼ ,, Scrap at 90/-	28	2	3
6¼ ,, No. 3 Pig at 100/-	31	5	0
Hydraulic Supply at 40/-	2	0	0
Wages 1 Man at 40/-	4	5	0
,, 2 Boys at 12/-	2	12	6
	£167	4	9

A furnace loss of 11 per cent. on 50 tons leaves 44.5—say, £6 per ton for an iron of 36 cwt. Transverse Test:—

Tons.	Cwts.		
44	10	at £6	£267
Cost of same		.. ..	168
			£99

this metal are due to the mechanical elimination of graphite by the machining processes productive of the borings and turnings, and possibly also during the early melting stages, with a consequent diminution of the length and number of possible cleavage planes in the mass. In this way the product is similar to what is called "semi-steel." A daily use of briquettes, when such are available, in quantities varying from 5 to 25 per cent., have been amply proved to be productive of a corresponding increase in the strength of cast iron. They appear to function in an almost exactly similar way to steel, although perhaps in the higher percentages, steel is in the ascendant owing to its dilution of the sulphur and phosphorus content. The author has had transverse tests on a 2 in. × 1 in. bar on 36 in. centres of 46 cwts in semi-steel.

Table I shows a somewhat crude balance sheet, but it is fairly illuminative.

Taking the proposition all round, it will be noted that it is a fairly profitable one.

Blast Control.

With regard to the 12-in. water-pressure on the tuyere box, the control is now really confined to a "fixed volume of air" method. There are so many variables associated with the functioning of a cupola, that it is felt advisable to have one fairly constant factor; so it is worked as nearly as possible to 32,000 cub. ft. of air per ton of iron. If, then, the iron is cold, it is known that more coke is required of the quality being used. If, on the other hand, the iron is hot, but the melting is slow, then too much coke is being used, and it can be controlled accordingly.

For volume control, the author is using a Pitometer tube (Fig. 10) in conjunction with an inclined manometer, one limb of which is larger in bore than the other; in this way a relatively long sensitive column of water is obtained, and a very fine adjustment of the air is possible.

It is found that a Pitot tube is inexpensive, does not materially affect flow of air, is easily fitted, takes up very little room, and is very accurate when installed as indicated. It may be of interest to give the formula for the Pitot tube calculation with reference to the flow of air in a pipe. The formula is:—

$$V = C\sqrt{2gH.}$$

Where V is the velocity in feet per sec., C is a slightly variable constant, depending upon the contour and size of the Pitot tube, but 0.865 may be taken as a good figure; g is the gravity, and H the inches of water pressure in a vertical U tube, converted into the equivalent of feet of air pressure at 15 deg. C. and 760 mm. pressure.

Incremental, vertical water-pressure-heads are calculated out by above formula, thus getting the air velocities at these heads, and under the pressure of the blast main. From these velocities in conjunction with the area of the blast main, the respective volumes are calculated, and these are again corrected from the blast-main pressure to that of the normal atmosphere or 760 mm.

A curve is then plotted from the foregoing data, and from this curve, equal incremental volumes are noted with reference to the respective heads of water. From these figures a sloping manometer with a wide and narrow tube is calibrated, giving a very sensitive and accurate instrument.

Conclusion.

In conclusion, the author expresses his thanks to Mr. Kennedy, managing director of Messrs. Clenfield & Kennedy, Limited, Kilmarnock, for permission to read this Paper. His thanks are also due to Mr. Robert M. Robertson, the plant draughtsman, for humouring his vagaries in machine design, and most materially assisting in many ways. Lastly, he thanks Mr. William Wyllie, one of the Institute members, who is to him a never-failing friend in times of trouble.

Lancashire Branch.

(BURNLEY SECTION).

THE FOUNDING OF ADMIRALTY GUN METALS ALLIED ALLOYS

By F. W. Rowe, Member.

In dealing with such a subject as this, it is neither possible nor desirable to avoid touching on brass foundry practice in general. A large portion of the matter in this Paper may be taken to apply to all brass foundry practice unless specifically excepted.

The major portion of the work of non-ferrous foundries is producing gun-metals of some kind or other. Strictly speaking, the term "gun-metal" denotes a ternary alloy of copper, tin and zinc, in which the copper is not less than 80 per cent. In the average gun-metal casting there is also an appreciable proportion of lead (added intentionally or otherwise), and it is proposed to include a consideration of these alloys also.

Simple binary copper-zinc alloys containing zinc up to 20 per cent. are not used to a very large extent for engineering castings. They are not so easy to handle as ternary alloys in the foundry and their mechanical properties do not fit them for many duties. Their appearance is not so good in the finished casting as the ternary alloy, and they are more liable to unsoundness and blowholes; also they are too soft, that is, the yield point is low, and consequently are very easily deformed and possess very little resistance to abrasive wear. Despite these disadvantages, it is the writer's contention that there are a great many more applications for these alloys, especially with a zinc content of from 15 to 30 per cent., than is usually appreciated. The great need for reducing the world's consumption of tin in order to bring down the price to a reasonable level should render one conservative in the use of this element.

The Hardness of Bronze and Brass.

The binary copper tin alloys are fairly extensively used especially if one includes those in which phosphorus is present also. Tin has a much greater hardening effect on copper, as will be seen from Fig. 1, which shows the relative hardnesses of copper, zinc, and copper tin alloys in the commercial ranges. Moreover, apart from the general hardness figure, the constitutional difference between the brasses and the bronzes render the latter much more valuable for resisting wear.

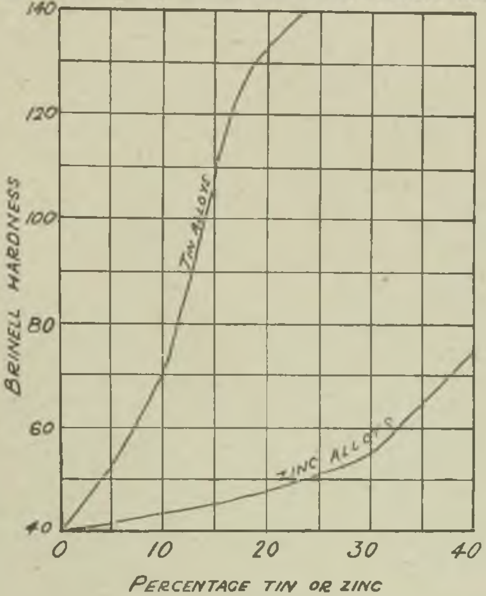


Fig. 1.—Comparative Hardness of Sand-Cast Copper Zinc and Copper Tin Alloys.

The brasses within the range under consideration comprise a metal built up of crystals of practically uniform composition and hardness throughout, as will be seen in Fig. 2, which is a photomicrograph of a sand cast 20 per cent. zinc-copper alloy at a magnification of 100 dias. On the other hand tin bronzes with fairly large amounts of tin have a quite different structure.

Up to 7 or 8 per cent. tin in a sand-cast alloy the structure is essentially the same as a brass, *i.e.*, built up of homogeneous crystals all of the same variety, but harder than those in a copper-zinc alloy containing an equivalent amount of zinc.

Above 7 or 8 per cent. tin a new constituent makes its appearance, which is metallographically known as the beta eutectoid or complex.

This constituent varies slightly in composition in different alloys, and the point at which it makes its appearance depends on the other constituents present and the method of casting and cooling the alloy. These crystals are intensely hard, and have a hardness approximately nine times that of copper. The proportion of this constituent present varies of course with the tin content. With a simple tin bronze of about 16 per cent. tin this constituent forms about 20 per cent. of the total alloy. It is this constituent which gives the bronzes their good resistance to abrasion and their excellence as bearing metals.

Fig. 3 shows a photomicrograph at 100 dias. of a simple bronze containing 16 per cent. tin. The mottled network is the beta complex in a matter of a solid solution in copper containing about 7 per cent. tin. The Brinell hardness of this alloy in the cast state is 120, the copper-tin solid solution having a hardness of about 55, whilst pure cast copper is about 40.

Gun-Metal Alloys.

Perhaps the best known of the ternary alloys—the gun-metals—is Admiralty gun-metal consisting of 88 per cent. copper, 10 per cent. tin and 2 per cent. of zinc. The Admiralty specification fixes the minimum tin content at 10 per cent., with maximum impurities. other than zinc, of 0.5 per cent. which is generally interpreted to mean lead

The physical tests required by the Government in this country are 14 tons tensile with not less than 7 per cent. elongation.

These physical test requirements are quite low, and no founder whose supplies are normal and whose melting practice is anything approaching good should fail to meet them. A good foundry working on these bronzes will average a tensile strength slightly over 16 tons per sq. in., and an elongation of 15 per cent. It is quite possible with a modicum of care to obtain over 20 tons tensile strength with more than 20 per cent. elongation in ordinary sand-cast bars.

A foundry with which the writer has been connected averaged 16.96 tons and 17.8 per cent. elongation on 187 test bars, many of which were cast on the job or machined from the actual castings. The Brinell hardness for Admiralty gun-metal should not be less than 60 on average sections, *i.e.*, $\frac{3}{4}$ to $1\frac{1}{2}$ in. thickness of metal.

Influence of Re-melting.

It is often amusing to note the pride with which many brassfounders advertise the fact they use only virgin metals in the production of their gun-metals.

It is an undoubted fact that twice-melted metal gives much sounder and stronger castings than virgin metal. It is a definite rule in the foundry with which the writer is connected never to exceed one-third virgin mix in the gun-metals. Heavy scrap is much better than virgin metal provided the composition is correct. Probably the best mixing for ordinary foundries who consume their own machine-shop scrap is one-third virgin, one-third heads and runners and one-third re-melted borings. It is never safe practice to use an appreciable quantity of borings in gun-metals without first re-melting and ingotting, nor is it economical in the long run.

The ordinary 120- or 150-lb. pot is not suitable for melting borings, and the length of the heat is unduly prolonged and considerable surface oxidation of the borings takes place before they are melted. The golden rule in all brass-foundry practice is to melt rapidly and avoid oxidation.

More trouble is caused by " stewing " metal and melting under oxidising conditions than is usually appreciated. Working on the ordinary pit-fire furnace a 150-lb. pot of gun-metal should not be in the furnace longer than $1\frac{1}{2}$ hours. It is no uncommon thing to find foundries taking 2½ hours to get this weight of metal down, and an infinite amount of trouble may be experienced from this cause alone, especially when working on more sensitive alloys than Admiralty metal.

Liquation Troubles.

In heavy castings of Admiralty gun-metal, trouble is sometimes experienced due to liquation of the eutectoid. That is, the eutectoid drains away from the heaviest portion of the casting, leaving it porous. Another trouble that is experienced with heavy sections is that in the slowly-cooled portions of the casting the eutectoid forms a network of fairly large masses of the metal which considerably reduces the strength of the metal and makes it very brittle. In rapidly-cooled gun-metal, the eutectoid is dispersed in fine particles, and is present in a less quantity. Both these troubles can be considerably reduced

FIG. 2.—ADMIRALTY GUN METAL, SLOWLY COOLED, SHOWING EUTECTOID SEGREGATION ETCHED $(NH_4)HO + H_2O_2$, MAGNIFIED 100 DIAS.

by paying proper attention to moulding and casting conditions. Green-sand moulds should be used wherever possible, and very close attention should be paid to the temperature at which the metal is poured. The primary solidification of Admiralty gun-metal sets in at 995 deg. C. + or − 5 deg. C. The correct casting temperature varies, of course, with the section of the casting and the method of moulding, *i.e.*, green- or dry-sand. It is usual, with all alloys, for most foundrymen to err on the high side rather than the low. This is usually especially evident when a fair number of boxes have to be cast up from one pot of metal and the bogey of short runs looms high.

It may be taken as a fair average that it is impossible to cast more than eight boxes with one pot of metal and have the requisite mechanical properties in the castings in each box.

During the war it was generally noticed that those foundries which had most difficulty in meeting Government Specifications were those who were using large melting crucibles in pit-fire furnaces. It is false economy to use in this type of furnace large crucibles when the majority of work is light. By that is meant that using 200- and 250-lb. pots for work which runs 10 to 15 lbs. of metal to the box. When this is done it necessitates pouring the first box at from 1,290 to 1,330 deg. C. in order to have the metal sufficiently fluid to run the last box. The best results for light work and using ordinary pit-fire furnaces are obtained when 100- and 120-lb. crucibles are used, that is, when crucibles are used holding sufficient metal to run six or seven boxes at the most.

Casting Temperature.

The casting temperature for Admiralty gun-metal should never exceed 1,200 deg. C. for all normal work, and should preferably be lower. The writer has cast some tons of fairly small light-sectioned castings ($\frac{1}{2}$ in. to $\frac{5}{8}$ in. thick) at 1,110 deg. C. to 1,140 deg. C. with excellent results. Bars cut from these castings regularly show over 19 tons tensile strength and 18 to 22 per cent. elongation.

No paper on gun-metal would be complete without some reference to the remarkable increase in ductility which accompanies the annealing of these castings. This fact was first brought into prominence by the brothers Primrose. Admiralty gun-metal castings, after annealing at 650 to 700 deg. C., often show an increase in ductility of 100 per cent. This ductility is due to the absorption of the eutectoid present—the microscopic appearance after annealing being a single solid solution.

The general hardness of the metal is not appreciably altered, but of course the metal is homogeneous, *i.e.*, it consists of crystals all of the same hardness, not as previously of small intensely hard crystals embedded in a softer matrix. This type of structure is not always desirable, especially in work to resist abrasion, and it may be safely said that bearings of parts subject to frictional wear should never be so treated. For ordinary castings annealing is of great value, and especially for castings in this alloy for pressure work where trouble is experienced with porous sections. The effect of annealing is to render the metal much closer and able to stand liquid pressure without leaking.

Allied Alloys.

Although Admiralty gun-metal has been dealt with at some length owing to its important position in the engineering industry, it is the writer's opinion that the value of this alloy is considerably over-rated. The close adherence of the Government Departments to this particular alloy has led to its popularity with engineers in general, but it is more than certain that very few brass-founders would prefer to work this alloy if left with a free hand.

As a bearing metal and to resist abrasion it is undoubtedly inferior to phosphor bronze, and the same may be said regarding its resistance to corrosion.

Where these two qualities are not required the same strength and much greater ductility can be obtained with gun-metals lower in tin and higher in zinc. Alloys with a lower tin content and higher zinc are much easier to work in the foundry and less liable to liquation, segregation and porosity troubles.

Quite a noticeable improvement with regard to strength and ease of working in the foundry can be effected by reducing the tin content to 9 per cent., and increasing the zinc to 3 per cent. The quantity of eutectoid is, of course, lessened, but the general hardness is the same as that of standard mixing. The average tensile strength is higher, and no difference is observable in the yield point. The elongation is materially improved, and the metal is more homogeneous, *i.e.*, less variation is experienced in light and heavy sections of a casting.

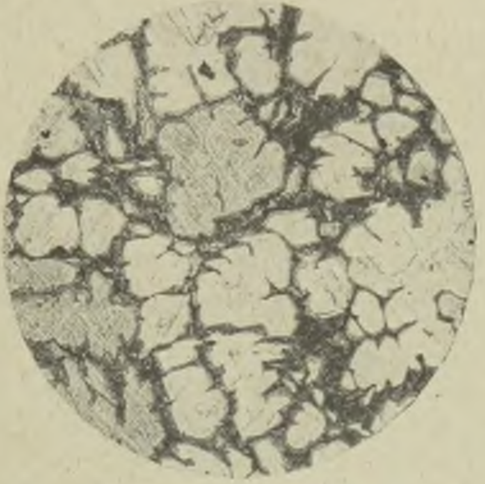


FIG. 3.—TIN BRONZE (16 PER CENT.) ETCHED WITH AMMONIUM PERSULPHATE, MAGNIFIED 100 DIAS.

A very good serviceable bronze of great toughness is one containing 8.8 copper, 6.5 tin, 0.5 lead and 5 per cent. zinc, which will give 18 tons per sq. in. tensile, 8 tons yield point, 45 per cent. elongation and Brinell hardness of 60. This bronze will give better or at least as good service as the more difficult and expensive Admiralty gun-metal in all cases where no bearing surface or no resistance to corrosion is required. It should be cast at a higher heat than Admiralty gun-metal though never above 1,225 deg. C.

Gun-Metal for Pressure Work.

One of the great calls for bronze castings is for small parts to resist liquid or gaseous pressure. The composition of the alloys used for this work often vary somewhat, but all of them contain a proportion of lead. Lead is of considerable value where soundness and freedom from porosity are primary requirements, and it also greatly facilitates machining operations as is well known. That portion of the alloy containing lead is the last to solidify, and therefore fills in the crevices caused by the natural shrinkage of the high melting point constituents of the alloy. A typical composition of gun-metal for pressure work is copper 88.56, tin 5.11 zinc 3.07, and lead 3.23 per cent. It gave 16.16 tons per sq. in. tensile, 7.36 tons of yield point, 27.5 per cent. elongation, and a Brinell hardness of 43. The usual composition of gun-metal for pressure work lies within the following range:—Copper, 84 to 90; tin, 3 to 8; lead, 1.5 to 7.5; and zinc, 3.5 to 7.5 per cent. All the alloys within this range can be made to give excellent results for this class of work. The composition is varied to give some particular characteristic or combination of characteristics for the work in hand. High tin-content gives stiffness and hardness with consequently less rapid machining. The lead gives easy machining and softness proportional to the amount present, and zinc aids casting up to a certain point. With high lead-content trouble may be experienced with lead segregations if the castings are heavy and in such castings the lead should be reduced to 2 or 3 per cent. It may be said that in all pressure work the casting temperature is of vital importance. The best and most economical procedure when castings of a new design are started is to cast four or five boxes at different temperatures and follow these through the shops before any more are cast and afterwards break these up and examine the fractures.

Gating Castings.

Frequently also there is one place and one place only successfully to gate a casting, and careful and logical deductions should be drawn from recorded past experience and the moulder properly instructed and not left to use his own judgment. This, by the way, is not intended as a slur on the brass moulder. It is obvious that the actual moulder cannot be expected to form a correct opinion regarding the best method of gating a casting without the fullest knowledge of the past performances of such castings under test pressure when gated in various ways.

Instruments Necessary.

With reference to casting temperature, it may be said that one of the greatest aids to successful brass founding is the intelligent use of a pyrometer. It is realised that only a comparatively small percentage of brass foundries in this country can afford to make full analyses and physical tests of their castings. There are two instruments which can be used to give information and build up experience of the utmost value. These are the pyrometer and the ball hardness test. Undoubtedly the only possible type of the former for a brass foundry is the base metal bare thermocouple with a robust indicator. One thermocouple will give 50 to 80 readings with ordinary use. The cost of the instrument is about £16.

The writer recently checked one of these instruments which has been in constant use for two years in a foundry, and the maximum error over the range was found to be 5 deg. C.

Regarding the ball hardness tester, one of the most useful and inexpensive types is the hand machine operated by a heavy spring. This instrument costs about £9, and gives an impression somewhat similar to that given with a 750 kilos and 10 mm. ball in the standard machine. In fact, the type of instrument is decidedly more useful in a brass foundry than the big machine, as one can check the hardness of jobs any size and in any place.

With a pyrometer, a hardness test, a study of fractures and bend tests, it is possible to build up a knowledge of brass-founding metallurgy of the greatest practical value. Everyone knows that it is not the cost of labour or materials, but the wasters which eat up the profit, and wasters can only be eliminated by careful study and standardised conditions of practice.

DISCUSSION.

Mr. Jackson asked what measures should be taken to get homogeneity of the metal. By that he meant how to ensure that in a number of small castings on a plate the first casting had the same composition as the last.

Mr. Rowe replied that if due care was taken and the pot well stirred up immediately before casting he did not think it likely that there would be any appreciable variation between the top and bottom of a casting or between the first and last casting in a plate box. Sometimes trouble did occur when the percentage of lead was high, say 8 or 9 per cent. This could be avoided by well stirring the pot immediately prior to pouring and casting at the correct temperature.

Mr. Jackson said that to stir up the pot when it was in the fire was an unpleasant job. He had seen the practice of stirring in the fire adopted but he did not like it.

Mr. Rowe: It is not necessary to stir in the fire.

Mr. Jackson: When the pot is drawn it requires a great deal of stirring to get a thorough mixing unless some special methods are adopted.

Mr. Rowe said he did not think he could agree with that, as he had had as many as 20 or 30 castings on a plate of ordinary bronze (5 tin, 5 zinc, and 5 per cent. lead), and there had never been any appreciable variation between the first and the last. With a heavy percentage of lead, if it is cast too hot and the metal is molten a considerable time, it allows time for the lead to segregate.

The Utility of Fluxes.

Mr. Pell asked what flux Mr. Rowe used and the quantity per cwt.

Mr. Rowe said in the foundry he was connected with they always melted only under charcoal; he thought that was necessary, but they did not use any flux. Some people adhered to the practice of fluxing, but there were very few alloys where it was required and these special cases. Many patent fluxes had been placed on the market, but his experience was that they did not make any appreciable difference.

Mr. Pell said in asking the question he had in mind the melting of non-ferrous alloys, whether the fluxes were worth buying for that purpose or not.

Mr. Rowe: There are one or two special alloys —aluminium alloys for instance—where they are of considerable value, but for the ordinary run of gun metal or phosphor bronze they are of no use at all.

Replying to Mr. Derbyshire, Mr. Rowe said in making Admiralty gun metal there was a slight advantage in adding zinc before tin. The theoretical reason was that although melted under charcoal, a certain amount of oxide was generally present. If the tin was added first the tin would deoxidise the copper. Tin oxide was very sluggish and did not rise to the top to be skimmed off nearly as rapidly as zinc. There was just a fear if the tin was added first and it did sometimes happen—that crystals of tin oxide would become embedded in the metal, and tin oxide was the worst possible constituent one could have in a bronze casting. It was about twice as hard as the hardest crystals in a hardened tool steel, and in a bearing would score any journal.

Phosphor Bronze Mixtures.

Mr. Glover asked the author to give an approximate mixture for phosphor bronze for general use, as it was not often mentioned in the text books.

Mr. Rowe: The most general mixture for phosphor bronze is 90 copper and 10 per cent. phosphor tin, which gives a metal the composition of which approximately is copper, 90; tin, 9.5; and phosphorus, 0.5 per cent.

Mr. J. Beecroft: Is there any advantage in using phosphor-tin instead of phosphorus in making a heavy bearing?

Mr. Rowe said if stick phosphorus was used there was a risk of a pyrotechnic display and injury to the men, and there was no advantage in using it when it was just as easy to get phosphor-copper or phosphor-tin..

Mr. Beecroft: If one makes a phosphor-bronze casting, phosphorising it oneself, and in a few years that casting is returned and remelted, is the phosphor bronze the same?

Mr. Rowe explained that there would be a slight loss of phosphorus through oxidation. Supposing the casting had contained 0.5 per cent. phosphorus, the loss would be about 0.1 per cent. phosphorus.

Mr. Beecroft: It has ceased to be a genuine phosphor bronze.

Mr. Rowe: If a little phosphorus is added to make up that loss on oxidation exactly the same thing is produced. In fact, if virgin metal is originally used and is then remelted, it will give a sounder metal. In further explanation Mr. Rowe said if stick phosphorus was damp when put in the pot, or if not put well under the metal, it would splash and probably burn the operator's hand, and a phosphorus burn was the hardest burn to cure. There was no necessity to take such a risk when manufacturers were making tons of phosphor-tin every day, much better and more cheaply than the foundryman could do it himself, and quite the same results could be got much more easily than with phosphorus.

Mr. Beecroft said he failed to see that there was any grave risk in using phosphorus.

Mr. Rowe said he had known people burned by it and he thought the risk was considerable. It ignited at 40 deg. C. and was liable to burst into sudden flames.

Types of Furnaces.

The Chairman asked what was the best method of melting?

Mr. Rowe said there was nothing better than the ordinary pit-fire furnace for small parts such as were generally made. In 100- to 200-lb. pit-fire furnaces one obtained just as good melting as with any of the patent furnaces. If it was properly built and properly charged, the results were quite as good and economical as those had from a tilting crucible or the like. The coke consumption might be a little higher, but there were compensations for that. With care one could get 60 to 80 heats out of an ordinary crucible in a pit-fire furnace.

Mr. Pell: Which is the more economical—the square pit fire or the round pit fire?

Mr. Rowe: I think the round pit fire is more economical than the square pit fire, but there is not a great deal in it. There is more in the setting of the fire bars and the arrangement of the blast than whether it is round or square.

Mr. Pell remarked that the reason he asked the question was that in the square pit fire the corners had to be filled up, and in the round pit fire the supply of coke was equal all round.

Mr. Rowe said Admiralty gun metal was not a really good bearing metal, and the trend of modern practice was not to use it for that purpose. For heavy loads on wide bearing surfaces the most commonly used bearing metal was leaded phosphor-bronze, *i.e.*, an ordinary phosphor-bronze with about 82 copper, 8 lead, 10 tin, and 0.5 per cent. phosphorus.

Sands for Non-Ferrous Work.

Mr. Derbyshire asked whether he would get the same benefit as when casting green sand if he used dry sand, letting it go cold?

Mr. Rowe said it was the moisture in the green sand which robbed the metal of its heat, and cold dry-sand moulds had not the same chilling effect as green sand.

The Chairman: Have you any particular sand for this class of work, such as Mansfield sand or yellow sand?

Mr. Rowe said it all depended on the class of work that was being made. For practically all brassfounding one could use a local sand. But there were some castings with which it would not be safe to use a local sand.

Mr. Hogg: Is there any special method of annealing Admiralty gun-metal castings or do you just put them in the fire?

Mr. Rowe said the temperature of the casting must be even and under control. With a gas-fired muffle furnace one could control the temperature very closely between 600 and 700.

Mr. Hogg: Does the openness of the sand, or the closeness of it, have any effect upon the casting? Suppose one is casting anything in brass. Can one use Mansfield sand or a very close yellow sand? Would that be the cause of small blow-holes forming?

Mr. Rowe said clayey sand like Mansfield tended to produce blow-holes on the surface and was useless for pressure work.

Mr. Hogg: Even if the mould is dry?

Mr. Rowe: Yes, very often, even if the mould is quite dry.

A vote of thanks to Mr. Rowe was moved by Mr. Hogg, seconded by Mr. Jackson, and passed unanimously.

East Midlands Branch.

THE SELECTION OF PIG-IRONS FOR HIGH-GRADE CAST IRON.

By F. W. Rowe, Member.

There is hardly another phase of iron founding concerning which there is more divergence of opinion, or more lack of understanding of the basic principles involved, than the proper selection of the components for the production of high-grade cast iron. It is seldom one meets two iron foundries using the same irons, or whose ideas do not radically differ. Lest it should be misunderstood, it is well to emphasise at the outset that the selection of pig-irons, though a vital factor in high-class iron founding, is hardly more important than correct melting and casting conditions. There has been a great tendency in the past on the part of metallurgists and chemists to assess the value of a pig-iron solely on the analysis shown, without any regard to the raw materials from which the pig has been made or the conditions of smelting or the fracture exhibited. Unfortunately the opinion that the only criterion of a pig-iron is its analysis has recently been reiterated by people who should know better. It is to be deplored as a retrograde step, and one which will not be supported by those who have approached the subject from an unprejudiced standpoint.

It rather looks that, with those who hold this opinion, "the wish is father to the thought," and certainly iron founding would be a great deal simpler if it were so. Most people will agree, however, that analyses, though important, do not tell the whole story, and due consideration must be paid to other characteristics of a pig-iron.

The selection of raw materials for the commoner classes of castings is, of course, chiefly governed by economic considerations, the actual strength of the iron being of minor importance, and the skill of the foundrymen is more profitably expended in ensuring that clean, sound castings are produced.

When, however, one turns to the highest class of engineering castings, such as steam and internal-combustion engine parts and hydraulic work, the initial cost of the raw materials is a matter of secondary importance, provided the resulting castings successfully withstand the duties imposed upon them in service. Indeed, it is a bad business policy to be parsimonious in the matter of pig-irons for high-class work, and no lasting reputation has ever been built up where such a policy has existed. As regards the analytical requirements for high-grade cast iron, these can be defined within fairly narrow limits for all normal work.

Table I sets out on a broad basis the proportions of the various elements desirable. It will perhaps suit the purposes of this Paper better if the elements are dealt with in order of ascending importance.

Table I.—*Analysis of Cast-iron for High-grade Work*

	Percentages.
Total Carbon	3.0 to 3.3
Combined Carbon	0.6 to 1.0
Graphitic Carbon	2.3 to 2.7
Silicon	1.0 to 1.8
Sulphur	0.10 to 0.15
Phosphorus	0.3 to 0.8
Manganese	0.5 to 0.7

Manganese.

The chief value of manganese in cast iron is to counteract the evil effect of sulphur, and as long as sufficient is present to do this, *i.e.*, above 0.40 per cent. for a normal iron, one need not worry further about the manganese content. It has been asserted that manganese tends to whiten cast iron, but this is unsupported by experience and research work, and it can be safely said that in those proportions met with in cast iron, *i.e.*, 0.40 to 1.5 per cent., it is without effect on the iron carbide-graphite ratio.

Sulphur.

This element, which has been named the "bogey" of the iron foundry, should not trouble the iron founder whose supplies are normal. It should be kept within the limits given. This is an easy matter provided a good coke with a maximum sulphur content of 1.0 per cent. and a slag with not less than 35 per cent. lime is used. Up to 0.1 per cent. sulphur has a distinctly beneficial effect on cast iron, as it tends to give a finer graphite. Experience has shown that it is extremely hard to get iron of high strength with abnormally low sulphur content. Above 0.15 per cent. sulphur tends to become a menace, depending on the class of work for which the iron is used. The iron has distinctly less life and is more liable to blow and shrinkage defects are accentuated. These faults are, of course, more pronounced in light than in heavy sections.

Phosphorus.

The limits for phosphorus have been set down fairly widely owing to the variation in the requirements for different classes of work. There is no conclusive evidence that phosphorus up to 1.0 per cent. seriously diminishes the tensile or transverse strength of cast iron. The resistance of cast iron to fracture by shock is greatly influenced by the phosphorus content. High-phosphorus cast irons (0.8 to 1 per cent.) are definitely weaker against show than low phosphorus (0.2 to 0.3). Anyone who possesses an Izod impact-testing machine can easily verify this fact.

Table II.—*Impact Tests using a* 120 *ft.-lb. Izod Machine. Bars* 20 *mm.* × 20 *mm.* × 75 *mm. with no Notch.*

Analysis.	No. 1.	No. 2.	No. 3.	No. 4.
Total Carbon	3.31	3.21	3.17	3.28
Graphite Carbon	2.69	2.64	2.44	2.58
Combined Carbon	0.62	0.57	0.73	0.70
Silicon	1.46	1.68	1.31	1.18
Sulphur	0.096	0.107	0.092	0.101
Phosphorus	0.36	0.68	0.88	1.29
Manganese	0.46	0.62	0.53	0.58
Energy absorbed in ft.-lbs.	29.00	22.60	16.00	10.50

Table II shows the results of some impact tests on irons only varying to an appreciable extent in phosphorus content. These figures have been selected on account of the uniformity of the analyses and well illustrate the conclusions which have been drawn from the study of some hundreds of similar tests. Phosphorus also is distinctly harmful to castings which have to undergo changes in temperature. For internal-combustion and steam-engine cylinders, valves, etc., the phosphorus should be kept as low as is consistent with safe working in the foundry. High-phosphorus castings are much more liable to crack under repeated temperature changes than those in which this element is low. High phosphorus should not be allowed in work subjected to steam pressure as the phosphide is rapidly attacked in such situations. In heavy work and in castings having rapid changes of section, the phosphorus should not be above 0.3 to 0.5 per cent., or considerable difficulty will be experienced due to porosity caused by liquation of the eutectic.

Combined Carbon.

The percentage of combined carbon is, of course, governed by the silicon content and the rate of cooling. The combined carbon to obtain the best strength and hardness and best resistance to wear should be kept as high as possible consistent with normal machining practice. It is usually a safe guide to arrange that the thinnest section of the casting shall have a combined carbon content of not more than 0.75 per cent., and preferably, of course, not less. No difficulty should ever be experienced in machining a cast iron with this combined carbon content, though, of course, the feeds and speeds will not be as high as the machine-shop superintendent would like.

Silicon.

The silicon content varies within the limits given and, according to the thickness of metal, to give the required combined carbon content.

Graphite Carbon.

The graphite carbon is by far the most important constituent of a cast iron, and is worthy of a great deal more time than can possibly be devoted to it here. The amount, form and distribution of graphite has by far the greatest influence on the strength of cast iron. This fact is often not as fully appreciated as it might be. Undue importance is usually attached to the amount of other elements present. It is doubtful whether the combined carbon *per se* has any effect on the actual strength of cast iron, although it is essential for wearing properties. It is more likely that the beneficial effect of the combined carbon is an indirect one. By that is meant the effect on the graphite content, *i.e.*, the more carbon that is present in the combined form, the less the graphitic carbon. This fact will be better appreciated if one considers types of cast iron made by other processes than the cupola.

To take black-heart malleable cast-iron. At first sight there is very little similarity between this product and grey cast iron, but fundamentally the irons are not so widely apart. In Table III specific examples are quoted which have been selected on account of their similarity in composition. The material difference lies in the total carbon contents, the grey iron containing 3.24 per cent. and the malleable iron 2.62 per cent. There is the same amount of graphite in each, the matrix differs in that the grey cast iron has a pearlitic matrix while the malleable has a ferritic matrix. This, however, should theoretically render the cast iron stronger than the malleable, as pearlite has

TABLE III.—*Relative Properties of Cast iron and Malleable*

	Grey cast iron.	Black-heart malleable.
Graphite Carbon	2.68 per cent.	2.62 per cent.
Combined Carbon ..	0.64 ,,	—
Silicon	1.38 ,,	0.51 ,,
Sulphur	0.094 ,,	0.088 ,,
Phosphorus	0.16 ,,	0.19 ,,
Manganese	0.43 ,,	0.33 ,,
Tensile Test (Tons per sq. inch)	15.36	23.56
Elongation	—	8.5 per cent.
Transverse Test. 15 in. × 1 in. × 1 in.	26 cwts.	—
Brinell Hardness ..	196	113

a much higher tensile strength than ferrite. The phosphorus contents are the same. Why, then, the enormous difference in physical properties? Obviously this is due mainly to the nature and distribution of the graphite content. In one, it occurs generally in lenticular tenuous plates, and in the other in a nodular form well intermeshed with ferrite. The photomicrographic appearance of these two particular examples is illustrated in Fig. 1. The fairly obvious fact which is drawn from this comparison is that the nodular form of graphite gives an iron which is far stronger than one in which the graphite is present in lenticular plates. This deduction is well borne out in practical experience that the closer the graphite approaches in form and distribution to that shown by malleable iron, the stronger the cast iron becomes. Inversely, any iron showing long, large

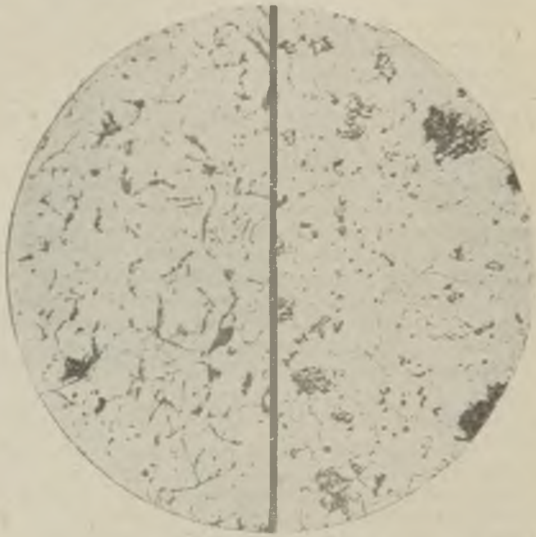


Fig. 1.—Micrograph of 100 Dias. of Grey Cast Iron (Left) and Malleable (Right). They Both Contain the Same Total Carbon.

graphite flakes is very weak. There is also another factor which has not received sufficient attention, and that is the structure of the graphite flake itself. *It is not likely that there is any material difference in the actual graphite present in cast irons*, i.e., *that allotropic modifications are present in different irons.* It is, however, extremely likely that what we call graphite flakes are, in many cases, not solely and wholly graphite but graphite intermeshed with ferrite. It is nearly impossible, owing to the difficulties of polishing, to verify this absolutely microscopically, but is very noticeable that graphite flakes in strong cast-iron under the highest powers of the microscope exhibit distinct signs of an internal structure. It is only logical to presume that graphite intermeshed with ferrite will have a much smaller weakening effect than graphite alone. The ideal, therefore, to be aimed at in cast-iron founding is to produce an iron which will have the graphite in exactly the same form as a black-heart malleable cast-iron. If this was achieved, then the resulting iron would have a tensile strength of anything up to 30 tons per sq. in.

Fig. 2.—Fracture of a Scotch Pig-Iron, Half Full Size. It does not Correspond with the Analysis.

Naturally, the questions arise: How is this ideal to be attained? What factors govern the deposition of graphite in the nodular form? Frankly, we do not know. The present state of our knowledge is such that we have only problematical ideas on the subject. It is here that the question of judicious selection of raw materials—pig-iron, scrap, etc.—enters. The components of the mixture for strong cast-iron must be such that the resulting iron will have not only a low-graphite content, but also the graphite must be distributed in a form which closely resembles the distribution of that in black-heart malleable iron, *i.e.*, graphite produced by the decomposition of cementite and pearlite by subjecting white iron to high temperatures. Here we have two essentials, which, of all others, are least under the control of the foundryman. It may be taken as fairly axiomatic that if one starts at the cupola stage with a mixture high in total carbon, one will finish at the spout with a high total-carbon iron, no matter what the melting conditions may be. Inversely, if one starts with a low total-carbon mixture, it is not at all certain that a low total-carbon cast-iron will result.

This is well exemplified in making cast-iron containing very heavy steel-admixtures where, unless the melting conditions are very carefully defined, the resulting cast-iron is very high in the total carbon.

Hematite and "Off Irons."

Consequent on what has been said, it will be appreciated that hematite irons should not be used to any great extent for mixtures for high-grade work. Hematite irons are often a great temptation to ironfounders on account of their low phosphorus content and their cheapness when compared with cylinder and cold-blast irons, that is, they provide the simplest and at the present time decidedly the cheapest method of pulling down the phosphorus content of the lower grades of foundry iron. It should be remembered, however, that hematite irons are produced principally for the acid steel-maker, to whom low sulphur and phosphorus contents are factors of vital importance, and to whom total carbon matters nothing at all. It is quite true that the low total-carbon hematites can be obtained at times, but the irregularity of this element renders the iron of doubtful value. The writer has had consecutive deliveries of hematite iron, though fairly similar in analysis in other respects, vary as much as 1 per cent. in the total-carbon content. The low total-carbon hematite, when obtained, is very often an "off iron," *i.e.*, a production of abnormal working of the furnace. Abnormal irons are always untrustworthy and are a source of constant trouble to the foundryman. It is never good practice to use an iron which is not the normal regular product of a furnace.

FIG. 3.—FRACTURE OF AN IRON WHICH CONTAINED 4.25 PER CENT. SILICON.

Value of Fracture in a Pig-Iron.

The fracture exhibited by a normally-cooled pig-iron is a very useful guide as to its suitability for various work, if accompanied by the analysis. Without the analysis the considerations of the fracture are of little value. One of the fairly well-established axioms is that an open-fractured pig, no matter what the analysis may be, will give an open-fractured casting. On the other hand, a close-grained pig-iron will only give close-grained castings if its fracture corresponds fairly well with its analysis. What is known as a "dry" fracture among foundrymen (though close) should be looked upon unfavourably. A dry fracture may be generally interpreted as one which shows little or no exfoliation, or may be otherwise described as "crumbly" or "short." This type of fracture is, perhaps, seen to its best in a high sulphur (say 0.20 per cent.) fairly low-silicon iron. The large, spangled fracture of the foundry-numbers of hematite iron is, of course, well known, and the peculiar reticulated fracture of the cold-blast irons is fairly easy to identify.

FIG. 4.—SAMPLE OF UNDRILLABLE PIG-IRON OF NORMAL ANALYSIS.

The ideal fracture for an ordinary quality of pig-iron for foundry work is one which has a granular structure, which even over the whole section—not close at the outside and open in the centre, but of an even greyness (varying according to its analysis) throughout. While on the subject of fractures, it may be interesting to cite one or two examples of strikingly anomalous fractures presented by pig-irons. Fig. 2 shows a photograph of a fracture of a consignment of Scotch pig-iron of a well-known brand. As will be seen, the pig-iron is very open in character, on fracture would at least pass for a No. 3 with 2.50 to 3.0 silicon. The full analysis showed 3.78 T.C., 3.25 Gr.; 0.53 C.C.; 0.32 Si.; 0.053 S.; 0.242 P., and 0.75 Mn. per cent. This was not a stray piece, but the whole of the consignment of 25 tons was the same. There is nothing in the analysis which could possibly account for the fracture.

Fig. 3 shows the fracture of a sample of pig-iron of a well-known brand. On fracture, this would be graded as a No. 4 or even a No. 5, but actually the analysis showed the silicon content to be 4.36 per cent. silicon. Microscopic examination failed to reveal any signs of the pig-iron being artificially chilled, and the pearlite present was well laminated.

It is not contended that such striking examples as these are extremely numerous, but the same sort of thing, in a minor degree, is regularly observable by those who study the fractures in conjunction with the analysis.

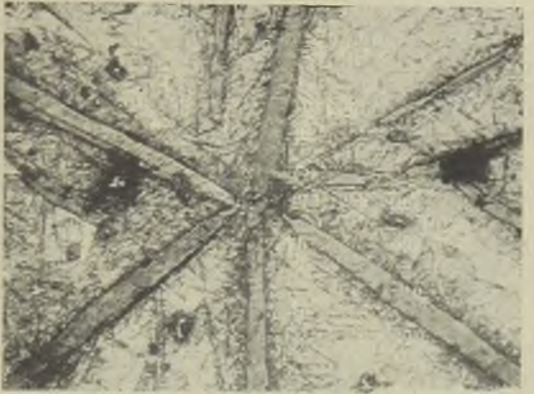


FIG. 5.—MICROSTRUCTURE OF THE SAMPLE SHOWN IN FIG. 3.

One does sometimes get anomalous fractures which can be suitably explained if traced back sufficiently far. Such is the case of a pig-iron the fracture of which is shown in Fig. 4. The analysis was 3.85 T.C., 3.35 Gr.; 0.50 C.C.; 2.04 Si.; 0.023 S., 1.18 P., and 1.83 per cent. Mn. For the sample and details of this pig-iron the writer is indebted to his friend, Mr. W. H. Poole, of the Keighley Laboratories.

This pig-iron, as will be seen, is of quite normal analysis, but yet none of the consignment could be drilled, even with a specially hardened tool. The microscope, in this case, showed the cause of the extreme hardness. As will be seen from the microphotograph in Fig. 5, the structure consists of large graphite flakes embedded in a matrix of a martensitic character, and the usual phosphide eutectic lakes. The martensitic is, of course, the cause of the extreme hardness.

Mr. Poole found that this unusual structure and fracture was due to quenching off the pigs in the bed above the point where the austenite decomposes, but not sufficiently high to prevent the almost complete separation of graphite.

Such a sample would probably, on re-melting, give an iron with a structure and fracture comparable to the analysis, but it is extremely doubtful whether such would be the case with samples previously mentioned.

The Fallacy of Relying Wholly on Analysis.

The mixing used for a particular class of work in a foundry with which the writer has been connected consisted of 30 selected home scrap, 10 mild-steel scrap, 20 cold-blast No. 4, and 40 per cent. cylinder pig "X." This mixing, owing to the extreme consistency of consecutive deliveries of the pig-irons used, shows an almost monotonous regularity in the analysis and test results which are taken daily. On one occasion another cylinder pig-iron, which shall be called "Y," was substituted for "X." The analysis of "X" was 3.06 T.C., 2.53 Si., 0.056 S., 0.62 P., and 1.86 per cent. Mn., and that of "Y" 3.15 T.C., 2.31 Si., 0.070 S., 0.71 P., and 1.45 per cent. Mn. As will be seen, cylinder "X" shows a slightly superior analysis, but there is no very material difference. The difference in price was 27s. 6d. per ton.

Table IV shows the averaged analyses of a standard mixing for the three weeks immediately preceding the introduction of the pig "Y," and the average of the daily physical tests. Two bars showing flaws have been omitted. Alongside are the averaged analyses and physical tests for the three weeks following, using pig "Y." The difference in the physical tests is quite definite. The behaviour of the metal in the ladle was also very noticeable. The standard mixing was perfectly clean when molten, even at low temperatures, but the mixing containing cylinder pig "Y" clean at a blue-white heat, but as soon as the temperature dropped was very dirty, and scum was continually rising to the top of the ladle. The surface of the resulting casting was by no means as clean, and several important parts machined all over failed to clean up satisfactorily where the machining allowance was small. The fracture of the test bars was also interesting. The standard mixing was dense grey throughout, but the mixing with cylinder pig "Y" showed a tendency to openness at the centre, although quite close on the outside.

TABLE IV.—*Showing the Influence of Changing a Brand of Iron.*

	Standard Mixing. (Average 13 Bars.)	Mixing with Cylinder Pig 'Y.' (Average 12 Bars.)
Total Carbon	3.13 per cent.	3.20 per cent.
Graphitic Carbon ..	2.37 „	2.42 „
Combined Carbon ..	0.76 „	0.78 „
Silicon	1.32 „	1.25 „
Sulphur	0.093 „	0.105 „
Phosphorus	0.65 „	0.71 „
Manganese	0.61 „	0.54 „
Transverse Test 12 in. × 1 in. × 1 in.	36.6 cwts.	29.8 cwts.
Tensile Test	16.8 tons	15.51 tons
Impact Test	23.2 ft.-lbs.	18.4 ft.-lbs.

This example naturally leads to the question of cylinder pig-irons. A great many blast-furnace people seem to think that they have only to cut the phosphorus in their pig to 0.5 per cent., raise the manganese to 1.5 per cent., call it cylinder, and they have iron worth two pounds a ton more than the ordinary grades. The writer can point out at least four specific brands of the so-called cylinder pig which regularly contain 3.5 to 3.6 per cent. of total carbon. A cylinder pig-iron, to be worthy of the name and price demanded, should represent the strict mean between a hot-blast foundry iron and an all-mine Staffordshire cold-blast iron. That is, it should be produced in semi-cold blast furnaces, and have a total carbon not exceeding 3.2 per cent. when the silicon is from 1.0 to 2.0 per cent. Also, it should be regular in composition. An iron which is irregular in composition is a real nuisance, and necessitates constant manipulation of the mixing, *i.e.*, juggling with the amounts of the various components. No iron is worth an enhanced price unless it is definitely regular in every respect.

Cold Blast Irons.

When one touches on cold-blast iron, it is reviving old memories for many foundrymen, for it is now only a memory to many people. The present depression and the high price has nearly killed the use of, if not the faith in, cold-blast iron, but the essential fact remains. One cannot get as good cupola-melted cast-iron without cold-blast iron as with it. This is stated quite dogmatically and without quibbling. The writer, in stating this, does not refer to any particular physical characteristic of cast-iron, but to all-round general properties. The nodular form of graphite is more well developed in cupola-melted cast-iron containing cold-blast than in any other.

The statement that the working temperature of a blast furnace, apart from the analysis of the finished pig-iron, has a profound effect on the graphite structure which persists, even after remelting in the cupola, is one which is deserving of serious consideration. Admittedly no tenable theory has yet been propounded to explain this phenomena or even as yet no thoroughly unchallengeable experimental data to support it has been given.

This position is, however, only in line with practically all our other knowledge, *i.e.*, we know the effect nearly always before we know the cause.

Electric Furnace Cast-iron.

The writer had the opportunity some few months ago of running several heats of cast-iron in an electric furnace, and the results were so remarkably good and illustrate so well many of the points which he has attempted to bring out in the Paper that no apology is offered for giving a *précis* of the results here. The furnace was an arc furnace of the Heroult type and acid-lined. The materials charged varied, as is shown in Table V, and no attempt at refining was made, the materials being merely melted under a lime slag. The figures given cannot be supposed to represent finality, as these were all experimental runs. The final composition of Charge No. 3 was made by making the necessary additions to a steel bath obtained by melting borings. The low total carbon is very significant, and although the combined carbon is only 0.26 per cent., the tensile strength reached 17.10 tons per sq. in. The writer has never seen any data from cupola iron showing such remarkable figures for high silicon, low combined carbon iron. The low graphitic carbon is undoubtedly the main cause of the high-test figures, coupled with higher casting temperature and general greater cleanness of the iron. The second example quoted, Charge No. 7, was run with a lower silicon-content but with a higher phosphorus. The results in this case demonstrate the value of a low total-carbon and the unimportance of combined carbon *per se* as affecting strength.

TABLE V.—*Electric Furnace Heats.*

Heat No.	3	7	4
T.C.	2.71	2.89	2.91
Gr. C.	2.45	2.53	2.19
C.C.	0.26	0.36	0.72
Si.	3.15	2.64	1.86
S.	0.086	0.092	0.10
P.	0.093	0.868	0.36
Mn.	0.71	0.53	0.41
Tensile Test, in tons per sq. in. on 1 in. dia. cast bar	17.10	16.60	18.6
Transverse Test, in cwts. on 15 in. × 1 in. × 1 in. cast bar	38	41.2	47.0
Deflection in ins.	0.19	0.14	0.18

NOTE.—Cast No. 3 is made from steel scrap, silico spiegel ferro-silicon, and graphite; Cast No. 7, from No. 1 Pig, steel and ferro-silicon, and Cast No. 4, from steel scrap, ferro-silicon, spiegel and graphite.

The last example, Charge No. 4, gives a higher test-result that the writer has ever seen for the same silicon content. Here the total carbon was down, and the graphitic carbon at an extremely low figure, and the iron was only machined with great difficulty.

Steel as a Pig-iron Substitute.

The experiences of ironfounders in the use of steel scrap as a component of cast-iron vary very widely from wholesale condemnation to whole-hearted praise. The great variations in results are chiefly due to variations in melting conditions. Speaking strictly from personal experience, the writer has found that with ordinary rapid melting-practice, uniformly good all-round results cannot be obtained from cast-iron containing more than 20 per cent. of steel. If it is desired to incorporate more than this percentage of steel in the iron, then the best practice is to run a high-percentage steel-mixture into pigs and remelt. Naturally it is more economical to purchase such a refined pig-iron from large makers. Refined pig-irons are generally produced in a similar manner, i.e., by melting steel scrap with pig, though more often not in the cupola.

Summary.

To summarise briefly the main points which the writer has endeavoured to bring out:—

(1) Pig-irons should be selected which will give the correct analysis in the finished casting, but it should be remembered that correct analysis is only about half the battle.

(2) Brands should be selected which experience has shown are associated with clean melting, close grain and high strength and which are regular in composition.

(3) Open-grained irons and abnormal irons, such as "over greys," etc., should be avoided despite their analyses.

(4) Keep the total carbon as low as possible and use low total carbon pigs, *i.e.*, cold-blast and semi-cold blast.

In conclusion the writer would like to point out that the present stage of our knowledge is so imperfect that we cannot afford to neglect any factor in the production of cast-iron. No one can yet reject any phase in cast-iron production from the mine to the fettling shop as being unimportant and without bearing on the final product. There is no doubt that as our knowledge increases the factors affecting the strength and casting properties of cast-iron will be more clearly defined, and certain variations in treatment will be found to have no bearing on these properties, but it is also extremely likely that variations, to which little attention is now paid, will be found to exert a profound influence. It is only, therefore, by paying attention to every side of the question with an unprejudiced mind that we can hope to progress in the knowledge of that extremely complex material—cast-iron.

London Branch.

THE FOUNDRY CUPOLA AND MECHANICAL CHARGING.

By A. A. Liardet, Member.

The re-melting of pig-iron and scrap for the production of grey and white-iron castings may be carried out by two distinct types of furnaces—the reverbatory or air furnace and the cupola furnace.

The name cupola was undoubtedly taken from the shape of some of the earlier furnaces, which resembled a dome-shaped building, being gradually tapered away from the centre diameter to that of the top, and in some cases actually closed in.

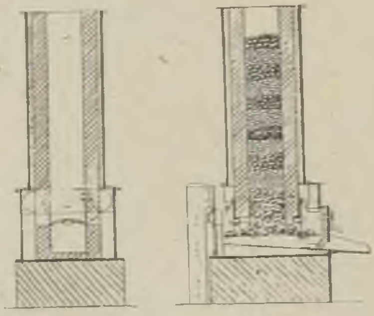


Fig. 1.—Krigar's Cupola.

The reverbatory or air furnace does not come within the scope of this Paper; suffice it to say, that it is more generally used where the material to be charged consists of heavy scrap iron which cannot be broken up for charging into a cupola, or where very heavy castings have to be made. The air furnace is more often used in malleable iron foundries. The cupola is also used for melting white iron, and is cheaper to operate than the air furnace, but unless care is taken there is a tendency for the metal to burn.

The cupola is a shaft furnace, consisting of a vertical firebrick shaft of rectangular, oval or circular section, held together by mild-steel plates.

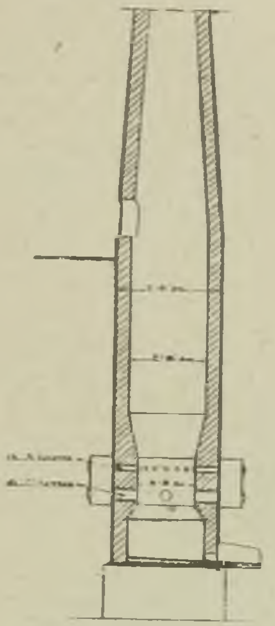


Fig. 2.—Ireland's Cupola.

The fuel and metal are charged into the top of the furnace, a blast of air is introduced at the lower end, and the molten metal drawn off at the bottom. This is the simple description of a cupola, and if a furnace were constructed on these simple lines, quite excellent results as regards the quality of the molten metal would be obtained, provided that the operator had a sound knowledge of melting. The problem which faces the designer of cupolas, however, is that of producing a furnace which will melt the most rapidly, produce the hottest metal with the least consumption of coke, and do this consistently and continuously over a reasonable length of time.

The key to the solution of this problem is a knowledge of the amount of fuel which will give sufficient heat to melt a certain quantity of iron in a given time, the necessary amount of air to give complete combustion of this fuel, and the requisite area of hearth in which to burn it.

When looked at in this light, we see there is a close resemblance in this problem to that of the steam boiler builder, who must know what heating surface, fuel, grate area and air are necessary to produce so many pounds of steam per hour.

The cupola builder, however, has a rather more complicated problem than the boiler builder, as he has to know the behaviour of various grades of material under certain heating conditions, whilst the boiler builder is dealing with one standard substance—water.

It is beyond the scope of this Paper to enter into what might be described as "the technology of combustion," but the chemical action which takes place in the cupola under blast requires consideration.

All the oxygen contained in the air blast should be consumed in burning up the fuel, and should combine with the carbon in it to form carbon dioxide (CO_2).

Carbon monoxide (CO), a gas which burns in the air with a blue lambent flame, should not be formed, although it is impossible to eliminate it altogether, as the hot CO_2 gas formed in the zone of combustion is bound to pick up some carbon as it passes through the layers of cold coke above, thus forming carbon monoxide. An analysis of the gases at the charging door in a cupola working under correct blast conditions should not show more than about 5 per cent. carbon monoxide and *an entire absence of oxygen.*

Cupola Gas should be Analysed.

The carbon dioxide should be about 16 to 18 per cent. An excess of carbon monoxide indicates an insufficiency of air, or lack of penetration of the blast to the combustion zone, whilst an excess of oxygen shows an excess of blast or bad distribution.

Cupola users would derive much useful information, and in all probability make economies in fuel consumption from this information, if they took samples and analysed the cupola gases at regular intervals. The samples should be taken below the charging door, as naturally, above, the gases are diluted by the air drawn in at this point. An excessive blue flame burning in the upper portion of the stack above the charging door should immediately arouse suspicion that the quantity or distribution of the air blast is not correct, as it

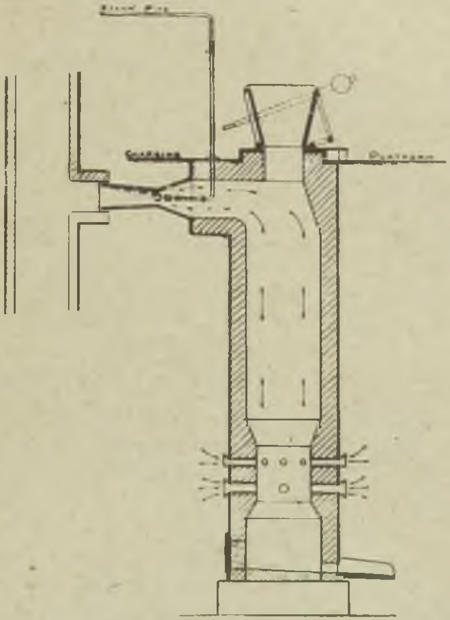


FIG. 3.—WOODWARD'S STEAM-JET CUPOLA.

indicates the presence of an excess of the carbon monoxide referred to above.

The combustion of coke when melting iron is set out in Table I.

TABLE I.—*Combustion of Coke.*

1 lb. of average quality coke contains 0.88 lbs. of carbon.

30 cub. ft. of oxygen are required to combust 1 lb. of carbon to CO_2.

∴ 1 lb. of coke requires approximately 26 cub. ft. of oxygen.

Air contains approximately one-fifth of its volume of oxygen.

∴ 1 lb. of coke requires approximately 130 cub ft. of air to complete combustion.

Calculated from the calorific value of the coke and the British Thermal Units necessary to raise 1 lb. of iron to slightly above its melting point, it is found 83 *lbs. of coke* will melt 1 ton of iron.

The necessary quantity of air to burn this coke would be approximately 11,000 cub. ft.

Losses in the Cupola.

1. Incomplete combustion of fuel	34 per cent.
2. Loss of heat in ascending gases, radiation and slag ...	6.5 per cent.
3. Moisture in fuel	3.5 per cent.
4. Ash from fuel	6.5 per cent.
Total	50.5 per cent.

Say 50 per cent. Therefore, under these conditions, to melt 1 ton of iron, 166 lbs. of coke would be required and 22,000 cub. ft. of air.

The theoretically perfect figure should be noted and considered in conjunction with some of the extravagant claims made by some cupola makers and users as to fuel consumption.

These ideal conditions can never be realised in practice; as has been shown, the coke is only burnt partially to carbon dioxide, heat is lost through the chimney of the cupola and through the slag hole, water is often present in the coke, heat is lost in the slag, and general radiation is taking place.

It is not unreasonable to assume that the total of these losses would reduce the efficiency of the cupola to about 50 per cent., by far the greater loss occurring from the incomplete combustion of the fuel, showing that this is the most important factor in determining the efficiency of a cupola

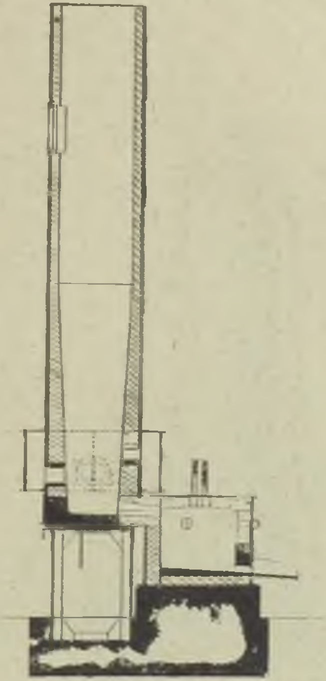


Fig. 4.—Thwaites Ultra Rapid Cupola with Receiver.

Hence a cupola having a 50 per cent. thermal efficiency will consume 166 lbs. of coke for every ton of iron melted, a result which is rarely, if ever, achieved in actual practice.

Returning again to the question of the necessary air to burn this amount of coke, we find that

18,200 cub. ft. is required. These figures are purely theoretical, and we shall see later from practical examples actual quantities of fuel and air which are used.

Early Forms of Cupolas.

Fig. 1 illustrates an early type of cupola rectangular in form. It was generally known as Krigar's cupola, of German origin, in use about 1860. The shaft was made oblong or square in section and parallel in length. A backing of sand is used between the brickwork and shell, to assist in preventing radiation. This brickwork is supported at the front and back by arches over a lower chamber or well. Around the bottom of the shaft and over these arches is arranged the air

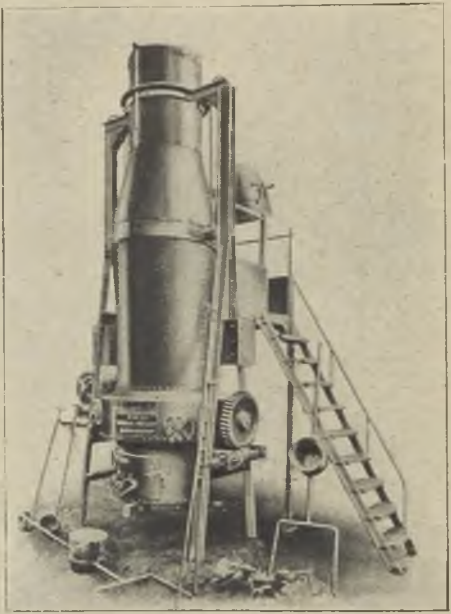


FIG. 5.—A CUPOLETTE, AS SUPPLIED BY THE CONSTRUCTIONAL ENGINEERING COMPANY.

passage, into which air is delivered by two mains. The air, entering this passage, cools the brickwork and also becomes heated by being in contact with it. The air passes down into the melting chamber through two long slots in the roof extending right across the width of the hearth. The front of the cupola is closed by an iron door on hinges; a smaller door is placed at the back.

The charging of this cupola appears to have been very similar to the present-day practice. One having a capacity of 3 tons per hour requires a filling of 2¾ cwts. of coke for starting it, then a charge of 8 cwts. of iron, then ½ cwt. of coke, and so on alternately. The average quantity of coke consumed was 1½ cwts. per ton of iron melted, based on a total blow of 3 tons and as low as 1¼ cwts. for blows over 6 tons. These particulars have been taken from a description of this German cupola, read before the Institution of Mechanical Engineers in 1868. The author can only surmise that, as this date was previous to the introduction of by-product plants in connection with coke manufacture, the coke was far better in quality, or perhaps the iron was more easily melted, or, again, the cupola manufacturers of that day were even more optimistic in their statements of coke consumption than they are to-day. This cupola has, in the author's opinion, one fault in design which cannot lead to economy of fuel consumption, the blast coming through the air passages not only abstracts heat from the brickwork, but also from the metal itself contained in the well at the bottom. Any slight advantage that may be obtained by the increased temperature of the blast must be outweighed by the chilling of the metal.

It is interesting to note that more recent designs of cupolas constructed by the same German —Krigar of Hanover—almost invariably include a forehearth or receiver, while the tuyeres are arranged radially in a single row around the walls of the cupola, slightly above the point where the metal flows into the receiver.

Another of the early forms of furnaces was known as Ireland's cupola. In its original design, this cupola was constructed with a bosh underneath the melting zone, of a larger diameter to give an increased capacity for liquid metal. It had two rows of tuyeres, one row being just above this bosh and the other near the base of it. Later designs of this cupola are very similar to modern practice. Fig. 2 shows in diagrammatic form particulars of two 7-ft. diameter cupolas of Ireland's design which were used in 1866 for casting a large anvil-block weighing 205 tons. Actually, 220 tons of metal were melted by the two cupolas in 10¾ hours; the coke consumption was only 1¼ cwts. per ton of iron melted. The blast pressure was 14 ozs.

FIG. 6.—SHOWING ALL-STEEL DROP BOTTOM.

Analysing the figures and dimensions, we find that each cupola melted approximately 10 tons of metal per hour, the hearth area approximates 160 sq. in. per ton per hour, and the tuyere area is one-fifth of the hearth area.

These figures are very little different from those adopted as a standard by some makers to-day. The author is of the opinion that an improvement in the melting performance would have been obtained by increasing the tuyere area.

Although a common present-day empirical figure is 10 lbs. of iron per hour for every sq. in. of hearth area, equivalent to 224 sq. in. per ton, yet it has been proved very conclusively from actual tests taken that this can be greatly improved if the proportion of tuyere area is increased. For cupolas of medium and large capacity, say from 4 tons per hour and upwards, the hearth area may be safely taken at a minimum of 150 sq. in. per ton per hour, with a tuyere ratio of not less than one-third, that is, 50 sq. in. of tuyere area per ton per hour.

Steam Jet Cupolas.

Cupolas have been worked with a steam jet to create an induced draught. Fig. 3 shows the arrangement of one known as Woodward's steam-jet cupola. It was claimed for this cupola that it was economical in coke consumption, and that the steam used was no more than that required to drive a fan or blower for ordinary blast. The air is drawn in through openings placed radially like ordinary blast tuyeres. These can be controlled from the outside by the closing or partial closing of a hinged cover over the opening. The author has not been able to obtain any information as to the actual performance of one of these cupolas. It is obvious, however, that, as the actual pressure of air inside this cupola will be less than that of the atmosphere, there would be a danger of air leaking in at various points of the cupola chimney, through badly-made brickwork, causing bad combustion of the fuel. The fact that the charging door would have to be more

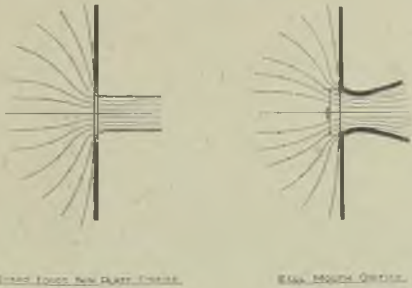


FIG. 7.—SHOWING ORDINARY AND *vena contracta* TUYERES.

or less hermetically sealed after each charge, appears to break down any claim of simplicity in design, which might be made owing to the absence of blowing apparatus and connections to tuyeres.

The modern cupola is almost invariably of the vertical type, having horizontal tuyeres in one or more rows near the bottom of the furnace. The majority of makes are fitted with an air belt for the distribution of the blast to the tuyeres, usually arranged so that these open directly into the air belt. An examination of the proportion of hearth and tuyere area in the various makes of cupolas reveals a complete absence of any general standard.

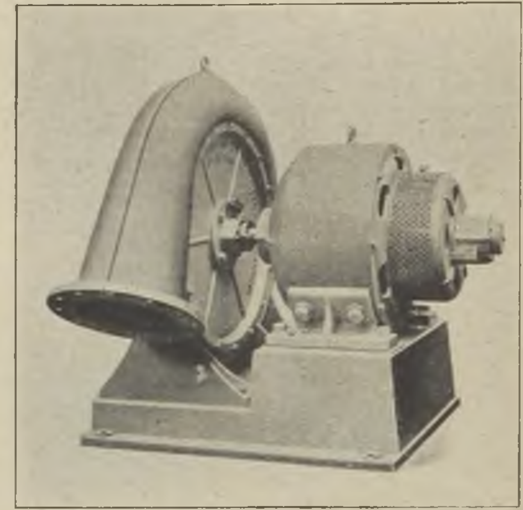


FIG. 8.—A KEITH-BLACKMAN FAN AND MOTOR MOUNTED ON THE SAME BED.

Four well-known makes, each having a nominal capacity of 4 tons per hour, were recently examined by the author, with the astonishing differences shown in Table II.

The last, as will be gathered from a previous statement, is the standard now adopted by the firm with which the author was connected.

Fig. 4 shows the Thwaites Ultra-Rapid cupola, fitted with a receiver, and Fig. 5 a Constructional Engineering Company's cupolette. This plant is designed to give small quantities of very hot metal, such as in bedstead foundries. It can be tilted for repairs, and the tuyeres can be regulated by quadrant levers, giving the furnaceman an increase of control which could not otherwise be obtained.

TABLE II.—*A Comparison of Four Types of Cupolas.*

	Area of hearth per ton.	Area of tuyeres per ton.	Ratio hearth tuyeres.
A.	220 sq. in.	25 sq. in.	8.8
B.	265 sq. in.	56.25 sq. in.	4.7
C.	180 sq. in.	14 sq. in.	27.1
D.	150 sq. in.	50 sq. in.	3

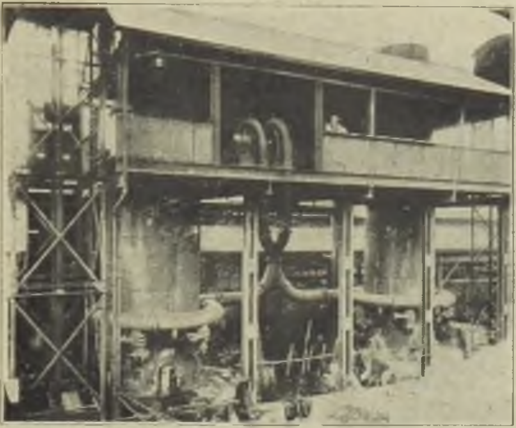


FIG. 9.—SHOWS A CUPOLA INSTALLATION BEING DRIVEN BY A KEITH-BLACKMAN FAN.

Receivers.

There is a great deal of diversity of opinion regarding the advantage of using receivers. The author has found it the best plan to leave the decision as to whether a receiver should be fitted or not to the prospective user, after having pointed out what, in his opinion, are the advantages. Where the practice in the foundry is to take small quantities of metal from the furnace continuously during the process of melting, then there is no advantage in having a receiver. If, however, the work is of a varying nature, heavy and light castings with variations in the mixture, then a receiver is undoubtedly an advantage. The receiver takes the place of a large ladle placed in front of the cupola, with the great advantage of having the hot gases from the cupola constantly playing on to the surface of this metal and maintaining it at its original temperature. Better mixing of the metal is thus assured, and the molten metal does not remain so long in contact with the coke. The bosh of the cupola itself may be very much smaller, as it is not required to store molten metal, which means an economy in the coke necessary to form the bed. The likelihood of slag getting into the tuyeres is also absent, as all slagging is carried out in the receiver itself, the melting therefore is very much cleaner. The usual method in a foundry having a cupola and receiver is to cast a fairly heavy section casting first, one not requiring very hot metal, as the receiver certainly has a tendency to chill the first

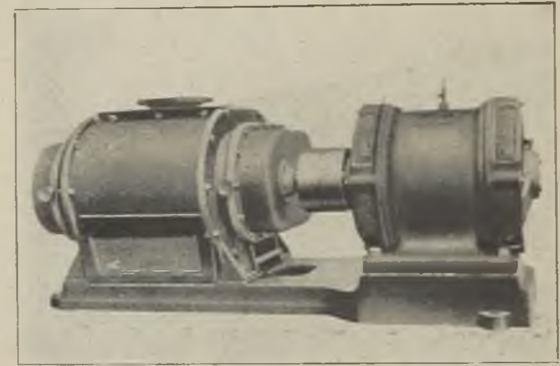


Fig. 10.—A Thwaites' Direct-coupled High-speed Motor-driven Blower, fitted with Hoffman Roller Bearings.

metal. The hand-shank work can be cast up at the end of the blow. In fact, metal can be taken from the receiver for some considerable time after the blast has been shut off, and the process of removing the charge from the cupola proceeded with.

Drop Bottoms.

A cupola fitted with a drop bottom is undoubtedly a great time saver, at the end of the blow, as the whole of the charge may be dropped on the floor within a few minutes of the blast being shut off. It also greatly facilitates the patching up of the lining around the tuyeres, as the operator can stand inside the cupola. On the other hand, additional work is required in making up the bottom after every blow. The risk of metal coming through the drop bottom doors is infinitesimal if the making up is properly done.

Fig. 6 illustrates the all steel drop bottom, which is a feature of the design of the cupola made by the firm with which the author was connected.

Coke Consumption.

It has already been shown that in a cupola working at 50 per cent. thermal efficiency the coke consumption would be approximately 166 lb. to the ton of iron melted. Large cupolas working over long continuous periods have come out with a consumption of slightly over 1¼ cwt. per ton, but the average iron foundry cupola of medium capacity, say, 5 to 6 tons per hour, over blows of three hours duration, rarely, if ever, gives such results. There is a very great difference between the results which can be obtained on a specially conducted test, where the closest attention is paid to all details, and those obtained over a period under working conditions. It is not safe to base calculations of melting costs on a less figure than 2 cwt. of coke per ton of iron melted, including the necessary bed charge. This is undoubtedly the amount of coke which would have to be paid for by the foundry owner, and after all, that is the most important point. If, on the other hand, the coke consumption is higher than this, there is something wrong somewhere, as from what has been shown it means that the melting plant is working at less than 30 per cent. efficiency. It should be understood that these figures regarding coke consumption are based on the melting of the ordinary mixtures met with in grey iron foundry practice. Hematite and white iron both require more fuel to melt.

Blast and Tuyeres.

To return once more to the question of the consumption of fuel, we see that a cupola running at 50 per cent. thermal efficiency required 22,000 cub. ft. of air for every ton of metal melted. The rating of a cupola is generally expressed as so many tons per hour, therefore this cupola will require for each ton 22,000 cub. ft. of free air per hour, or 365 cub. ft. of free air per minute. It has also been shown that in practice foundry cupolas are rarely met with working at so high an efficiency. It is usual to allow from about 400 to 500 cub. ft. of free air per min., varying inversely with the size of the cupola. This amount of air must be delivered in such a way to the cupola that it is evenly distributed through the burning coke to effect as nearly as possible its perfect combustion. In other words, its velocity must be such

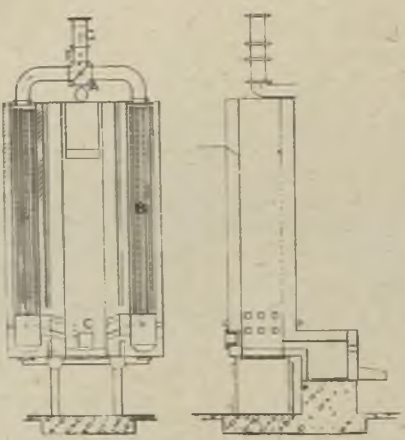


Fig. 11.—A Hot-blast Cupola of German Design.

that it is not too great thereby forcing the melting zone too high up the cupola, nor must it be too slow to trickle up the sides of the cupola, causing carbon monoxide to burn in the higher parts of the charge. It will be noticed in these conditions not a word is said about the pressure of the blast. Air pressure is only a necessary evil to force the desired quantity of air through the charge—it only indicates the velocity, and this is the only useful function it performs in connection with cupola melting. If the velocity could be obtained without pressure, it would save a very vast sum in the cost of the power taken to create the blast. Foundrymen have to do work and pay for power to compress the air only to let it expand again inside the cupola. It is very evident, therefore, that to obtain economical working the pressure must be kept as low as possible without reducing the velocity too much.

The resistance to the passage of the air through the cupola is made up of (1) the burden of the iron and fuel charge in the cupola; (2) the friction of the air passing through the tuyeres and (3) the friction of the air passing through the pipes and passages between the blower and cupola. The burden of the iron and fuel must exist, and we cannot alter it, therefore the cupola designer must confine his attention to the reduction of resistance in tuyeres, pipes and passages.

The author has already pointed out that from his experience a total tuyere area of approximately one-third of the hearth area is not too great, and with the correct quantity of blast gives the correct velocity. Tuyeres may be circular or oblong, but the chief essential is that they should be bellmouthed on the air belt side (Fig. 7), and also increase in cross sectional area as they enter the cupola. This forms what is called a *vena contracta* orifice, which will pass any given quantity of air with the minimum amount of resistance. In addition, this shape gives a good spreading effect to the blast inside the cupola. Pipes and passages can be dealt with by keeping their cross-sectional area large, avoiding sharp bends in the pipe line and keeping the blowing unit as near to the cupola as practical.

A water gauge reading taken at the cupola air belt, and also at the outlet of the blower, would in some foundries which the author has visited show such a difference that the users would be astounded at the amount of money they were daily throwing into the blast main in the form of wasted power.

Disposition of Tuyeres.

The author believes in having two rows of tuyeres in a cupola, preferably with control valves on the top row; this arrangement gives a better distribution of blast and enables a better control to be maintained on the melting, especially in the later stages when the cupola is very hot.

A word on the vexed question of semi-positive blowers versus centrifugal fans. Although it may be considered that the author may be prejudiced on this subject, he maintains that for correct melting conditions a positive or semi-positive blowing apparatus is an essential. All the arguments advanced in this Paper for successful cupola operation are based on correct fuel consumption, in its turn entirely dependent on the correct quantity of blast.

Blowing Apparatus.

The only blowing apparatus which is entirely capable of supplying a known quantity of blast under varying conditions of resistance is the old-fashioned reciprocating blowing engine. The machine which comes next in order of merit capable of doing this is the Roots blower. The blowing engine is cumbersome and has the disadvantage of creating a pulsating blast, but still it can measure out the same volume revolution by revolution independent of anything that is happening in the cupola.

The volume from a Roots blower running at constant speed varies but very little following variations in resistance. At the usual speed at which it is run the pulsations of the blast are hardly perceptible. The centrifugal fan produces the pressure, or velocity of the air, by the speed of the circumference of the disc, so that if its speed is constant any reduction in the resistance of the cupola immediately causes an increase in the volume of air, while any increase in the resistance rapidly reduces the volume delivered, a conditions most undesirable for consistent melting.

Electrically-driven fans working on a direct current supply are so arranged that any falling off in the volume of air automatically brings about an increase in speed. This overcomes the difficulty to a certain extent, but this cannot be accomplished with the belt-driven type.

The author is aware that there are many installations working satisfactorily with centrifugal fans, so he advances his opinions with a certain amount of deference, although with none the less conviction. Fig. 8 shows a Keith-Blackman fan and motor mounted on the same bed, and Fig. 9 a cupola installation being driven by this method.

The latest development in Roots blowers, building them throughout on precision roller bearings, enables them to be run at much higher speeds, so that much smaller machines are now installed for any given duty, whilst the higher speed gives increased efficiency. Fig. 10 shows a Thwaites direct-coupled high-speed motor driven blower. It is fitted with Hoffman roller bearings. The machine is totally enclosed. The smaller sizes of these machines can run up to 1,500 r.p.m.

Hot Blast Cupolas.

Whilst dealing with the question of blast it might be as well to refer to hot blast for cupolas. Several attempts have been made to introduce this, but with little success, as the average foundry cupola remains such a comparatively short time in blast that any heat that is imparted to the blast only produces an effect towards the end of the blow. It is obvious that if a satisfactory and reliable hot blast cupola could be devised, an improvement would be made in the thermal efficiency of the cupola.

Fig. 11 illustrates a hot blast cupola of German design. It incorporates an arrangement similar to a Cowper regenerator for blast furnaces.

This cupola apparently works approximately 10 hours continuously per day, and it is claimed that the coke consumption does not exceed 145 lb. per ton, which means a thermal efficiency of over 60 per cent.

Analysis of the waste gases gave 5 per cent. CO and 14 per cent. CO_2, almost the ideal analysis laid down at the beginning of this Paper. The cupola is 36 in. internal diameter, melts 5½ tons per hour, giving a hearth area of 180 sq. in. per ton and is supplied with 2,650 cub. ft. of air per min. or 480 cub. ft. per min. per ton per hour.

The Mechanical Charging of Cupolas.

The mechanical charging of cupolas is by no means a novelty. It is being carried out successfully in America, Germany, France and Belgium and also to a limited extent in this country.

In spite of this fact, in each of these countries there still exist practical foundrymen of wide experience who claim that mechanical charging of cupolas cannot give such good melting results as the older method of hand charging.

The author is of the opinion that these gentlemen must have some very good reason to back up their opinions. Probably this reason can be traced back to an experiment carried out with some form of mechanical charging apparatus that was not properly constructed and therefore gave bad results.

There is no reason why a cupola should not be charged by mechanical means to give at any rate results equal to those of hand charging, and under certain conditions better and more consistent results can be obtained, as the human element is to a great extent eliminated.

It is difficult to conceive that an operator can throw the pig-iron into a cupola in such a way that each pig lies beside its neighbour and forms a perfect layer, especially when the pigs have to be thrown into the furnace door from which hot gases and even flames may be issuing.

As a theoretical argument the possibility of doing this can be advanced, but anyone who has spent some time on a foundry cupola platform while the cupola is in blast will have noticed that to avoid the heat of the gases issuing from the furnace the operator generally has become skilled in throwing the pig-iron through the furnace door while his back is turned towards it.

Methods Used.

The mechanical charging of cupolas may be performed in several ways. First by the inclined skep hoist which elevates small trucks from the ground level and tips fuel and coke directly into the cupola. This system is applicable for small or medium-sized melting units and does away with the necessity of a charging platform.

Secondly, by elevating small wagons containing the necessary charges by means of a hoist to the platform level. The trucks run on rails, and by means of turntables can be brought directly opposite the charging door of the cupola, where their contents are tipped directly into it.

Thirdly, by an overhead runway system having electrically operated hoisting gear which lifts the material directly from the stockyard and delivers it directly into the cupolas.

FIG. 12.—SHOWING TRUCKS IN THE ACT OF TIPPING CONTENTS INTO THE CUPOLA.

When a new foundry is being constructed it is well worth taking into consideration the possibility of arranging the railway siding upon which the incoming material arrives, so that the end at which the material is discharged is on the same level as the charging door of the cupolas.

In some cases the nature of the ground upon which the foundry is erected makes this a simple matter to accomplish, but under any conditions it is not a very difficult matter to provide for a siding gradually rising away from the railway track to the ultimate destination of the trucks.

The metal and fuel arriving by this siding can either be dumped directly from the railway truck by means of an overhead travelling crane into the stockyard or placed into small wagons running on rails leading to the actual charging door of the cupolas.

Several methods can be adopted for the actual tipping of these trucks; the truck itself may be of the tipping type. When it arrives at the predetermined point it can be tipped either by hand or by a small pneumatic lift placed immediately over it so that its contents drop into a chute leading directly into the cupola.

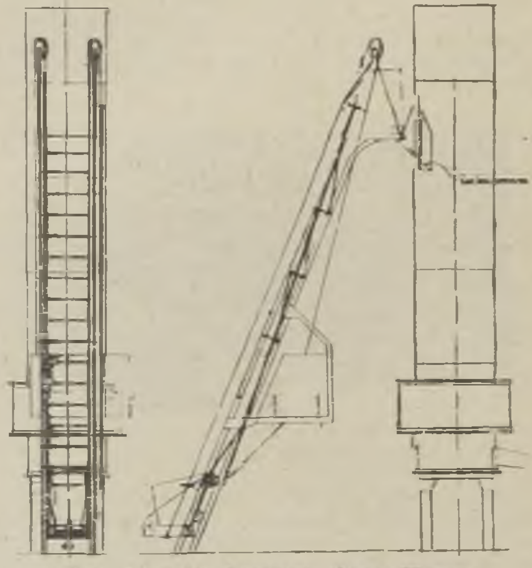


Fig. 13.—An Inclined Skep Hoist.

Another method which is used pretty generally in the United States is to have a pneumatically operated hinged platform immediately opposite the charging door, the truck being pushed on to this, locked in position and is then pushed over by the pneumatic cylinder to such an angle that its contents are tipped into the cupola.

This arrangement is illustrated in Fig. 12.

The author is aware that there are several foundries in this country so situated that the materials for their cupolas are delivered from the railway siding on to the actual platform level, but very few of them appear to take full advantage of this labour-saving condition by handling the material directly from the trucks into the cupolas by mechanical means. The majority still appear to prefer to stack the material on the platform and afterwards charge it by hand into the cupolas.

To return to the cupola installation where the material is brought either by railway wagon or by road vehicle to the foundry floor level, we find that the usual practice is to stack the pig-iron according to the various qualities in the stockyard. It is needless to say in passing that the fuel should be kept under cover to avoid absorbing unnecessary moisture from the weather.

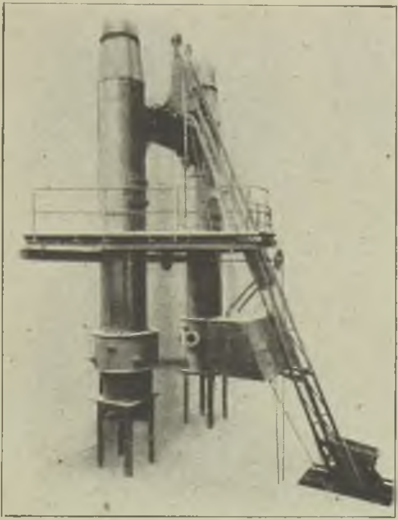


Fig. 14.—Showing Application of the Skep Hoist to Two Cupolas.

In this case, if we decide upon mechanical charging, we then have the choice of the three methods mentioned earlier in this Paper of transporting the material into the furnace itself.

Undoubtedly in the case of the small- or medium-sized foundry having not more than two cupolas, the only method which would not be prohibitive in first cost is the inclined skep hoist.

Fig. 13 illustrates an apparatus of this nature operating in connection with a cupola of 4½ tons capacity per hour. The hoist itself, which is operated by an electric motor, is fitted with a cradle running in the angle-iron framework.

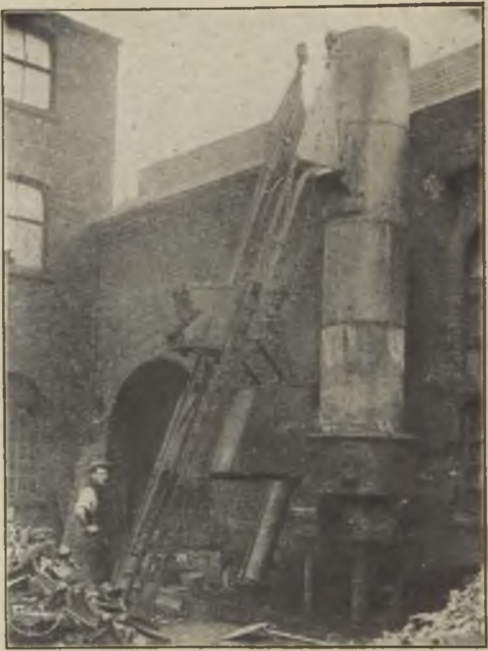


Fig. 15.—A British Mechanically-charged Cupola Plant.

This carriage is fitted with guiding rails and a locking device, so that trucks fitted with either flanged or flat wheels according as it is considered desirable to run them on a flat surface or rails, are loaded with the necessary pig-iron and fuel in the stockyard, pass over a weighbridge to check the amount, and are then wheeled into the cradle. The hoisting mechanism then elevates the cradle with the truck and tips the contents of it directly into the cupola.

From Fig. 13 it will be seen that a special form of hopper is fitted to the cupola which causes the contents of the truck to slide slowly into the cupola, at the same time spreading it so that there is no tendency for the charge to heap up against either one or other side of the cupola lining.

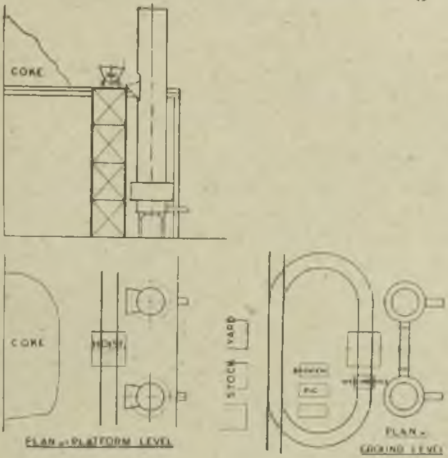


Fig. 16.—Illustrating a Method of Mechanically Charging two or more Cupolas.

It will, of course, be obvious that with an apparatus of this nature it is not possible to charge the cupola right up to the level of the charging door, as, were this done, the last charge would lie at an angle in the cupola, and consequently as it worked down subsequent charges would also be at an angle, causing the alternate layers of coke and iron to partially mingle and not lie horizontally upon one another.

When the skep hoist is supplied with new cupolas, the charging door is arranged at a greater height than standard practice. Where this type of machine is installed with existing cupolas it is usual to cut a charging door at a higher level than the existing door to maintain the charge at the original working height. It will be observed that the hoisting mechanism forms part of the machine, and is so arranged that one simple hand lever operates the ascending and descending movements of the cradle, and when let go automatically puts on a brake holding the cradle in any position.

When the bucket tips at the top it automatically brings the lever to the central position, applying the brake.

This size machine has a capacity of 6 cwts. of iron and ½ cwt. of coke so that to keep in blast a cupola of 4½ tons of iron per hour, about 33 journeys have to be made, or one journey in every 1¾ minutes.

Several of these skep hoists are working satisfactorily in this country, and it will be obvious that they represent a saving in labour and a better control over the charging of the cupola. Fig. 14 shows its application to two cupolas, and Fig. 15 a British installation.

The second method of mechanical charging is illustrated in Fig. 16, and the author is indebted to Monsieur Thomas, of the firm of A. Piat & Company, of Soissons, France.

It will be seen that this system is very similar to the skep hoist charger except that an ordinary hoist is used to elevate the charges in the flanged wheel trucks, and when they arrive at the platform level they are moved along rails provided to receive them, until they are opposite the required cupola, when their contents are tipped directly into the furnace door.

An oval-shaped truck is provided on the ground level, which enables the trucks to move in one direction when coming from or returning to the stockyard.

Another interesting method of handling these laden trucks on the platform is shown in Fig. 17, which has been taken from a well-known American catalogue. The author has seen this method in successful operation in the States in several plants.

The loaded trucks when arriving at the platform level are placed on to an electrically-operated transporter having on it a turntable. This transporter moves the trucks opposite one or more sets of rails, which lead directly to the sides of the cupola charging doors and also to other rails provided on the platform for keeping loaded trucks in position for rapid charging.

In these plants the coke was not handled in the same way, but was stored in hoppers at a higher level than the cupola platform, and by means of a specially arranged shutter the correct quantity of coke was liberated from these hoppers and allowed to fall directly into the cupola charging doors.

The next method of charging cupolas, which is certainly expensive to instal but ensures the mechanical handling of the material directly from the stockyard to the cupola, is illustrated in Fig. 18, which is also taken from particulars supplied by Monsieur Thomas, of Piat et Cie., who has supplied the following particulars:—

FIG. 17.—AMERICAN METHOD OF HANDLING CUPOLA TRUCKS.

" Tackling the problem by an electric overhead runway is, in my opinion, the most satisfactory, yet at the same time is the most expensive. Fig. 18 shows how we apply it to the charging of the cupolas in our steel foundry. It is used for two distinct purposes: (1) Discharging and storing coke in bins, the bottoms of which are placed on the first stage platform; (2) the charging of the cupolas on the second stage. The coke railway wagon which has to be discharged is at (A), two workmen throw the contents by means of a coke fork into the tub (B), which has a capacity of 1½ cubic metres. When this is full, a workman, by operating the controller (C) raises the tub to the level of the overhead beam, and at the same time sets it moving in the direction of the arrow. The moment the tub passed a selected point (H) on the bin being filled it comes in contact with an adjustable arm which causes it to tip.

"As soon as the coke is emptied the bucket returns to its normal position and continues travelling on the runway until it arrives at the point it started from, where by again operating the controller it descends to the ground level in order to be refilled. Thus, the discharging of a wagon containing 20 tons of coke is readily carried out by two men in 45 minutes and with the minimum amount of exertion since the top of the tub is exactly level with the bottom of the wagon.

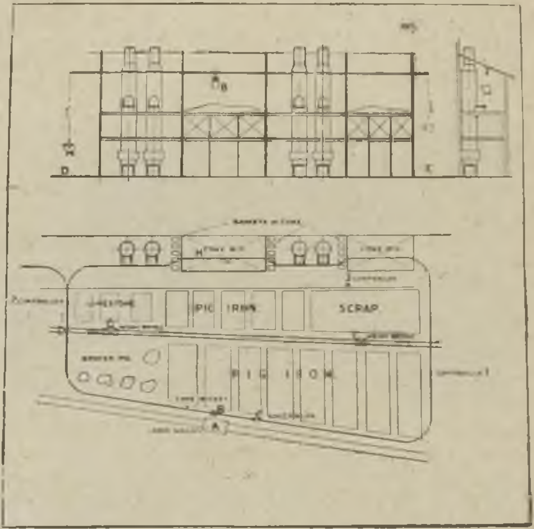


FIG. 18.

"The charging of cupolas is carried out as follows:—

"A small wagon filled with pig-iron—by methods which we shall discuss later—is waiting at the ground level at the despatching position D, the workman on the second stage charging platform operates a controller (2) which causes the hook of the electric winch to descend, this winch being attached to a carriage on the overhead runway, and having been brought to rest immediately over the small wagon. The workman in the stock-yards on the ground floor hooks on the wagon, which is then raised to the level of the overhead girder by another operation with the controller (2). Then the electric winch with its load starts automatically to move along in the direction of the arrow, and finally is automatically stopped in front of the cupola which is in blast. The cupola charger operates a small lever attached to this cupola which tips the wagon and allows its contents to be charged directly into the cupola, then by the further operation of one or other of the controllers on the platform according to which cupola is in blast, the empty wagon is carried forward on the runway and finally stops at B opposite the receiving position.

"The second workman employed in the stock-yard by operating controller (1) causes the empty wagon to descend. This wagon is fitted with whole travels on the overhead runway until it track B A, while the hook when freed from the wagon is elevated by the electric winch, and the whole travels on the overhead runway until it arrives immediately opposite the despatching position, and so on.

"Examine the work actually carried out in the stock-yard and on the charging platform, and, assuming that costing operations only take place in the afternoon, the morning is confined to the preparation and the storage of the metal and fuel required for melting. In the stock-yard two men are employed breaking up the necessary pig-iron in front of each stack by means of an electrically-operated pig-breaker. These are carried to the storage ground for broken pig-iron by means of an electric locomotive crane fitted with an electric magnet. The same workmen discharge the coke and pig-iron from outside wagons, as has been previously described.

"On the charging platform a man is employed filling a certain number of flat baskets with coke, which he has previously lifted out of the storage bins, and he places them at D close to the cupolas. He also assists his two mates in the stock-yard in their work; this man is in charge of the working of the cupolas.

"During casting, the workmen in the storage yard receive the empty wagon at E, run it over the weigh bridge for the scrap iron at F, where the necessary quantity of scrap iron is charged into the wagon, then on to a multiple arm weighing bridge at G, where the charge is completed with the broken up new pig-iron, selected runners, and the necessary weighed out flux, and finally take it to the position at D. One of these men then hooks on the wagon to the electric runway, whilst the other returns it to the receiving position E to receive the empty wagon, and so on.

FIG. 19.—ELECTRIC OVERHEAD RUNWAY.

"The workman on the platform receives the wagons one after the other, empties them into the cupola, and charges in the necessary fuel by hand which he has prepared in the morning.

"At the side of each cupola on the charging platform, as well as in the foundry under the air belt, are two kinds of clocks, electrically connected, the faces of which are marked off in graduations carefully calculated from the holding capacity of the cupola. Before starting melting, the foreman marks on this indicator the different qualities of iron which are required. During melting each time the charge is tipped into the cupola, the workman on the platform presses a button, which makes the needle advance one division on each of the clocks. He then is always aware at already been tipped in, and he can also check the already been tipped in, and he can also check the nature of the iron which is being dealt with. By the same way, in the foundry, any member of the staff, either the manager, foreman, or moulders, know at any moment the kind of metal which is contained in the hearth of the cupola."

In some installations where this runway system is in force the electric lift handling the charging buckets is fitted with a cabin in which an operator is seated—very much after the style of the luggage transporter in Manchester Victoria Station. This method is illustrated in Fig. 19, which is also taken from a well-known American catalogue. From this it will be seen that the bucket actually enters through the charging door of the furnace and the contents are then tipped.

DISCUSSION.

The BRANCH-PRESIDENT (Mr. V. C. Faulkner), in introducing the lecturer, said that Mr. Liardet was President of the West Riding of Yorkshire Branch of the Institute. He had been connected with Messrs. Thwaites Bros., the steel founders, and had also studied very intensely the manufacture of modern cupolas. He had, however, recently been appointed general manager of Leyland Motors, Limited.

Small Tilting Cupolas.

MR. G. HALL said he had had a tilting cupola installed some time ago, but the furnaceman had asked why it should be tipped over, and he (Mr. Hall) had replied that the main reason was for patching-up purposes. In answer to a further question as to whether he could crawl inside, Mr. Hall had told the man he could do so, but the object of the manufacturer was to avoid the necessity for doing that. The fact was, said Mr. Hall, that the man had never tipped it since it was installed. At the same time, he considered it was useful to be able to tip them if one so desired. He, personally, would not care to have to get inside any of these small furnaces. Dealing with the question of damage to the lining of the cupola through mechanical charging, he said that some years ago he had had a cupola, and his men were determined that they would knock it about when charging, and he had put some cast-iron bricks in, which had saved it. The cupola was charged by hand, but those bricks would answer in the same way if a mechanical charger were used.

Mechanical Charging and Repairs.

Mr. J. W. Gardom, speaking of mechanical charging, said he had had bad castings through bad melting, and this bad melting was brought about because the air supply was affected. This was undoubtedly due to the arrangement of the charges inside the furnace. It was all very well to say that we could go round and change the blast and the volume, and so on, but actually, during blast, nobody seemed to have time to attend to it, so that the arrangement of the charges was important. It seemed to him that, by hand charging, more uniformity of the layers inside the furnace could be obtained than by any mechanical method. It had been said that it was difficult for a man to put the charges on to the cupola because of the bad conditions, but he believed he was right in saying that, in the majority of foundries in England, 75 per cent. of the charging was done before the blast was on, so that that argument did not apply. Again, it should be remembered that the first charge had a long way to go, and, if it were thrown carelessly into the cupola, there would be much damage done to the walls. With hand-charging methods, it was quite ordinary for a cupola to run for a year without needing repair round the charging door, but the stage which had been put up specially for repairs on one of the cupolas Mr. Liardet had illustrated seemed to suggest that repairs were extra heavy. Was there any great advantage to the usual run of English founders, from the point of view of cost, in using mechanical as against hand charging? He knew that mechanical chargers could be put out of order very easily. Usually the men were in a hurry, and the apparatus underwent much knocking about, so that the cost of upkeep was high, which was a point to be considered. It might, perhaps, save one man's labour, but did it also save his wages through the use of mechanical chargers? Apart from that, he was very interested in mechanical charging, and hoped it would be successful.

Mr. M. Benbow was also very interested in mechanical charging methods, seeing that he was shortly having an apparatus installed at his own works. He was principally concerned as to whether the mechanical charging would knock the linings away when the charges were put into the furnace. He understood that there was a sill arrangement, which shot the iron or coke, or other material, into the furnace, but was that adequate to ensure the discharge of the iron or coke down through the centre of the cupola, or did it discharge on to the wall on the opposite side?

Mr. H. J. Maybrey considered that the sudden introduction of a very large mass of metal into the furnace by means of a mechanical charger was bound to have a very detrimental effect on the life of the furnace. That was a very important point to be considered.

A Method of Breaking the Fall.

Mr. R. Shaw referred to a mechanical charger which he had seen twenty years ago. It was of the ordinary bucket type, and those using it had rigged up some long, heavy weights just inside the charging hole. These were hung on chains, and the charge discharged right against them Evidently those people had found that the lining had suffered, and the principal use of the weights was to direct the charges so that they dropped into the centre of the cupola. He had not used a mechanical apparatus personally, and was rather sceptical about its spreading the charge properly. In his own practice he took the greatest care to spread the charges evenly up to the charging door, and after that it was fairly easy to keep the charges level. Every charge was put on as carefully as possible, and he could not visualise a mechanical charger doing it so well.

Labour Saving Aspect.

Mr. G. C. Pierce said that he was open to conversion, but was very sceptical as to whether a mechanical charging apparatus was beneficial when considered from all points of view. In the course of the lecture he had noted that two men were required for a mechanically-charged furnace with a capacity of 4 tons per hour. He had seen more than one furnace with a greater capacity than that worked by two men, and he had been trying to balance up in his mind whether it was really economical. Could Mr. Liardet give any figures, because he himself could not see that there was a great saving effected? After all, first cost had to be taken into consideration, as well as upkeep, so that it appeared that there was not much in it. If there were a saving, that had to be set off against damage to walls, etc.

Swedish Methods.

Mr. H. G. Sommerfield (Branch Hon. Secretary) said that the cupola was the most used and, in all probability, the most abused appliance in the foundry. At one particular foundry which he knew of in Sweden, which had works covering a very large acreage, he had spoken to the works manager last year about a system of mechanical transport and mechanical charging of cupolas. They had to push their iron and fuel along in big trolleys, and man-handle every pound of it to the charging stage, and at this time of the year both the iron and the fuel were under snow. The works manager had told him that the cost of the installation and the extra cost of machines, and so on, was not warranted, and thought that, with the fairly low cost of labour, the transport and hand-charging of cupolas was quite sufficient, and more satisfactory from their point of view. The supervision there could then be greater than with mechanical charging.

The Construction of Tuyeres.

Mr. Wesley Lambert asked whether there was not a greater tendency towards scaffolding in the cupola when mechanical charging methods were used than with hand-charging. Also, would Mr. Liardet kindly explain the object of the construction in the bell-mouthed orifice in the tuyeres? In theory, he believed, the introduction of such a constriction was bad, and he had always understood that it should be avoided. He would like to know whether Mr. Liardet had found any advantage in having a constriction in the throat of the bell-mouth tuyere as shown in Fig. 7.

Question of Rows of Tuyeres.

Mr. E. H. Brown, referring to the actual construction of the ordinary cupola, asked Mr. Liardet what he considered were the advantages to be obtained by the use of the double row of tuyeres. He personally had found them anything but satisfactory. In nine cases out of ten, where cupolas had two rows of tuyeres, the top row had been shut off, and only the second row was working, and he had found that the double row led to a tendency towards greater variation in the quality of the finished metal, and was not to be relied upon to the same extent as when the melting was carried out in a definitely narrow melting-zone, which was far easier to obtain—theoretically, at any rate—with a single row of tuyeres than with a double row. Then Mr. Liardet considered that the Roots blower, *i.e.*, with the positive, or very nearly positive, drive, was very much superior to the fan. He himself had seen the two systems working side by side on several occasions, and in almost every case the fan was working with a lower consumption of power for the same delivery, and, in his opinion, the fan gave a better chance of varying the pressure according to the varying resistance in the cupola itself. Towards the end of a blow it was quite a simple matter, with a fan, to shut down the speed, and so reduce the actual volume of air going through when the pressure was lower; also, with a fan, the pulsation was considerably less. The tendency was to give a far more regular blast, and for that reason, if for no other, the fan helped to ensure regular conditions inside the cupola. When producing a standard metal of definite composition, it was undoubtedly a very great advantage. With regard to charging direct from trucks into the cupola, that was an advantage in a foundry where a definite composition was not of very great importance, but where a very high-quality casting was being produced, there must be facilities for obtaining the analysis of the metal before actually charging. With the present variations between the makers' stated composition and what was actually obtained, that was rather an important factor. With regard to the bell-mouthed tuyeres, he appreciated that they were very good in theory, but tuyeres were articles that wanted renewing somewhat frequently, and what was the extra cost of making them bell-mouthed as against the plain type?

Sampling Flue Gases.

Mr. McRae Smith said that, like Mr. Benbow, he also expected to be interested in mechanical charging in the future, particularly in the inclined plane type of charger with the skep. He had hoped to hear something from those who had had experience of mechanical charging, but he was afraid there were many pessimists present; he had hoped to hear some optimists. With regard to the sill plate arrangement, could Mr. Liardet give his assurance that it would ensure equal distribution of the charges, and had the irregularities in the size of the iron anything to do with the equal or unequal distribution? Figures had been quoted with regard to the analysis of flue gases from the cupola, and he would like to know whether Mr. Liardet had any experience of sampling the gases from near or beneath the charging door. If so, he would like to know his method. As to air pressure, had Mr. Liardet any experience of systems of measuring the volume of air going into the cupola, because the ordinary water gauge on the cupola gave very little information about it?

Mr. J. W. Gardom said that the best type of mechanical charger he had ever seen was one in which the truck, which had a drop bottom, ran straight into the cupola. That had not been mentioned.

Age of Types of Cupolas Compared.

The Branch-President said there was one important question which everybody had neglected.

Mr. Liardet had given a comparison of four cupolas. He (the Branch-President) would like Mr. Liardet's assurance that these were modern cupolas and were being put on to the market at the present time, because it was not fair to compare a 1923 model of one particular maker with an older one. As to the calculations with regard to the theoretical amount of coke and the blast needed to burn the coke, apparently Mr. Liardet had not taken into consideration the expansion due to temperature factor which must exist, and which, he imagined, would alter materially the calculations.

THE LECTURER'S REPLY.

Mr. Liardet referred first to small tilting cupolas which Mr. Hall had never seen tilted down. As a matter of fact, he (Mr. Liardet) never could understand why cupolas were designed like that. The air came through the trunnions, and the trunnions had two ports in them, a sort of circular valve arrangement, so that, when the cupola was pulled down, the air was shut off. He could not imagine a person pulling down the cupola in the middle of a blow and shutting off the air. As to cast-iron bricks, he would not admit any necessity for cast-iron bricks with a mechanical charging device, even in the top section of the cupola. They certainly added to the life of the brickwork, however, under any ordinary conditions. He pointed out, in this connection, that the British Admiralty would not instal a cupola at any dockyard unless, for a distance of 8 ft. below the charging door, there were hollow cast-iron bricks, through which air was circulated to keep them cool.

Defence of the Mechanical Charging.

As to Mr. Gardom's remark that bad castings were produced through bad melting, that was quite correct, and he agreed also that it was important that the charges in the cupola should be regular. But there was no reason why we should not do equally as well as by hand charging if the iron were sent up in a bucket and tipped in. There was no difficulty at all in getting the right mixtures. It must be remembered that, after all, the object of running a cupola was not to get even and consistent charges, but even and consistent results from the cupola. No one would go inside the cupola to see how the pigs were lying, provided that the metal that came out was as it was required, and what had to be avoided with mechanical charging, or with any other system of charging, was the overlapping of charges. If there was overlapping, there would be trouble, because one part of the coke would burn before another, and the iron would mix up with the coke. If the layers were moderately level, there would be no trouble. Mr. Gardom had also said that charging machines were not applicable in this country because 75 per cent. of the charging was done before the blast was on. The only answer he could give to that was that he had had some three years' experience of charging machines in this country, and could assure Mr. Gardom that 75 per cent. of the charging machines he had fitted had been fitted to cupolas of that description. The skep hoist charging machine appealed to the small man. If a man was going to put down a cupola to turn out 4 tons an hour, there was a great incentive for him to have a mechanical charger with it, because he would get the plant more cheaply to start with, and would get better results. Therefore, he did not think the fact that small cupolas were used was an argument against the use of mechanical chargers. With regard to repairs to the cupola linings, he assured Mr. Gardom that the mechanical chargers did not damage them. Why should more damage be done by tipping the pigs from a truck than by charging them by hand? The pigs could only strike the lining once. He confessed that there was a greater tendency to crush the coke, but even that was not detrimental. He had investigated that very carefully, and had not found any loss in the coke, although it was broken because of the heavier load coming down. As to the use of a truck with a drop bottom, he had seen such trucks in operation in the United States, and the only thing against them was that he believed the trucks themselves got pretty well damaged. because they had to go right into the heat in the cupola. But they were quite satisfactory from the charging point of view, because there was a clear vertical drop of the charge into the cupola, which we were trying to aim at. The coke was crushed more than it would be otherwise, because the pigs were dropped from a greater height.

How the Fall of the Charge is Broken.

The object of the sill which had been mentioned by Mr. Benbow was not only to bring the charge to the centre of the cupola, but also to decelerate its fall. The decline was fairly flat, so that the iron did not run down quickly, but simply fell over the edge. Besides reducing velocity, it reduced damage to the coke. He had always been more worried about the coke than the lining.

With reference to the charging apparatus which Mr. Shaw had seen twenty years ago, he himself knew of a mechanical charging apparatus which had been in use for a very long time indeed at Horwich, Lancashire, and which seemed to be quite satisfactory. There were trucks, which were wheeled along on the platform level, and the charges were put into a cradle and sent up to the cupola, but the action of tipping was just the same as in other cases.

Labour Saving Possibilities.

Replying to Mr. Pierce, with regard to economy in labour, Mr. Liardet said that the reason there were two men employed on the cupola melting 4 tons per hour, which he had illustrated, was that there happened to be a wall between the cupola and the foundry itself, and possibly, if a hole were made through the wall, one man would be sufficient. He had seen cupolas of that size operated by one man only. However, he did not think that anybody who came to a foundry to talk about mechanical charging would say first of all that he was going to effect a saving of labour in respect of cupolas of 4 tons per hour capacity. He did not think that mechanical charging in that case would save a man, but it would provide perfect control over the charges. How often did the foreman go on to the platform? With mechanical charging he would be able to see what was put into the buckets, and the different mixtures could be checked and weighed. But he (Mr.

Liardet) had fitted chargers of the type used on the cupola Mr. Pierce had referred to, to cupolas of 12 tons capacity, and there was not the slightest doubt that saving was effected there. As to upkeep, the machine was very robust, and he did not see why it should be subject to any more wear than an ordinary hoist.

Scaffolding not due to Mechanical Charging.

As to the tendency towards scaffolding, he did not see why there should be a greater tendency in that direction with mechanical charging than with hand charging. He had found one cupola, fitted with a charging machine, in which scaffolding had taken place, but, on investigation, it was found to be purely a question of the handling of the cupola. There was insufficient flux used, and the blast was not quite right. The bell-mouthed tuyeres, to which Mr. Lambert had referred, were made the same shape as a pipe which passed the greatest quantity of air for any given pressure in the air-blower; not only did a pipe of that shape pass the greatest volume of air, but it also gave distribution inside. There was not a constriction. What Mr. Lambert had referred to as a constriction was the recognised diameter; in the ordinary way, tuyeres of that diameter would be adopted, but, by bell-mouthing on the air-belt side, more air went through it than would go through a straight pipe. With a straight pipe, the coefficient of discharge was in the neighbourhood of 0.5, but with the bell-mouthed pipe he believed the coefficient was as high as 0.9.

The Disposition of Tuyeres

With regard to the double row of tuyeres, he would not discuss that point with Mr. Brown. because possibly they were both right. He had tried cupolas with one, two and three rows, and he believed that, with two rows of tuyeres, there was better melting; also, if there were two rows, and one row had valves, it could be shut off. Probably, as Mr. Brown had said, they were shut off after the first week and never opened again, but he was of opinion that, taking everything into consideration, a double row gave better distribution of blast inside, and the tuyeres need not be too large. It was not the right thing to have a big tuyere area in one row, because there would either have to be a large number or the diameter of the tuyeres would have to be large. As to the Roots blower *versus* the fan, he did not think it was quite right to say that the fan was better because the quantity of air could be varied. What could be done with the fan in that respect could be done with the blower, by lowering the speed or by allowing the air to escape into the atmosphere. He did not dispute that there were many cupola plants running perfectly satisfactorily with fans in this country, but he could only say that, if we wanted the very best controlled melting, he was sure we could get it by means of the positive blower rather than by the fan. As to facilities for obtaining an analysis of the metal before charging, Mr. Liardet said that, with mechanical charging, the pig-iron could be graded in the yard; the pig-iron required could be selected and weighed out, and sent up in the right order. He did not think the bell-mouthed tuyeres cost much more than the straight ones, because they were only castings, and could be produced easily once the pattern was made. In attaching these tuyeres to the furnace, a space was left, the tuyeres were dropped in, and packed round with ganister to keep them in position. As to the size of the iron, half-pigs were quite satisfactory for cupolas of over 4 tons, and probably quarter-pigs for others. As to the analysis of flue gases, that was quite a phantasy on his part. The volume of air could be measured by finding the velocity passing through any given area in a certain time, and therefore all so-called volume-measuring gauges, which were very beautiful, but expensive, really did no more than measure pressure, which indicates velocity.

He was glad that the Branch-President had pointed out that it was perhaps unfair to have compared four cupolas without knowledge of the date they were constructed. Those four cupolas were not guaranteed to be modern, and he had no information as to the date of their construction. But they were all constructed by firms whose names are in the market to-day for the sale of cupolas. As regards expansion and temperature, he did not think that came into a theoretical discussion of the amount of air required, because, after all, what was wanted was oxygen, and not the weight of air. The volume which he worked on was taken at ordinary atmospheric temperature and pressure.

Vote of Thanks.

Mr. Wesley Lambert, in proposing a hearty vote of thanks to Mr. Liardet, said he had thoroughly enjoyed the Paper. There was not very much agreement among those present with regard to mechanical charging, but that did not detract from the value of the Paper, because Mr. Liardet had brought to their notice the different types of apparatus in use.

Mr. C. A. Otto, who seconded, said that Mr. Liardet could be congratulated on the discussion he had aroused; it did show that considerable interest had been taken in the Paper. Incidentally, there was one subject which had been mentioned at the first meeting of the session, and which he had thought might have been mentioned in this discussion. Mr. Liardet had referred to a cupola in which it was possible to get six or seven different kinds of mixtures. At the previous meeting referred to, two members of the Branch had discussed that subject, and there was some difficulty in coming to any sort of decision as to whether it was possible to get more than one definite mixture from the cupola.

Mr. Liardet, in returning thanks, said if the mechanical engineer had given more consideration to the foundry in the past, he did not think there would have been quite so many dissentients at that meeting with regard to mechanical charging.

West Riding of Yorkshire Branch.

THE ELIMINATION OF STRUCTURAL WEAKNESSES IN CASTINGS.

By O. Smalley, Member.

This Paper treats structural weaknesses in castings in relation to the nature of crystallisation of the alloy on solidification and the design of the casting.

FIG. 1.—HIGH TENACITY BETA BRONZE.

Alloys.

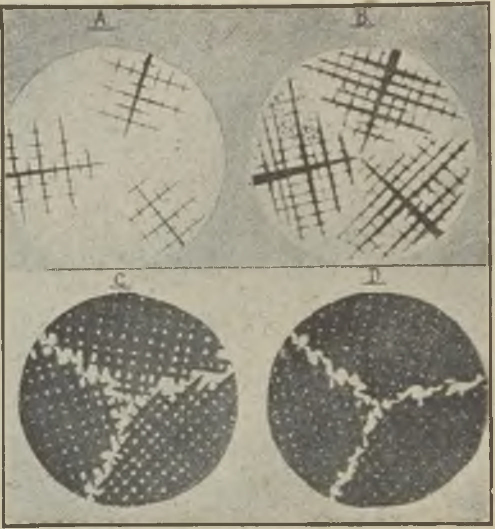
The fundamental factors governing the physical properties of all metals and alloys are composition and structure. In practice these factors are not simply interpreted, being complicated by such external agents as occluded gases, impurities, temperature and time, the influences of which are incompletely understood.

Genesis of Structure.

Metals and alloys, like minerals, are the products of crystallisation of a liquid solution, and the size of the individual grains is a function of the length of time taken during solidification, the nature of the material and its purity.

Alloys may be sub-divided into two classes:—(1) Those which freeze at one specific temperature or through a short range of temperatures; and (2) those which freeze through an extended range of temperatures.

The origin of each crystal grain of alloys of Class 1 appears to be its centre, whence it develops in a regular manner, its orientation determined by the crystallographic system to which it belongs, the last particle of metal freezing at the same temperature as the first (Fig. 1). Such alloys are homogeneous throughout, and possess unit degree of solidity, which in ordinary practice is little affected by temperature and time influences.



Figs. 2 to 5.—Showing the Growth of Crystallites in Metals.

When an alloy freezes through a range of temperatures the crystal grain appears to develop from within. Solidification being progressive, the high melting point materials fall out of solution along the axes of the crystal system, and give a skeleton outline of what is termed the primary crystal grain. This progressive development is best followed by reference to Figs. 2—5, a diagram produced by the late Dr. Stead. Fig. 6 illustrates an actual bunch of crystallites taken from the pipe of a large steel casting when insufficient metal remained to feed the interstices of the skeletal framework of the primary crystal grains.

Fig. 6.—Showing Crystallites Taken from the Pipe of a Large Steel Casting.

Because of such progressive crystallisation, alloys of this class are subject to defects of crystallisation and liquation not encountered in alloys of Class I, and the crystal grains themselves are often heterogeneous. The extent to which these structural weaknesses manifest themselves depend naturally upon *the range of temperature through which the alloy freezes, the alloying properties of the constituents, the temperature, rate of pouring and the rate of cooling* during solidification.

Alloys of Class I.

The alloys representative of this class are those of eutectic composition, inter-metallic compounds and some special alloys having an exceedingly short freezing range, such as alpha-beta brasses, high tenacity beta brasses, aluminium bronzes and mild steel. Of these, attention will be confined to high tenacity beta brass and to aluminium bronze to show that, given an isomorphic alloy of homogeneous texture, the mechanical properties of a casting depend upon the size, orientation and contour of the crystal grains. It is characteristic, however, of crystal grains of an isomorphous mixture of metals to develop faster in one direction than in another, and the extent to which such unbalanced crystals form is not only a function of the nature of the metal and its purity, but also of *temperature of pouring and rate of cooling.*

FIG. 7.—SHOWING COLUMNAR CRYSTALS ACROSS A SECTION OF THE CASTING.

The two alloys under consideration are no exception to the rule, and the physical properties of castings—assuming correct melting conditions—are influenced by (1) the temperature of pouring;

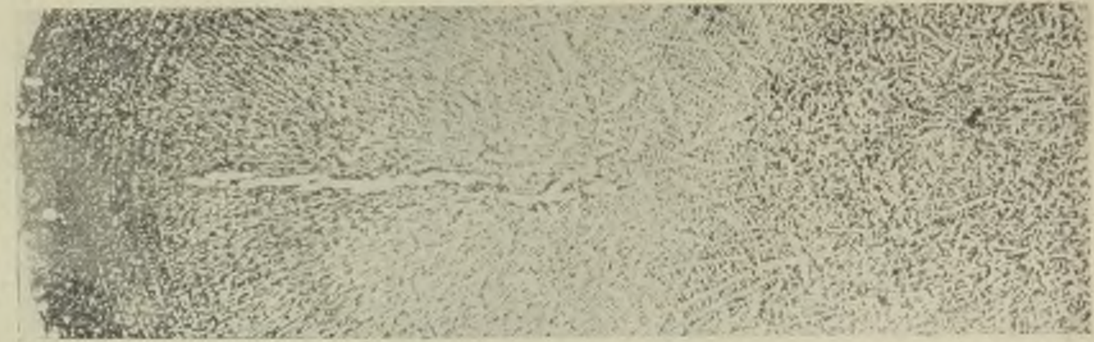


FIG. 8.—ILLUSTRATING HOW ADHESION BETWEEN CRYSTAL BOUNDARIES MAY BE SO LOOSE AS TO SHOW CRACKS.

(2) the rate of cooling; and (3) its dimension and form. The higher the temperature of pouring the greater the tendency to develop unequiaxed crystals, and by pouring sufficiently hot it is possible to grow columnar crystals across the section of the casting (Fig. 7). Developing at right angles from the plane of cooling surface, they interfere along a plane of junction, and a sharp boundary is formed where there is little or no cohesion, whilst the crystals themselves, separated by smooth, straight boundaries and often by films of gas or impurities, are easily separated (Fig. 8).

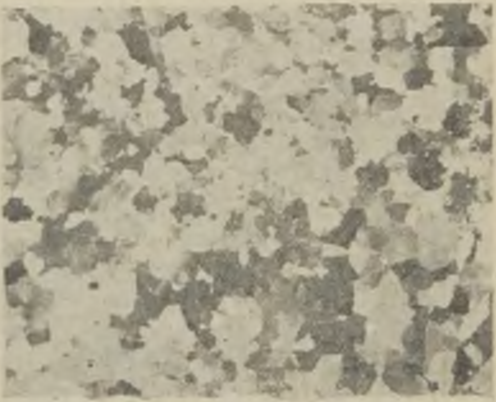


FIG. 9.—CRYSTALLATIONS FROM INDEPENDENT CENTRES FROM WITHIN.

Such structural weakness cannot be eliminated by heat-treatment, and if used for forgings or pressings will always carry the defects of the casting.

Its prevention necessitates the establishment of such conditions as will ensure crystallisation from independent centres from within (Fig. 9). There are three methods which render this possible:—(1) Control of pouring temperature and running slowly; (2) change the nature of the solution; (3) introduce some finely divided insoluble substance in the molten metal to create a nuclear action for the germination of the crystal grains.

To demonstrate this a high tenacity brass and an aluminium bronze will be considered, alloys which are prone to crystal weakness under the slightest influences of temperature and time.

High Tenacity Beta Brass.

This alloy, which contains Cu, 59; Zn, 38; and Al, 3 per cent., was chosen because of its simple polygonal structure and tendency to develop large coarse crystal grains under the slightest influence of purity, temperature and time, as shown in Fig. 1. Pure metals were used in manufacture. The temperature and rate of pouring were adjusted so that only equiaxed crystal grains would be formed. The rate of cooling was maintained constant by casting in the ordinary 3-in. sq. ingot mould controlling its temperature at 110 deg. F. for casting.

The number of crystal grains obtained when made in this way was 152 per sq. cm. Details of the physical test results obtained are embodied in Table I. After forging the lower half of the ingot in one heating into a 1-in. sq. bar, the number of crystal grains was increased to 2,535 per sq. cm., which reduction in dimension is shown to be responsible for an all-round improvement in strength, ductility and shock-resisting properties.

Iron alloyed with copper gives rise to a high melting-point constituent containing approximately 8.0 per cent. copper of a density slightly less than that of brass. The suspension of this compound in molten brass in a finely divided state and homogeneously distributed presents no difficulties in quantities of up to 1.0 per cent. iron.

The test results of alloy 1A show the effect of 1.0 per cent. iron on alloy No. 1 in both the cast and forged conditions, the iron being substituted for a similar quantity of zinc. The effect has been to yield a casting of physical properties equal almost to those obtained from alloy No. 1 after forging; whilst, it will be observed, the number of crystal grains has been raised from 152 per sq. cm. to 2,500 per sq. cm. A further interesting feature of this alloy is that it is little improved by mechanical work and heat treatment.

Aluminium Bronze.

Alloy No. 2, Table I, portrays the test results obtained from this alloy—which possesses a duplex

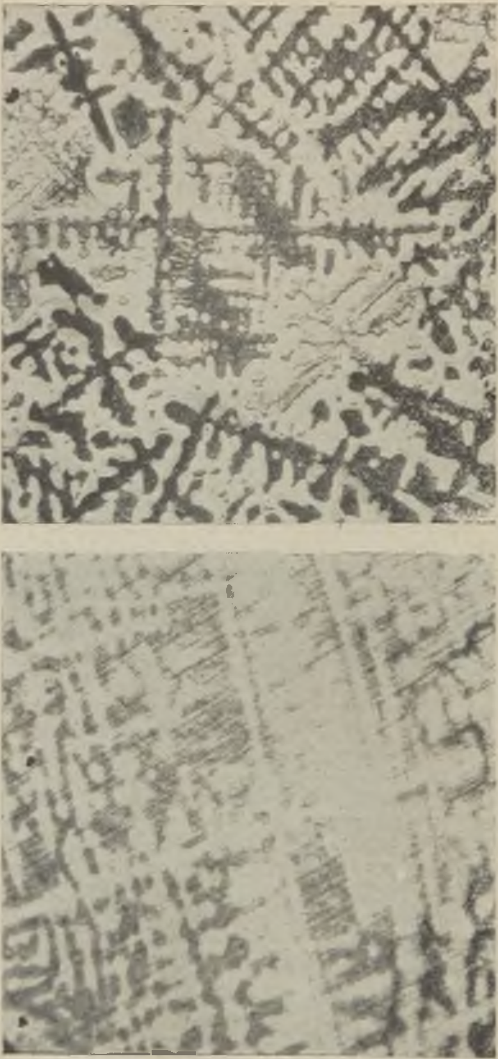
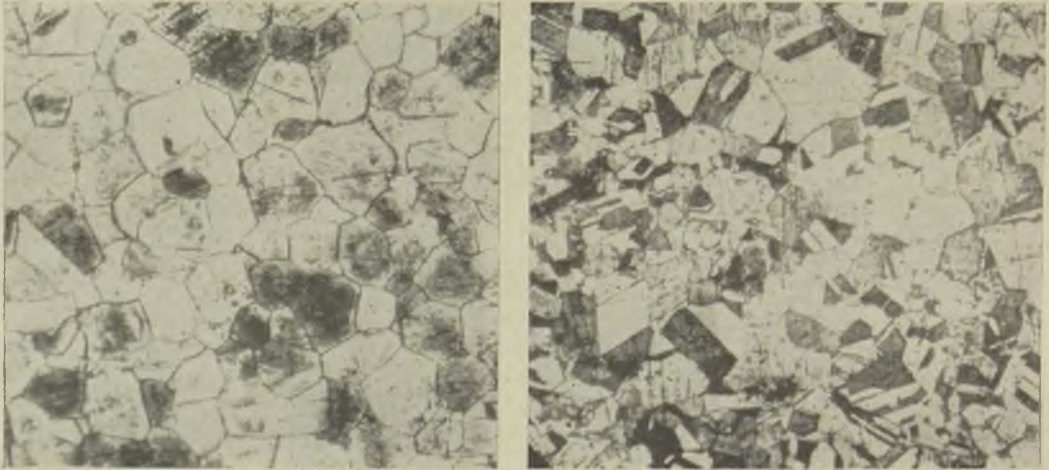


FIG. 10.—PHOTOMICROGRAPHS NOS. 1 AND 2.



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4

Fig. 10.—Photomicrographs Nos. 3 and 4.

structure—when made under controlled conditions. It presents very similar features to alloy 1A, although the result was obtained in quite a different way.

Class II Alloys.

As the range of freezing temperature increases the more susceptible do alloys become to the influence of temperature and time. In consequence of this, castings are more prone to columnar crystallisation, weak-crystal zones, sponginess, and general unsoundness than alloys of Class I.

Fig. 11.—Microphotograph No. 1.

Of the well-known alloys representative of the above alpha brass, tin bronzes, cast iron and alloy steel will be considered.

Alpha Brass.

The special features of castings made in this material being the ornamental appearance, resistance to corrosion and ductility, structural weakness resulting from differential freezing is only of secondary importance. That it can be demonstrated to exert a pronounced influence on the properties of a material whose constituents have a high alloying power and which freezes through so short a range of temperature is, however, of the highest importance in the manufacture of brass castings as a whole.

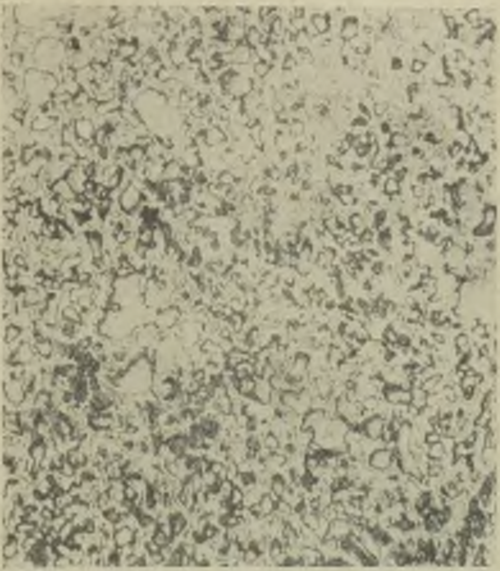


FIG. 11.—MICROPHOTOGRAPH NO. 2.

The micro-structure of this simple phase alloy when cast from a normal temperature into a 1-in. slab is illustrated by photomicrograph 1, Fig. 10, depicting the cored or heterogeneous crystal structure obtained. After cold-rolling and annealing the slab, this coarse structure and heterogeneity are removed and replaced by a simple homogeneous structure consisting of polygonal twin grains, as shown in photomicrograph No. 4, Fig. 10.

The test results and details of treatment given both before and after removal of the cast structure are embodied in Table II, alloy No. 1. These show refining of the grain to have resulted in raising the yield point 1.5 tons, the tensile strength 4.8 tons, the elongation 10, and the reduction of area 13.8 points.

MICROPHOTOGRAPH NO. 3.
FIG. 11.—ILLUSTRATING THE MICROSTRUCTURE OF THE EXTREME OF NO. 1, MAG. 50 DIAS.

Representing a purity which is rarely attained in ordinary practice, the presence of impurities must be either to accentuate or eliminate casting structural weakness. The effect of soluble impurities which extend the freezing range and intensify differential freezing will necessitate a more rigid adjustment of both the temperature and time factors, whilst insoluble impurities if distributed homogenously, and do not give rise to mechanical weakness, must automatically reduce the dimension of the crystal grain and crystal heterogeneity.

The presence of such impurities would, therefore, not only result in the production of stronger and tougher castings, but render possible a wider latitude of both temperature and time.

To demonstrate the effect of impurities two casts were made alongside with the pure alloy; to the one 1 per cent. of arsenic was added, and to the other 1 per cent. of iron. Because arsenic is soluble in molten brass and forms an arsenide of zinc and copper, its influence on brass should be somewhat similar to that of phosphorus in iron or steel, *i.e.*, to increase heterogeneity due to the extended freezing range, and to embrittle, due to the deposition of the low melting-point and brittle constituent at the junction of adjacent crystal grains. Alloy No. 2 (Table II) gives the test results obtained as cast, and after the same treatment—cold rolling and annealing—as given to alloy No. 1. As cast, the properties are much impaired, both the strength and ductility being appreciably reduced. After the attempt to remove the cast structure, the properties are much improved, but still inferior to those of the pure material. Photomicrograph 2 (Fig. 10) illustrates the microstructure as cast. The effect of arsenic is shown to intensify the cored structure of ordinary 70:30 brass, and to have resulted in the deposition of a low-melting point brittle constituent at the junction of the crystal grains as anticipated, and which is responsible for the poor test results obtained.

Iron, from the experience with alloy 1, Table I of Class I, should exert a beneficial influence in the same way, and the iron-rich constituent should be deposited in the centre rather than at the junction of the crystal grain, strengthening without embrittling.

Alloy No. 3 (Table II) shows the test results obtained. The outstanding feature here is that the casting possesses a strength and shock-resisting power superior to and equal in ductility and malleability to pure 70:30 brass after its cast structure has been removed by means of mechanical work and heat-treatment.

The explanation of this is clear from photomicrograph No. 3 (Fig. 10). The effect of the iron has been to reduce the crystal grain to such an extent that, despite the freezing range of the alloy, it does not display any heterogeneity. It will be observed also that the alloy, in contradistinction to alloy No. 2 shows the least improvement by mechanical work and heat-treatment. In many ways the test results are very similar, whereas the improvement effected by the elimination of the cast structure is most marked with the arsenical brass.

Tin Bronzes.

These alloys have a protracted range of solidification, and are somewhat analogous to ordinary grey cast iron, being peculiarly susceptible to the influence of both temperature and time.

From the range of alloys this series offers, the two commoner have been selected for consideration, viz., phosphor-bronze and Admiralty gun-metal.

Table III shows the physical test results obtained from phosphor-bronze when poured at various temperatures between 1,112 deg. C. and 1,040 deg. C. into chill bars 9 in. × 1¼ in. × 1¼ in. Photomicrographs 1, 2 and 3 (Fig. 11) illustrate the microstructure of two extremes, and the bar cast at an intermediate temperature, at a magnification of 50 times. No. 1 shows the well-developed dendritic structure and the heterogeneity resulting from differential freezing despite the rate of cooling. No. 2 portrays a finer structure and a complete absence of the well-developed dendrites of No. 1. No. 3 presents an adumbrant cellular structure together with mechanical defects due to pouring too cold.

These microstructures are self-explanatory of the test results obtained, and show that a dendritic structure resulting from high casting temperature reduces both the strength and ductility, and that casting cold is equally injurious owing to the formation of defects due to entrapped oxide, overlaps and blowholes.

Admiralty Gun-Metal.

Freezing through a more extended range—approximately 200 deg. C.—the difficulty of casting solid and free from crystal weakness increases proportionately.

TABLE I.—*The Mechanical Properties of Aluminium Beta Brass.*

Mark.	Composition.				Physical con-dition.	Number of Crystals per sq. C/M.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. % on 2 in.	R.A. %	Brinell hard-ness No.	Alter-nating Impact No.
	Cu.	Zn.	AL.	Fe.								
1.	59	38	3	—	Cast ..	152	20.5	38.6	19.0	21.5	159	23
					Forged	2,535	18.9	43.0	29.0	33.5	159	27
1A.	59	37	3	1	Cast ..	2,500	18.6	44.5	26.0	27.0	159	19
					Forged	2,565	19.8	44.9	27.0	29.0	159	26
	Cu.	AL.	Mn.	Fe.								
2.	89.59	9.36	0.90	0.10	Cast ..	—	11.7	29.9	43.0	39.2	97	19
					Forged	—	11.5	30.6	45.0	45.0	101	20

TABLE II.—*The Mechanical Properties of Alpha Brass.*

Mark.	Composition.				Physical state and Treatment.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. %	R.A. %	Brinell hardness No.
	Cu.	Zn.	As.	Fe.						
1	70	30	—	Tr.	Cast	6.50	16.70	58.0	48.2	55
					Cold worked and annealed	8.00	21.50	68.00	62.0	55
2	69.16	29.87	0.97	Tr.	Cast	5.8	13.20	23.0	21.5	52
					Cold worked and annealed	8.0	19.20	38.0	19.1	59
3	69.5	29.5	Nil	1.0	Cast	10.70	24.00	50.00	59.30	72
					Cold worked and annealed	11.00	26.50	54.00	67.00	74

TABLE III.—*The Influence of varying Casting Temperatures on the Properties of Phosphor-Bronze Castings.*

Cast No.	Composition.			Casting temperature in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. % on 2 in.	R.A. %	Fracture.	Brinell hardness No.
	Cu.	Sn.	P.							
1	93.90	5.25	0.85	1,112	10.40	23.50	23.50	4.50	Earthy, dendritic, exhibiting slight oxide inclusions.	73
2	—	—	—	1,085	10.90	24.60	28.00	6.20	As Cast No. 1, but free from defects.	75
3	—	—	—	1,075	10.90	25.30	30.00	6.60	Fine, earthy, almost free from crystallinity.	78
4	—	—	—	1,050	10.40	24.20	22.50	5.00	Earthy, with a small copper - coloured cavity in the centre.	78
5	—	—	—	1,044	10.00	20.40	12.50	3.10	As Cast No. 4, but more defective.	74
6	—	—	—	1,040	10.00	18.80	8.00	2.70	Earthy, exhibiting copper - coloured patches in which cavities are contained.	79

Photomicrograph 1 (Fig. 12) shows the microstructure obtained from this alloy when cast in a chill mould. This large crystal structure, obtained by rapid cooling, serves to indicate the difficulties which will be encountered in the manufacture of sound sand castings, and that to attempt production without a knowledge of the influence of both temperature and time is courting trouble and losses.

Consider, as a practical example, the simple cylindrical propeller-shaft liner casting, which is free from any complications of design. The dimensions of these reach 24 in. dia., 25 ft. long, and with a section of 1½ in. When cast in dry sand or loam moulds in the ordinary way, trouble invariably arises in the form of patches of open-texture, liquation-holes and segregation due to selective crystallisation, no matter what precautions are taken in the control of the mixture, melting and pouring temperatures or rate of running (Fig. 13).

The crystallisation range is so extended that solidity and homogeneity are not affected materially by small quantities of either soluble or insoluble impurities. Soluble impurities such as aluminium, antimony and arsenic have but little deleterious effect. Pb, a low melting-point metal, which is often introduced in considerable quantities and which does not alloy with copper, increases casting difficulties. To a certain extent its injurious influence in this direction may be overcome by the introduction of antimony or sulphur, which combines with both copper and lead, and ensures the formation of an alloy with these constituents. Sulphur is best introduced by means of galena.

On the other hand, metals such as iron, chromium and titanium, which give rise to the formation of insoluble compounds, are not of the same value as in brass, for example, whilst any beneficial influence that they may have as "grain-refiners" is often negatived by their tendency to give rise to hard spots and to segregate.

The manufacture of sound castings thus resolves itself into the question of the time taken to solidify, although temperature and rate of running

TABLE IV.—*Effect of Forging on the Physical Properties of Nickel Chrome Steel (Composition C 0.50, Si 0.10, Mn 0.071, P 0.03 S 0.025, Ni 2.00, and Cr 2.01 per cent.) in the Annealed and Hardened Condition.*

Mark	Physical condition.	Treatment.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. % on 2 in.	R.A. %	Fracture.	Brinell hardness No.	Calculated tenacity.	Alternating impact No.	Izod impact. ft.-lbs. absorbed.
1.	" As Cast "	None	28.80	30.50	1.50	1.00	Coarse crystalline, exhibiting brilliant crystal facets.	223	55	1	4
	" As Cast "	Annealed 900°C. 1 hour cooled in furnace. Re-annealed 700°C. 1 hour, cooled in furnace.	31.50	50.00	13.50	28.00	Coarse Crystalline, but of dark velvety appearance.	207	51	107	20
	" As Cast "	Annealed as above and oil-hardened.	54.20	54.20	Nil.	Nil.	Fine, amorphous exhibiting an adumbrant dendritic pattern.	578	140	1	1½
1F.	" As Forged " reduced to half the original cross sectional area.	Annealed 900°C 1 hr. Cooled in furnace. Re-annealed 700°C. 1 hr. Cooled in furnace.	31.80	50.00	23.00	55.00	Grey velvety. Cup and Cone.	207	51	173	53
	" As Forged " reduced to half the original cross sectional area.	Annealed as above and oil-hardened.	80.00	80.00	0.30	Nil.	Fine, amorphous.	578	140	5	3½
1 FF.	"As Forged" reduced to ¼th the original cross sectional area.	Annealed 900°C 1 hr. Cooled in furnace. Re-annealed 700°C. 1 hr. Cooled in furnace.	30.00	49.60	20.00	63.00	Grey, velvety. Cup and Cone.	207	51	201	72
	"As Forged", reduced to ¼th the original cross sectional area.	Annealed as above and oil-hardened.	124.00	124.00	1.00	Nil.	Fine, amorphous.	578	140	7	2½

are factors which cannot be ignored altogether. The methods suggesting themselves, therefore, for the manufacture of sound propeller-shaft liners were (1) cast centrifugally; (2) build the mould up by means of a series of cast-iron rings; (3) insert chills into the sand, cool the sand by air or water pipes, or allow both mould and core to cool to room temperature 80 deg. F., for castings.

Method No. 1 proved most successful, but demands special plant The use of chills increases cost. Cooling the mould by means of air and water pipes proved successful but somewhat dangerous, and the experiments were discontinued when it was found that these castings could be produced successfully in a simple sand mould by making conditions as favourable as possible for rapid cooling, by controlling the casting temperature between 1,050 and 1,100 deg. C., and running quickly from the top.

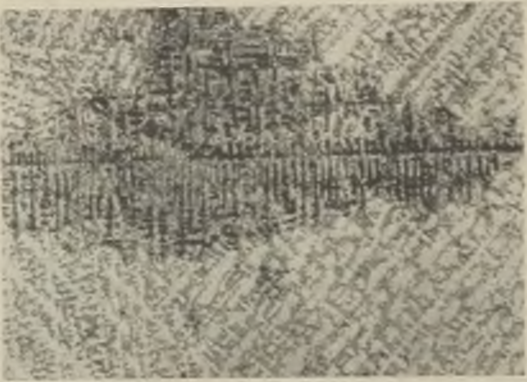


FIG. 12.—SHOWS MICROSTRUCTURE OF GUN-METAL CAST IN A CHILL MOULD, MAG. 50 DIAS.

This example, chosen to illustrate the difficulties encountered with this metal and the rigid control necessary in the manufacture of sound castings of simple section, also shows the relative importance of design in limiting and proportioning of sections in bronze castings of complex form.

Grey Cast Iron.

Columnar crystallisation and weak crystal zones common to metals and alloys when cast hot and rapidly cooled are rarely encountered in grey cast iron cast under similar conditions. Die casting with a high-carbon hematite iron, free from weak crystal zones—and which machines, without annealing—is quite commonplace, despite a freezing range of 200 deg. C. Modify the composition, however, such that all the carbon is retained in complete solution at normal tempera-

Fig. 13a.—Open Texture in a Propeller Shaft Liner

tures of melting and pouring, and it behaves as any other alloy, and strength becomes a fruition of temperature of pouring and rate of cooling.

In ordinary cupola practice the change between these two extremes is gradual, and not subject entirely to chemical control. It is for this reason that grey iron has so long been regarded as an uncertain metallurgical product.

FIG. 13B.—LIQUATION HOLES IN A PROPELLER SHAFT LINER.

Speaking broadly, casting temperature influences are not pronounced on ordinary sand castings, although general experience indicates that the higher the casting temperature, the closer and finer the grain; although published test figures are confusing, West and Longmuir finding the best results could be obtained from a low or medium temperature, whilst Cook and others state casting hot gives the best test results.

Does not this anomalous behaviour of grey cast iron suggest that it only differs from true alloys by the presence of suspended graphite particles in the molten iron, and that the explanation of the conflicting test results published by various investigators must be sought in the nuclear action of free graphite on the crystal growth during solidification. From this theory it is not difficult to under-

FIG. 13C.—SEGREGATION IN A PROPELLER SHAFT LINER CASTING, MAG. 5 DIAS.

stand that an iron containing but little free graphite will be peculiarly susceptible to casting temperature influences, a high temperature being responsible for a weak crystal formation; whilst an iron which contains appreciable quantities of suspended graphite would be immune from such crystal weakness. Similarly, does it not explain why the latter iron is soft and weak when poured cold?

Regarded in this way, grey cast iron falls into line with true alloys, and its metallurgy is simplified.

Steel.

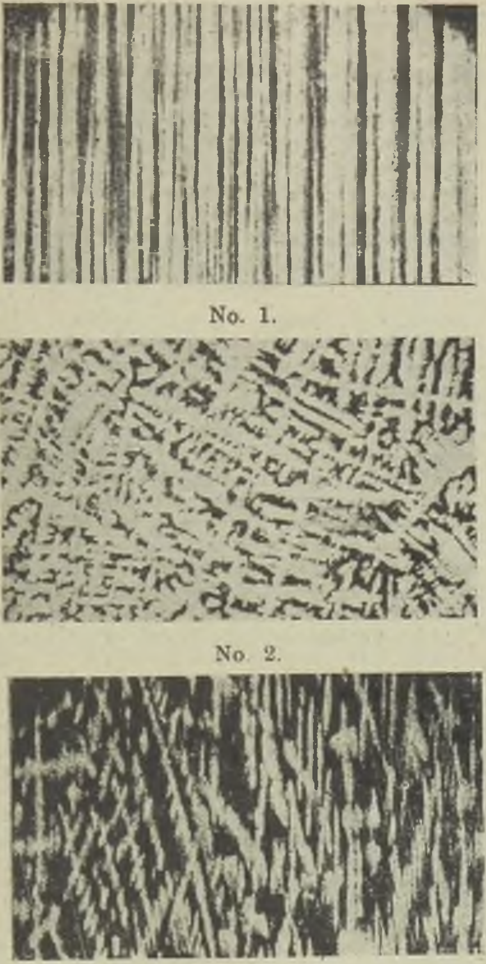
The high temperature necessary in melting and the ready oxidation of iron and its alloys render the manufacture of sound steel castings peculiarly difficult, and although science now furnishes an explanation of the different forces operating in manufacture, remedial measures are inter-dependent upon plant limitations and common sense.

A noteworthy feature of the alloys already considered is that the harder they become the more susceptible are they to crystal weakness. Cast steel is no exception, and the ill-effects of a defective primary crystal formation manifests itself throughout the career of the casting, no matter the subsequent treatment. Photomicrographs Nos. 1, 2 and 3 (Fig. 14) delineate the persistency of such structural weakness in a nickel-chrome steel which was scorched in melting and poured too hot. No. 1 is as cast, No. 2 after forging to half the original cross-sectional area, No. 3 after forging to one-eleventh the original in area in three heatings. They show heat-treatment and mechanical work to have merely crushed the primary dendrites together without removing cleavage brittleness.

The test results obtained at each stage of manufacture, as cast; as cast and annealed; and as cast and heat-treated to refine the structure of the carbide, also after the same heat-treatment in the forged conditions, are detailed in Table IV.

The following observations are of interest:—

The strength of the casting is 19.5 tons lower than that obtained from the forging, although of similar Brinell tenacity hardness, and is devoid of ductility. Annealing improves the ductility,



No. 1.

No. 2.

No. 3.

FIG. 14.—SHOWING PERSISTENCY OF STRUCTURAL WEAKNESS IN NICKEL-CHROME STEEL.

although it is not comparable with that obtained from the forging. When hardened to 140 tons Brinell tenacity only 54.2 tons are actually obtained, against 80 tons tensile from the forging whose sectional area was reduced to one-half that of the casting, and 124 tons from the section reduced to one-eleventh the original cross-sectional area.

To some degree all commercial steels exhibit structural weakness, depending upon the extent of control in melting and of the pouring temperature.

Impurities.

In view of changes which steels undergo in the process of solidification, impurities influence the mechanical properties to a degree depending upon their nature and quality. They may be classified as follows:—(1) Those insoluble in the molten metal; (2) those separating out as definite constituents during solidification; and (3) those entering into solid solution. Insoluble impurities, comprising alumina, sulphides and silicates, create a crystal growth from within and are entrapped in the meshes of the branches of the primary crystallites, thus taking a skeleton outline of the dendrite. The pressure of impurities which separate from the solution during solidification depends upon the condition of the metal as received into the ladle. If scorched or oxygenated, it is quite conceivable that oxides and gases may be rejected on freezing and appear in the finished casting in mechanical admixture at the junctions of adjacent crystal grains. An example of this type is illustrated by photomicrograph, Fig. 15. There is every reason to believe, therefore, that a correctly deoxidised steel may still contain considerable oxygen in solution, and that its solubility is increased by the presence of such refractory metals as nickel, chromium and molybdenum, which metals, incidentally, are a common source of structural weakness because of their low alloying power.

Whilst it has not been possible to consider steel to the length it deserves, it is evident that it presents much the same difficulties in regard to structural weakness as the lower melting-point alloys which freeze through a range of temperatures;

that the cause and elimination presents a similar problem, and that impurities behave in the same way.

Conclusions.

Summarised, this Paper shows:—

(1) That analogies exist between alloys with regard to the origin, constitution and effect of the primary crystal structure on the mechanical properties of castings.

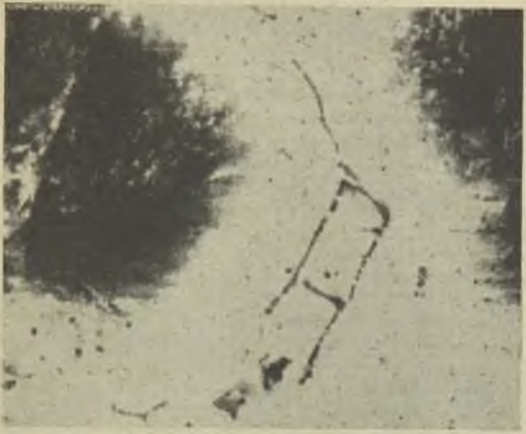


Fig. 15.—Showing the Presence of Impurities at Crystal Boundaries.

(2) That soluble impurities give rise to a structural heterogeneity in all alloys which is peculiarly persistent and detrimental to the physical properties despite subsequent treatment.

(3) The possibilities of considering grey cast iron as a true alloy.

(4) Lastly, the value of research on crystal structure in the manufacture of castings to compete with forgings and stampings.

Birmingham and Sheffield Branches.

RELATIVE VALUES OF FEEDERS OR DENSENERS IN GREY IRON AND MALLEABLE IRON.

By E. Longden, Member.

The subject matter of this Paper is obtained from works practice and experiment. Two classes of iron are dealt with—white, which is subsequently annealed to produce either Reaumur or black heart malleable iron castings, and the more commonly-used grey iron for general castings. A comparison is made of the merits of feeders and denseners; also, in the course of the experiments, a comparison is made between white and grey iron treated in the same way and poured into the same form of mould. Such a procedure helps to demonstrate a definite result rather than trust to general deduction. Although not quite in line with the title of this Paper, much evidence will be given showing the effect of gases in producing unsoundness principally in grey iron.

White and grey iron act very differently on cooling from the liquid to the solid, and to produce sound castings in each class of metal, different feeder and runner gates are applied. A sound casting is very often easily obtained in grey iron which presents much difficulty in white iron.

White Iron has Shorter Freezing Range.

Ordinary foundry grey irons contain large quantities of silicon and carbon; these elements together are mainly responsible for the softening of cast iron. With the exception of sulphur, white iron holds smaller amounts of the common impurities found in grey iron, and consequently possesses a shorter fluid life.

The dissociation of the iron carbide when grey iron cools provides compensation for liquid shrinkage. Only a trace of carbon is precipitated when white iron cools, the bulk remaining in combination, and consequently there is more liquid shrinkage.

The principal factors which govern the rate of solidification in cast irons are:—Degrees of superheat above melting temperature and freezing point as determined by composition. The amount of combined carbon governs the melting temperature, and the higher the total carbon the longer the period of cooling. It is generally accepted that, in melting grey iron, the graphitic carbon must first be dissolved before fusion point is reached, which results in a considerable amount of heat being rendered latent, and is stated to be equal to a superheating of about 270 deg. C. The melting temperature of grey iron is given as 1,250 deg. C., and that of white iron about 1,120 deg. C. Silicon, by reducing the stability of iron carbide and compelling carbon to precipitate, generates heat and prolongs the life of the molten metal, so that grey iron freezes at a lower temperature than its melting point.

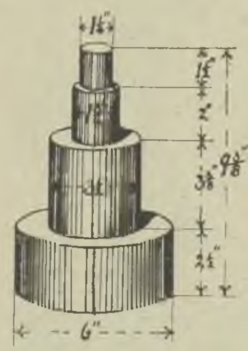


Fig. 1

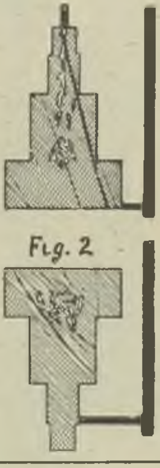


Fig. 2

Liquid Shrinkage and Gas Holes.

Many foundrymen and metallurgists state that they can distinguish the difference between a gas hole and liquid shrinkage cavity. Personally, the author admits that he has never been too sure, especially with grey iron. Blow holes from cores and moulds sometimes show up very clearly; blow holes from occluded gases are not certain.

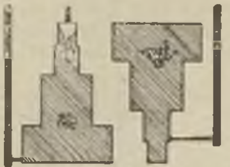


Fig. 3

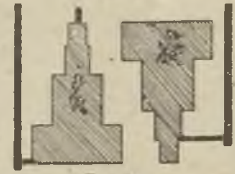


Fig. 4

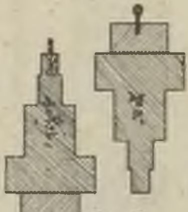


Fig. 5

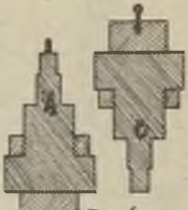
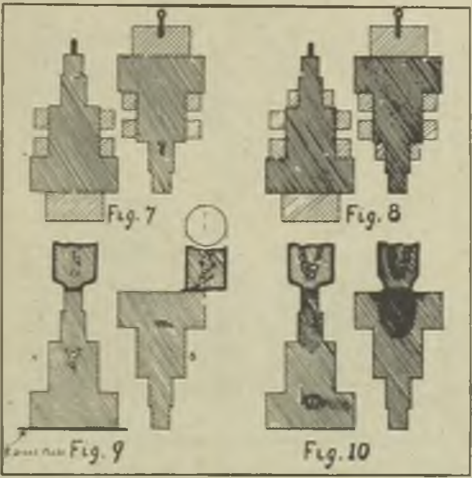


Fig. 6

Methods of Feeding.

To obtain sound castings, feeding is resorted to. In grey iron, feeding is accomplished in several ways, the most common of which is pumping with a wrought-iron rod inserted in the riser heads mainly, and runner gates. Sometimes the gates are subjected to a pumping movement obtained by placing sand on the metal in the runner basin, using a spade with an up-and-down movement until the motion of the metal in the riser ceases, the object being to keep the metal moving on the top side of the mould, thereby preventing it solidifying before the metal below. In other cases fluidity of the metal is prolonged by additions of hot iron to riser and runner heads. What are termed self-feeding heads are fixed on certain types of castings. In many cases the latter method is preferred rather than risk the often unintelligent use of the feeding rod. When feeding a heavy section, hot metal is supplied from time to time. In very heavy castings fed over a long period, a reserve number of loose riser bushes are provided, so that when the metal in the head congeals from the outside, restricting the movement of the rod, the whole bush, with its solid and solidifying metal, is torn off and a new bush substituted, which is then filled with hot iron.

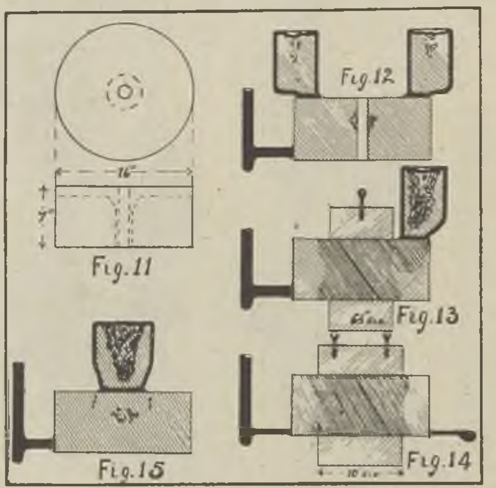


In white iron, large self-feeding heads are applied both inside and outside of the mould. Considerable skill is needed to locate the feeders. Shapes of runner and feeder heads have so often been dealt with that they will only incidentally be referred to.

Small pieces of solid iron are inserted inside and outside of moulds to shorten the period of cooling and prevent the formation of cavities in sections which are prone to defects.

Short Chills are Preferable.

Irregular thin plates of large area can be kept straight by building in the mould short lengths of cast iron or steel, placed judiciously so that the rate of cooling is hastened diagonally, crossways and in the centre. Care must be exercised in placing such chilling pieces. (In such cases, the term chill might be used, as the object is not to densen the metal, but to obtain a more uniform contraction.) When used for such a purpose, chills should be made in narrow lengths. If long pieces are built in the mould, the side of the chill in contact with the molten iron will expand more rapidly than the reverse side whilst the iron is still molten; consequently the convex surface thus formed leaves the level of the mould face and rises into the metal, producing a scrap, or at best an unsightly casting. Even with the greatest care the mark of the chill is very evident, and unless the chilled side of the casting is out of sight when erected, such a process cannot be strongly recommended.



Chills and Denseners.

Chills are also used to equalise the rate of cooling between heavy and light sections to prevent fracture and distortion. Denseners are used to improve and close the grain of wearing surfaces in various important castings, but the principal duty of the densener lies in its use to eliminate cavity and porosity in ferrous castings.

Occlusion of Gases in Metals.

It is generally understood that most of the porosity and cavity in grey and white iron is caused by liquid shrinkage. The author believes Mr. J. E. Fletcher is responsible for the statement that "feeding is necessary to facilitate the escape of occluded gases." At a meeting of the Faraday Society, held on November 18, 1918, an exhaustive discussion took place on the occlusion of gases by metals. Mr. P. Peakman there stated that he "was inclined to think that cast iron does occlude certain gases, and some of the failures which there seems some doubt as to their cause are possibly due to these occluded gases desiring to escape or interact on the constituents of the iron." Dr. Hatfield then stated that:—"The high percentage of silicon normally present in grey cast iron enables it to take care of the gases which could possibly be absorbed under melting conditions. In my works experience I do not remember seeing cast iron containing blow-holes

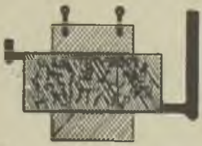


Fig. 16

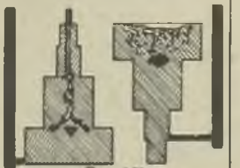


Fig. 17

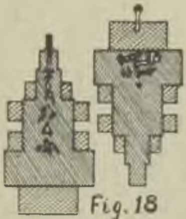


Fig. 18

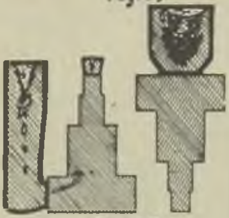
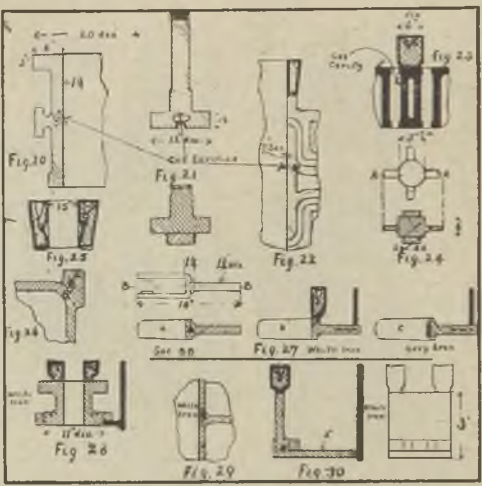


Fig. 19

due to occluded gases if the silicon content was over 0.3 or 0.4 per cent., and silicon is always higher than that. Blow-holes in cast iron are almost invariably due to what the foundryman calls trapped air; that is, the mould has not been made in a proper manner or it is a damp mould."

For the moment it is sufficient to state that the following experiments lead the author very strongly to believe that gases produce cavity and porosity in grey iron and gases and liquid shrinkage are together responsible for cavity and porosity in white iron.



Experimental Procedure.

Fig. 1 represents an experimental block casting designed to give a maximum of gas or liquid shrinkage cavity with a view to discovering the cause and the best way to eliminate the defects found. The casting weighs about 28 lbs. Where one section meets another, the corners were left sharp and square to facilitate easy breaking of the blocks into distinct sections. Each piece was again broken through the centre at right-angles to the previous fracture. The second fractures were obtained by crushing in the jaws of a hydraulic press. This was accomplished by placing the piece of casting on a V block and then holding a triangular rod of steel over the top of the piece to be broken and then subjecting to hydraulic pressure. A neat fracture is obtained, and all vital spots of the casting disclosed.

With one or two exceptions, the blocks were poured in two positions for each test, one with the small end up and the other large end up.

The following is the approximate analysis of the grey iron poured into the block moulds:—Si, 2.5; Mn, 0.3; S., 0.09; and P., 0.9 per cent.

Fig. 2 shows what was disclosed after the first attempt. The moulds were made in green sand, bottom poured, and all ordinary precautions exercised to secure a good casting except that no effort was made to feed. The result at once opened up an interesting field for further experiments. Did not the formation of the cavities show distinct outlines of gas streams, especially in the block cast small end up? In the block cast large end up, the cavities are collected in the centre, where the two heavy parts meet.

Small Runners Reduce Cavities.

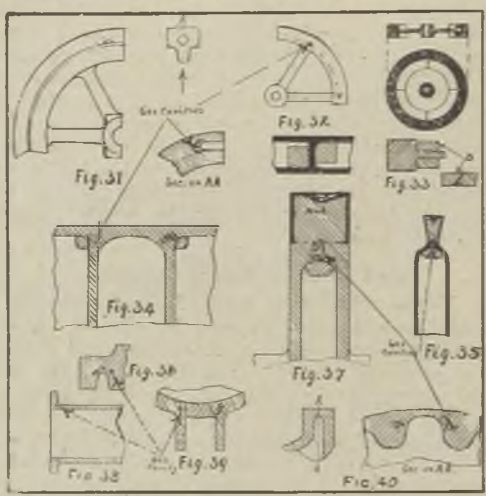
Two blocks were then poured, each through a $\frac{1}{4}$-in. dia. pencil gate, as seen in Fig. 3. There is certainly a reduction in the extent and change in the position of the cavities. The next two blocks, depicted in Fig. 4, were poured in thoroughly dried moulds. The amount of cavity compares very favourably with those run through pencil gates. Fig. 5 shows the effect of applying a 4-in. densener to the centre of the heavy part of the casting. It is interesting to note that the cavity is reduced.

Two additional half-circular denseners were placed about the neck of the heavy sections when making the next two moulds. Defects are again reduced and moved to the positions as shown in Fig. 6.

Another pair of denseners was added, which resulted in a further diminution of the cavities, as depicted in Fig. 7.

A third pair of denseners was then applied in the position shown in the next illustration, Fig. 8, giving a perfectly sound close-grained casting throughout. A pair of castings made from an iron mould also gave a similar result. In the last two tests with soft phosphoric iron, a small area about the size of a threepenny-piece, of open-grained structure, appeared in the centre of the juncture of the two heavy parts. When the silicon and phosphorus were reduced to below 1.6 and 0.6 per cent. respectively, a very close-grained structure was obtained even at this vital spot.

With a view to excluding mould gases from the bottom side, an $\frac{1}{8}$-in. iron plate was inserted in the mould, as depicted at A in the sketch, Fig. 9.



A riser gate, the same size as the small end, was carried through the mould and a basin of iron provided to act as a self-feeder. Defects were not so pronounced as in the first test, the plate having excluded some of the mould gases which had previously escaped upwards through the metal.

Feeding Experiments.

A half-circular self-feeder was then applied in the following block poured, as shown at B in Fig. 9. Only a small defect is disclosed, showing that the heavy feeder had maintained a hot passage for the occluded and mould gases to pass out.

Fig. 10 illustrates unsoundness with rod feeding. When poured and fed small end top, a large cavity was found in the bottom heavy section. With the heavy end top, as will be expected, a more sound casting is obtained, but the result is not quite satisfactory; small gas holes appear under the outer edges of the feeding head, with the usual disturbed crystallisation.

Absence of Mould Gases gives Sound Castings.

Later the author came to the conclusion that a sound casting might be obtained if all or most of the mould gases were prevented from entering the molten metal. Moulds were constructed in plumbago bound together with a small proportion of core gum, thoroughly dried and gated in the same manner as the earlier attempts. Perfectly solid castings were secured, the grain of the iron being a little closer than those cast entirely in green sand. Well-dried ganister moulds also gave a very sound, but much closer grained, casting.

Photograph No. 1.

A number of photographs were taken of the cross-section of these experimental block castings. No. 1 shows one of the first castings poured into a green sand mould without any feeder. The second is a photograph of the sound casting finally obtained by a progressive application of denseners. It might be here noted that the denseners were loose and, except the one on the heavy section, in halves and free to be pushed back into the sand when the grey iron expansions take place on cooling. Nos. 3 and 4 are sound castings obtained from plumbago and ganister moulds respectively, as described above.

PHOTOGRAPH No. 2.

A Further Type of Casting.

Fig. 11 gives particulars of another experimental block casting weighing about 3¼ cwts. An apparently simple casting, but most foundrymen appreciate the difficulty in securing a definitely sound casting by ordinary moulding methods, especially if it is to be machined all over and through the centre, as depicted by dotted lines in the sketch

The first castings produced had a sand-cored hole through the centre; they were bottom poured and two heavy self-feeders located, as shown in Fig. 12. A large cavity was disclosed about the centre core and a little towards the top side. A similar cavity was experienced when the central hole was formed by an iron core or densener. A block cast without core, riser or feeder gave a slightly larger cavity. Fig. 15 shows a casting fed through a 6-in. riser and head, but this was again defective.

A passable casting was secured by applying 6-in. denseners to the centre of the mould, one top and one bottom, and a feeding head situated as shown in Fig. 13.

Fig. 14 shows the same casting poured through several bottom spray runners without any riser or feeder whatever. Two denseners, 10-in. dia., were placed in the centre of the mould, top and bottom. A perfectly sound, close-grained casting resulted. Photograph No. 5 shows a piece cut from and across the centre of the casting.

Fortified by the experience gained from the smaller blocks, one of these heavy castings was poured in a plumbago mould without riser or feeder, and secured a sound casting, the crystallisation not being so pronounced as those poured in greensand moulds. Further, a mould made in ganister, thoroughly dried, gave a casting also without any defects and a much denser structure

Experiments with White Iron.

Fig. 16 represents a block of white iron, which shows a striking contrast with those made in grey iron and of the same dimensions.

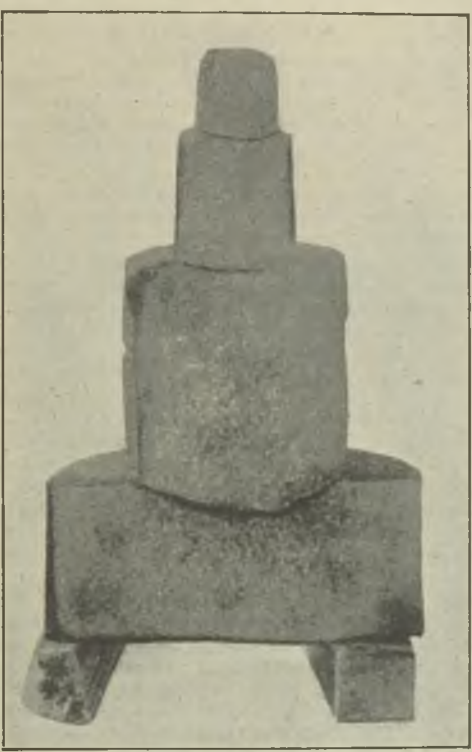
Blocks similar to Fig. 1, made in greensand moulds and not fed, were poured in white iron, and disclosed, as would be expected, much cavity, as illustrated in Fig. 17.

The four sets of denseners, which had proved so effective when applied to the blocks poured in grey iron, did not bring any noticeable improvement with white iron. As will be noted in Fig. 18, the defects are almost as extensive as those poured in green sand without feeding.

PHOTOGRAPH No. 3.

Fig. 19 depicts two attempts to obtain a sound casting. The block cast small end up required a large feeder to secure the result shown—only small cavities. It is interesting to note that the formation of the defects seem to indicate that the gases have worked down and them up through the feeder head Pouring the casting large end up, with a 3-in. riser gate and a self-feeding head, resulted in a sound casting.

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 just described.



Photograph No. 4.

Gas Cavity Defects Illustrated.

From the group of drawings illustrating sections commonly experienced with defects which are usually explained as liquid shrinkage holes, it is suggested that they are, with grey iron, in every case, gas cavities.

Fig. 31 shows a section of a heavy half-flywheel. Tee-shaped holes are formed in the rim by cores. Sponginess occurring at the nose of the core in spite of heavy rod feeding, was eliminated when a very free core vent was provided.

Gear blanks similar to Fig. 32 give trouble where the arm meets the rim. Gases play off the hot corners of the core. Denseners placed in the cores, as shown in the enlarged section, is the remedy.

At Fig. 33, another type of gear blank is outlined. A very sound and hard-wearing gear is obtained by employing a ring of denseners top and bottom of the web. The denseners are constructed as depicted in the enlarged sections. Only common iron is used for the castings.

Fig. 34 illustrates a section which also gives trouble. Here again gases play into the hot spot formed where the bracket meets the body. Holes formed through the bracket, preferably by an iron core, as described, will prove effective.

Figs. 35 and 37 show defects in small ram and heavy hydraulic cylinder castings. Denseners attached to the cores are employed. If gases are conducted freely away, and the core very carefully made, the denseners are not needed. Fig. 36 is another common defect. Cavity is disclosed when the recess is cleaned up by machining. Figs. 38, 39 and 40 can all be explained in a like manner.

Fig. 20 is a part section of a sleeve casting, which is machined all over. Defects occur about the place where a portion of the mould protrudes into the metal. Such a piece of sand quickly reaches a high temperature and acts as a heat retainer; the grains of sand expand and loosen somewhat, allowing a freer passage for the imprisoned gases in the body of the mould, and unless an easy and clear vent is provided, the gases will flow into and be found in those places last to freeze, as indicated in the sketch. A densener placed on the bore opposite the unsound place hastens cooling of the metal, thereby reducing the time that the gases can generate and flow from the sand.

More Defects Explained.

Fig. 21 shows a spindle casting. Sponginess is in evidence at the root of the shaft when the tee-headed slots are machined out. A great depth of head metal would not remove this defect. A densener placed as shown in the bottom section eliminates unsoundness.

Fig. 22 is another common defect—porosity about cylinder ports. Such thin cores act as heat retainers. If the lightening core between the ports is not freely vented, defects as indicated might be expected. A number of small clean nails pushed in the mould or cores about the vital spot generally eliminates such a trouble. Fig. 23 illustrates a similar case. The drawing shows a portion of a Diesel cylinder head.

Photograph No. 5.

Sponginess in pulley bosses can be eradicated by removing the core and placing denseners both top and bottom, as depicted in Fig. 24. The size of densener should always be less than the diameter of the boss by 1 in. Not only is cavity removed, but rate of cooling is much more equalised and danger of fractured castings minimised.

Shrinkage holes in heavy feeding heads with a core running through the centre show up as in Fig. 25. Cavity is disclosed on the core side as well as in the centre of the head section. The core becomes very porous and over-heated at this part, allowing gases to flow freely into the metal there, possibly to react with occluded gases and generate heat in the locality.

Fig. 26 shows a section often encountered in cylinders, etc. After tapping a hole, cavity is found at the root of the boss. A number of small clean nails inserted in the mould so that they do not protrude into the machined portion will overcome this trouble.

In the next example, Fig. 27, of a fork-like casting, a comparison can be made between grey and white iron. "A" is a section showing the position of the cavity when cast in grey or white iron. In grey iron, the defect disappeared when a densener was applied as indicated in the sketch "C." In white iron, the densener proved useless. A sound casting was obtained in white iron by enlarging the section above the troublesome spot and providing a self-feeding head, as shown at "B."

Various Cavities Eliminated.

Fig. 28 might represent a double-pinion blank cast in white iron. Here the combination of denseners applied to the blank-cast bottom along with two good feeding heads is necessary to secure a sound casting.

Fig. 29 shows a section commonly met with both in grey and white iron. With white iron, the gases which pass into the hot spot react with occluded gases, probably generating heat and allowing metal to drain away and supply feed to other parts of the casting. Denseners placed in the corners will remove the defect.

An L-shaped casting is illustrated in Fig. 30. The casting is of white iron, and weighs about 4½ cwts. If denseners are not applied to the heavy-section corners, together with good feeding heads, unsoundness and weakness would there be expected.

How to Prepare Denseners.

There are still many foundrymen who are prejudiced against the use of the densener, probably because they have allowed them to be carelessly used. Little trouble need be feared from their use if they are systematically cared for. Flat denseners can be used for a considerable number of times if they are ground on an emery stone each time after using. Denseners to be placed in greensand moulds are quite safe if smeared with oil, followed by an application of dry plumbago, but those to be placed in cores and moulds which are dried should be painted with stiff core oil and dried in a stove before inserting in the sand.

Photograph No. 6 shows a densener which has been used only twice below the head in a heavy casting. This example shows the necessity for casting denseners in low silicon and phosphorus iron, especially the latter. A rapid wasting has evidently taken place. There appears to have been liquation of the phosphide eutectic.

Photograph No. 6.

Conclusions.

In commonly-used foundry grey irons, with silicon ranging from 1.3 to 2.8 per cent., and the other elements in proportions usually encountered, defects, excluding distinct mould and core blowholes, etc., as described in this Paper, are caused by trapped mould gases reacting or interacting with occluded gases, probably forming, mainly, carbon monoxide. If mould gases can be prevented from entering the molten metal, a sound casting results, even if poured with dull iron. Although not commercially practicable, castings made in dried ganister or plumbago moulds gave perfectly solid castings. It would also follow that a cavity is not necessarily transferred to another part of the casting when eliminated at a particular part by a densener.

Defects, excluding moulding errors, in white and mottled iron are due to liquid shrinkage and gas inclusions.

Density in grey iron is determined by the rate of cooling and composition. Freedom from cavity and porosity or solidity depends on the absence of mould gases. The solidity of metal poured into iron moulds is due to the above-mentioned combination, and not, as has been stated, to the resistance of the iron mould to the expansions which take place when grey iron cools.

Finally, the author desires to acknowledge his gratitude to the directors of Messrs. Tangyes, Limited, for help and permission to carry out the experiments in their foundries.

RELATIVE VALUES OF FEEDERS AND DENSENERS FOR STEEL.

By H. Bradley.

Mr. Bradley (Sheffield) said it was improbable that denseners would ever take the place of feeders, but in many types of castings denseners were very useful; almost indispensable.

The densener in many cases saved much machining where the feeder would have to be shaped or planed after the sawing or burning off.

In castings with sections of unequal thickness denseners, internal or external, applied to thick sections regulated the cooling, and therefore made the casting stronger and saved it pulling. Everything depended on the design of the casting to be made and the quantity required.

In using internal or external denseners, the greatest care had to be taken to see they were perfectly clean and dry, or trouble would be experienced. The safest plan was to tin the internal ones. External ones should be covered with black lead and dried, or tarred or smoked as a crucible ingot mould. One of the frequent causes of failure was using rusty denseners. Denseners eliminated waste in steel, as in some cases no feeding heads were required; in others it enabled one to put on a much smaller feeder.

Consider a hydraulic cylinder, say with 24 off, weighing approximately 5 tons 10 cwts. The pattern was received with the feeding head on the bottom end of the cylinder. Denseners were made, and fixed round the thicker part, where possible, to enable the steel to freeze quicker at that particular part, therefore tending to equalise the cooling and saving a pull at the junction of the varying thicknesses. After casting a few, in testing them porosity was found in the thinner section where it joined with the press portion, one being a complete waster. The body was parted off at the above-mentioned position, finding four cavities or pipe holes underneath the column boss. It was then decided to cast them the opposite end up, with a feeding head, and still using the denseners, at the same time saving 20 cwts. to 25 cwts. of steel in the feeding head without any further trouble.

Mill Pinions.

Here internal denseners were used, so as to save having to put such a large head on the top neck and wobbler, therefore saving much machining, and also getting a much better and stronger neck and wobbler by the grain being closer, owing to it being nearer the casting size. Whenever the pinions were, say, 30 in. and upwards in diameter it was preferable to core them out, in place of using the densener, providing the engineer would allow it, for the bottom wobbler was large enough to allow, say, a 4 to 4½ in. hole through it.

Yoke Castings.

Internal denseners had again to be resorted to in order to solidify the casting and to save much costly shaping if feeders were used. Feeders were fixed on the outer rim portion, also at the feet.

DISCUSSION AT SHEFFIELD.

Mr. Edginton, in opening the discussion, said he had had some experience in the use of chills in cast iron. He thought it was a pity the subject was not more widely known. He remembered when he commenced to use them the considerable difficulty which arose. On a series of castings he used a chill just under the top flange. This practice continued for probably nine or ten days. It was then they encountered some trouble. Six of these cylinders were cast per day. After the first six castings they found the castings began to "kick" or "blow." It was found there was a gas hole in the top of the cylinder above the chill, and eventually it was discovered that the cause of the trouble was that they had used the chills repeatedly, and as a result some oxide formed on them, which reacted with the molten metal. Now, when they had a series of castings they never exceeded five or six times before they used a new set of chills.

Mr. S. R Robinson agreed with much Mr. Edginton had said. He thought chills eliminated many troubles in casting. He was of opinion that many of the samples shown on the screen by Mr. Longden could have been overcome with chills and without the difficult method of runners. To his mind, many of the castings he had seen, if they had been top-poured, would have eliminated much trouble so far as the shrinkage holes were concerned. During the war period he had had considerable trouble with the making of cylinders, due to the core. After experimenting, instead of putting in the core, they used a chill, and with chills they cast 100 cylinders without a waster. Then they had a blow on the top, and cast seven more before they had another good one. Chills would only stand using a certain number of times. He broke the chill mentioned, and discovered that every time the chill was used more oxide was formed, and eventually blew the casting. He would like to know the number of times chills could be used.

Mould and Metal Gas Reactions.

Mr. Kayser said that while he did not think that anyone would deny that the use of chills would give the results Mr. Longden stated, yet similar results could in numerous instances be obtained by other more suitable and at the same time cheaper methods of procedure.

It was nevertheless interesting to have the different uses of chills brought forward, but he was afraid that Mr. Longden had seriously depreciated the value of his Paper by the strange and, in his (Mr. Kayser's) opinion, erroneous explanations he put forward. There were no grounds whatsoever for the assumption that a gas evolved from the mould whilst the metal was still molten reacted with gases occluded in the metal to give rise to another type of gas which produced blow holes, and until the lecturer could give evidence in support of his contention, he thought it would be best not to advance such an incomprehensible theory.

In the case of cast iron, a chill would, with a suitable mixture of metal, produce a hard surface, but as far as chills were considered that evening, they were considered not so much as surface hardeners but rather as a means of producing sound castings, and in that respect the whole idea in using them was so to control the direction and rate of freezing that no pockets of molten metal were created, as such pockets always gave rise to shrinkage cavities and consequently were a source of weakness.

Mr. Kayser remarked that it was unfortunate that all the castings upon which post-mortem examinations were held were broken open to demonstrate the defects they contained. It was much better to machine castings open, as many shrinkage cavities were quite unoxidised, and although the cavity in the casting may have been as much as ¼ in. across, the two halves were such apparently perfect fitting male and female surfaces that it was impossible to distinguish the fact that they had not been in absolute contact before the casting was ruptured.

Mr. Darley said, in regard to steel, chills, in his experience, on the outside were not a success unless it was a complete circle. It was essential there should not be any joints, for if there were they produced a pull at each joint. He remembered several instances where they had tried it resulting in curious problems. Gases generally came from the bottom side of the mould. This he thought was on account of the steel having to travel long distances in the mould, and it was not sufficiently liquid to drive out the gas. It was necessary to have many years of experience to understand the mechanism of a steel casting, for although the "drawing" might be carefully examined and every precaution taken, it was so easy to get the casting milled in two pieces. One of the chief arts of the steel moulder is a knowledge of chilling and feeding.

Chilling not Necessarily Hardening.

Mr. P. T. Bailey stated that the principal thing to get impressed on one's mind was the fact that "chill" did not necessarily mean hardness, and if or when, it was generally understood that a casting which had been chilled locally, in say a thick boss adjoining a thin section, the casting might be quite soft and machinable, and also quite sound, then much prejudice would be overcome. The same remark applied to castings made entirely in chills, or permanent moulds. The point should be borne in mind, particularly in castings made in grey iron, and if care was exercised in the proper proportioning of chills and the removal of the chills at the correct temperature, no difficulty would be presented in the subsequent machining operations. In most instances no annealing or other heat treatment should be necessary. In the case of malleable castings, hardness brought about by chilling was of little consequence, as that would be removed in the usual course of annealing. It was in the malleable industry that the use of chills was most valuable, and although chills had been used in some malleable foundries for a good many years, in others their utility was scarcely known, or was only in its infancy. There was a somewhat common impression in some quarters that if a chill was used to prevent drawing or unsoundness, the chill only drove the draw or unsound portion further in. In his opinion that should not occur if the chilling and feeding were done systematically, because it should be possible to run and feed that part of the casting adjacent to the part which had been chilled, and so ensure soundness throughout, even if the chill was not perhaps properly proportioned and made such a course necessary. As far as malleable iron castings were concerned, he would always feed a casting to ensure soundness, in preference to using a chill if it were possible, but in view of the more exacting demands of the engineer and the greater variety of section than formerly, he was satisfied that it was impracticable, if not impossible, to produce some castings of recent design in malleable iron by feeding, or by chilling alone. It was only by using both methods in conjunction that certain modern requirements of the designer might be met. Each had their advantages and disadvantages, but if those were carefully considered it would be found that chills or denseners were a very important and valuable adjunct to the malleable foundry. Using a chill was only a quick method of feeding, and it would be well to emphasise the point.

Chills for Steel Castings.

Mr. T. W. Brown, referring to the use of chills on steel castings, said he was not a great believer in using chills for such a purpose when solidity could be obtained by other means; but where a chill was used, the chill should cover the whole part to be chilled, and it should be all in one piece. One unpleasant experience was the chilling of wheel centres at the arm ends, which was not successful, as they proved to have slight cracks on the rim at the junction of the chill and sand. Some were only slight, and did not show until machined. Another case was the chilling of a hydraulic cylinder, which was chilled around its heavy belt, the chill for this being in segments and somewhat open at the joints. On an examination of the castings, it was found to be cracked at every joint where the chills did not quite meet each other, and that was why he insisted that if chills were used they must be in one piece, and entirely cover the place to be chilled. As to the cause, he thought, at the point where the chill and sand joined each other, they had at one side the metal kept hot by the sand, and on the other the metal solidified by the chill face. As soon as solidification had taken place, contraction commenced, and in this case contracted to centre of chill and the joint between the hot metal kept hot by the sand, and the cooled metal by the face of the chill being the weakest then cracks must develop at that point. That was one of the reasons why he did not approve of chills. Another reason was from an economical point of view. In a foundry it was quite easy to make a chill suitable for many purposes themselves, but in a steel foundry it was a different proposition, as they generally had to get a suitable pattern made and sent out to other foundries to be cast, as not many steel foundries had a metal shop as well as steel.

Fresh Aspects of the Use of Chills.

Mr. A. Rhydderch said that Mr. Longden had confined himself purely to the production of sound castings in chills, but had unnecessarily complicated the issue by discussing the interaction of gases from the mould and metal in producing unsoundness. The photographs shown on the screen, particularly a few of them, were very obvious cases of piping or liquid shrinkage, which one would expect on casting a solid object, bottom run and thin end up. If Mr. Longden's theory holds, it is impossible to produce a sound casting in sand moulds.

Coming to Mr. Bradley's Paper, numerous instances had been given of the application of chills to various castings, but a large number of the important points had been missed.

For instance, the length and thickness of chill in relation to the size of the job had not been mentioned. Naturally a long chill, due to the unequal heating of the faces, would camber; thin chills would probably burn on; chill cracks are set up if small chills are not accurately jointed, and, finally, chill cracks are set up by over chilling. This is particularly so in hard steels, clinking taking place on subsequent heating. Speaking very generally, the thickness of the chill should approximate to the thickness of the casting, and should be of a double wedge shape, as shown in Fig. A. This type of chill meets most of the above objections.

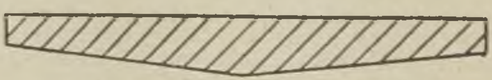


Fig. A.

Another important feature is that it is not so much a question of feeders *versus* denseners, as feeders with denseners or chills. Most foundrymen could call instances to mind where it was imperative to use chills if a solid casting was desired. The use of chills does not diminish shrinkage; it simply accelerates solidification, thereby allowing more effective feeding to take place. Further, it enables the size of the feeder heads to be considerably reduced, resulting in some cases to a saving of 10 to 15 per cent. of metal.

Mr. Longden had mentioned the painting of chills. This is very necessary with old chills, but if they can be thoroughly cleaned, the results are equally satisfactory, unless the moulds are to be dried, when it becomes necessary to paint.

The trouble of pinholes, mentioned by Mr. Edginton, is due to the cracking of the chills, the cracks being filled with oxides.

Regarding the material used for chills, mild and medium carbon steels can be used as well as cast iron. The trouble of cracks does not then arise if the chills are ground before being used.

Mr. Hyde said there was one point he would like to mention in connection with cast iron, and that was that the number of times a hematite chill could be used in safety has been known for a number of years. His father had mentioned the subject in connection with hydraulic tools, and he had said they always had trouble if they used a chill too often. He scrapped chills after they had made 30 tools. When old chills were broken there were a series of cracks, and, in addition, the composition was distinctly altered. Some of the silicon had oxidised, and the carbon had almost disappeared. He would like to ask the meeting if they had had any experience of mild steel chills in place of hematite chills, as the alteration due to the oxidation of the silicon and carbon did not apply if the chill was made from steel.

DISCUSSION AT BIRMINGHAM.

Opening the discussion, Mr. Parsons expressed the view that if the densener was somewhat of the same thickness as the part on which it was placed, unless the iron was a very high silicon iron, with fairly high total carbon, it was likely that they would get a chilled skin. As to the sketch showing the gas coming down out of the mould and flowing up into the riser, he asked whether the gas really flowed or was squeezed during solidification by the smaller part of the casting cooling first. He also asked for information as to the composition of a densener that would not break down readily.

Mr. A. Marks said there were no doubt many causes of cavities in castings. Mr. Longden had emphasised one, namely, absorption of gases by the metal, and it was one they experienced great difficulty in impressing upon practical foundrymen as a leading factor in connection with soundness. Even in a dry mould they were dealing with a very considerable amount of gas, and with modern oil sand cores it was necessary to carry out venting to a large extent. Mr. Longden had shown in his experiments how occluded gases in the metal caused trouble, and that was a fact which was frequently lost sight of. In the case of running water from a tap they would notice how the air was carried several inches deep into the water in a bowl, and the same effect went on in metal, only more intensely. A heavy material like liquid iron was capable not only of dissolving gases, like water, but of carrying gases down mechanically. In addition, they had a large amount of slag and dross carried down. Carbon monoxide was dissolved in the metal and was eliminated on solidification of the metal, although Mr. Longden did not quite clearly explain what was the exact action of the chill in eliminating the dissolved gas One found cavities due to gas at places where it was least expected that they would occur. One would produce solid chunks in a casting which were perfectly well fed, while a little further away, at the junction of a few cores, a pull would be exhibited. He thought they would make further progress in foundry work if they could all appreciate the fact that the liberation of dissolved gases was frequently the cause of cavities in cases which to the eye appeared to be cavities due to pure liquid shrinkage.

Mr. F. C Edwards thought the main use of denseners was to bring about a uniform cooling rate throughout the whole of the casting. If they could get a casting to cool simultaneously he believed they would have a perfectly sound casting. The trouble was that in many cases they did not receive an evenly designed casting. As a consequence, they had unevenness of cooling. He did not suppose they would ever overcome the effect of temperature on iron. Whatever composition they used, unless they attended to the cooling factor they would always be in trouble. He asked if Mr. Longden had had any experience of denseners when they covered the whole of the boss.

Speaking again, MR. MARKS said they were inclined to consider denseners from the foundry point of view. Perhaps, in his reply, Mr. Longden would say something about the engineer's point of view—the life of the casting in relation to denseners. His own view was that they were a device on the foundryman's part to overcome his immediate troubles, but he was not sure that, from the standpoint of the engineer, denseners were an unmixed blessing. He knew that they were not an unmixed blessing in actual foundry production.

Vote of Thanks.

Proposing a vote of thanks to Mr. Longden, MR. A. PARSONS said with regard to the various porous places shown on the screen and described by Mr. Longden it became very obvious to all foundrymen that to eliminate the porosity that was met with in the various sections opened up a wide field for the application of denseners. The experience he had himself had with denseners outside actual chilling had been the application of such denseners to the bottom neck of a large chilled roll. Since the coal strike the material that had been on the market for the manufacture of chilled rolls had been very much below the quality that they were able to get prior to the strike.

MR. D. WILKINSON, in seconding the motion, expressed the opinion that cavities in moulds resulted from various causes. In explaining one of his slides Mr. Longden said that it appeared to prove that the gas had flowed down the riser and up into the mould. Personally, he could not see why a gas superheated to about 1,200 deg. C. should flow downwards at all and push molten metal on one side. That seemed to prove that the difficulty was not due to occluded gases or trapped gases, but was entirely due to liquid contraction. Ganister, rammed solidly, conducted heat more efficiently than sand, so that a ganister or plumbago mould would act in a minor degree as denseners. He had held the view for a long time that trapped air and air carried into the mould by the rush of the metal and air generated in the mould by the action of the heat on the moisture contained in it had a great and persistent effect in producing cavities. Cavities resulted from trapped air, gases given off by the mould, occluded gases in the metal and also liquid shrinkage. He did not think it could be said in the present state of knowledge that any one cause was solely, or even almost entirely, responsible for the defects. Denseners or chills certainly had been very effective on a number of occasions. Personally, he had found that trouble sometimes occurred with a densener put on the top of the mould from a very simple cause. Gas given off by the other parts of the mould, or the gas carried in a stream of metal going into the mould, or even occluded gases, had been trapped under the top of the chill. For a long time, therefore, he had been rather averse to putting chills or denseners on the top of the mould. But he noted that Mr. Longden carefully stated that at least one inch of the casting beyond the densener should be left free. Possibly that would be the cure for the trouble he had found in similar cases, because in putting the densener on the top of the boss he had gone to the trouble of covering the boss entirely. It was certain that they could not have too much experience of these experiments. They could not make too many experiments, nor could they be too careful in applying the knowledge they obtained if they were to obtain sound castings. The average engineer made no allowance whatever for a defective casting. If it was not sound he said, with parrot-like reiteration, "Scrap." Altogether apart from that, it was their duty as foundrymen to do all they could to produce sound castings.

The President supported the vote of thanks, which was heartily accorded by the meeting.

The Author's Reply.

Replying upon the discussion, Mr. Longden said he found that there was a chilling effect from the use of denseners even if they were just below red heat. A densener not only formed a skin which projected the crystals forward, thereby exerting pressure, but it reduced the period of time in which gases could escape in the metal. A number of denseners used on the experimental blocks did, more or less, exclude the mould-gases from entering the metal. As to the reference to plumbago and ganister moulds acting as a densener, he did not quite agree that that was the real action which produced solidity. He stated that the castings made in plumbago moulds were a little denser than those cast in green sand, but that there was little to choose between the two. He did not claim that cavities were formed by occluded gases. Cavities would not form unless there were mould-gases. Gases were certainly generated in a dry-sand mould. He thought far too much blame in the past had been meted out to the metallurgist, and that foundrymen must take their share and carry out systematic experiments. He was firmly convinced that the trouble arose from the interaction taking place between the mould-gases and occluded-gases. If in a mould with a number of cores they ran it by drop runners, especially if the metal was a little dull, they inevitably had gas holes and dirty places. The cracking of denseners depended upon the section. He suggested that they would certainly have cracking if they attempted to put a comparatively thick densener into a thin, wedgelike place. He did not agree that the phosphide eutectic caused the cracking trouble, but imagined that it was the contraction of the casting being resisted by the iron core or chill. He did not make any statement to the effect that in white-iron unsoundness was caused only by gases. He was convinced that gases were in part the cause, but there was certainly heavy liquid contraction. In the case of grey iron they had the compensating effect of graphitisation. He had tried denseners over the whole of the boss, but he could not say that he had experienced quite the same trouble as Mr. Wilkinson indicated. As to the machinability of the chilled castings, when broken the sections proved that they were quite machinable. To cast hot was the wisest course in all ferrous metals, and especially malleable iron. So far as the use of denseners in malleable iron was concerned, he did not claim a great deal of benefit from them, except that in special cases it hurried the rate of cooling in the heavy lower section, freezing it before the upper, and probably thinner, sections, and allowing the feed to go through that thin section, which was later fed by the head metal. One very important factor in the use of chills was that eventually it was possible considerably to reduce the melted metal. In the case of comparatively small castings they had perhaps half a cwt. of head metal, and when they compared the difference between that as returned scrap and the pig-iron put into it it might amount to 8d. or 9d. on a small job. The saving would be very considerable if it were systematically arranged about the foundry. He did not possess any data whatever as to the length of life of castings which had been chilled, but it was certain that the use of a chill prolonged the life or increased the wearing possibilities of the material.

Sheffield Branch.

THE INFLUENCE OF CASTING TEMPERATURE OF ALUMINIUM ALLOYS.

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

Although the founding of aluminium is in its early infancy, as compared with that of iron, this branch of the foundry trade occupies a very important position, and is now an industry of considerable dimensions. The automobile and aeroplane trade is largely responsible for the great strides made in the use of aluminium castings, and many important investigations have been undertaken and much useful information obtained. To a large extent foundrymen are indebted to the Light Alloys Research Committee for their scientific knowledge of aluminium alloys; but at the same time, useful work has been carried out by private individuals, and published in the technical journals.

In the foundry of the Rover Company the present average output of aluminium castings is just over 400 tons per annum, and this represents a very considerable number of individual articles. As different castings have to comply with different tests, some to a tensile test, some to a water-pressure test, some to an oil-pressure test, some to withstand vibration, and some to hold their strength at high temperature, it will be obvious that a measure of scientific control is essential. Analyses are regularly undertaken, but this does not go sufficiently far.

For some years now the author has been interested in casting temperature, which he considers to be of vital importance in the successful production of aluminium castings. Any average aluminium foundry worker knows that a casting which has been poured very hot has a yellow, or light brown, skin, instead of pure white. This is only an empirical test, and is being wise after the event. It is impossible to enunciate a hard-and-fast rule that all castings must be poured within a specific range of temperature, as the mass, thickness, type of alloy, and purpose to which the casting is to be put all demand consideration.

The author insists that for any one casting there is a short range of temperature at which the metal should be poured, to obtain the best results; and this temperature range can only be discovered by definite experiment in actual practice. One important point to bear in mind is that the composition of the alloy is also a determining factor in the consideration of casting temperature. It does not necessarily follow that a casting which gives good results when cast at a certain temperature in L5 alloy will give equally as good results at this temperature when a radical alteration is made in the composition of the alloy. Change begets change, and even a comparatively small change in the make-up of the metal charge will necessitate a certain amount of experimental work to determine the most suitable casting temperature for each job. Once a good casting has been produced, it is advisable to take note of all the variables which occur in production, and endeavour to standardise. Good results can be obtained, and have been obtained, by rule of thumb methods, but there is far more certainty with some kind of scientific control, yet scientific knowledge must be combined with a knowledge of foundry practice, and also a study of human nature.

Pouring Temperature the Governing Factor.

In a Paper which the author read in Birmingham in March, 1917, he stated that, "by attention to casting temperature, it does not matter what temperature the metal has attained, nor how long it has remained in the furnace, results may be obtained equalling those from metal which has been melted with every care."

This view was also taken by Rosenhain and Grogan in a Paper read before the Institute of Metals, and published in their "Journal," 1922, Vol. 2, although their experiments were conducted on commercially pure aluminium only. In the light of knowledge gained since 1917, and more especially during the last twelve months, the author is compelled somewhat to modify his views, which will be outlined later.

In determining the effect of casting temperature, one has also to consider many other factors which have, or may have, an important bearing on the results. For instance, there is the question of the maximum temperature the metal has attained in the furnace, and the length of time the molten metal has remained in the furnace before pouring. It is not always possible to use metal the moment it is melted, desirable as such a course may be, as delays in moulding may occur.

Effect of Ageing.

Then there is the effect of ageing, a subject on which a considerable amount of research has been carried out of late. This is a very important factor in production, as aluminium castings may not come into use as a finished article for some months after they have been produced. This particularly applies in the motor trade, where it is estimated a period of at least four months elapses between the actual casting of the article and its debut on the road as part of a finished car.

Effect of Internal Strain.

There is also the effect of internal strain, and this is one on which no measurable data are obtainable. Castings have been produced and carefully examined by two independent parties, placed in the stores without any rough handling, and found to have developed cracks some weeks later, owing apparently to internal stresses.

Experimental Conditions.

In the figures to be submitted the maximum temperature the metal has attained in the furnace is given, and, unless expressly stated to the contrary, the tests have been made on metal which has remained in the furnace not more than 20 minutes after actual melting. Later on, it is proposed to give some results obtained after ageing. All test bars have been either sand-cast or chill-cast, as stated, in parallel bars $\frac{7}{8}$-in. dia. in the rough, and for tensile test turned down to

0.564 in. for 2 in. of parallel. All bars have been produced under actual working conditions, the metal being melted in the ordinary course of foundry practice, and the temperatures taken with a Foster base-metal couple immersed in the metal. This type of pyrometer is in constant use in the Rover Company's aluminium foundry, and the accuracy of the readings is checked periodically in the laboratory.

It is not claimed that the results given in this paper represent research of a high degree of scientific accuracy, but it is considered that they give some indication of what might be expected in the commercial production of aluminium castings, when foundry practice is allied with science. At the same time, it must be clearly understood that troubles in the foundry will still persist, unless good melting practice is coupled with good moulding practice. First-class metal poured into a third-class mould will only result in a second-class casting; just the same as a good mould will be spoiled by disregarding pouring temperature, or pouring with badly-melted metal.

Defects Encountered.

The most common troubles from which aluminium castings suffer are cracked and drawn places, porosity, fine pinholes visible on machined surfaces, sponginess, and blowholes. With the exception of the last, these difficulties can be remedied by attention to melting practice, and paying due regard to the importance of casting temperature. Blowholes are generally due to faulty moulding practice, but may be attributable to excessive oxidation during melting.

Tests on L8 Metals.

Table I outlines tensile tests taken on what is usually known as L8 metal, an alloy of aluminium and copper, more often used for die-casting than for sand castings. These bars were sand-cast, and it will be noticed that the bar cast at the intermediate temperature, 700 deg. C., gives the best results, although both this and the bar cast at 600 deg. C. show a higher tensile than that obtained at 800 deg. C. All the results given in this Paper are the average of duplicate tests. It will be noticed also that the metal attained rather a high temperature in the furnace before withdrawal.

This metal was melted in a small crucible furnace, and should have been withdrawn at about 800 deg. C., but the operator's attention was diverted for some few minutes, and during that time the temperature of the metal had increased to 960 deg. C.

TABLE I.—*Influence of Casting Temperature on Sand-cast L8 Alloy* (aluminium, 87.90; copper, 11.14; zinc, trace).

No.	Casting temperature in degs. Cent.	Max. stress. Tons per sq. in.
10	800	7.28
11	700	8.24
12	600	8.00

Maximum temperature in furnace, 960 deg. C.

Table II gives tensile tests on chill cast bars from the same material. It will be observed that the higher breaking stress is obtained in the bars cast at the lower temperature, and also that these bars show a small amount of elongation. In these bars, and in those in the previous table, no yield point was visible. The yield point, in all these results, is taken as the stress at which an extension of the gauge points commences.

TABLE II.—*Influence of Casting Temperature on Chill-cast L8 Alloy.*

No.	Casting temperature. in degs. Cent.	Max. stress. Tons. per sq. in.	Elongation, per cent.
13	750	7.68	—
14	650	8.20	1.0

Maximum temperature in furnace, 960 deg. C.

Table III gives the results of some early experiments on the now well-known "Y" alloy. This is an alloy of aluminium, copper, nickel, and

TABLE III.—*Influence of Casting Temperature on Sand-cast "Y" Alloy* (Al, 92.15; Cu, 3.44; Ni, 2.59; Mg, 1.37; and Fe, 0.45 per cent.).

No.	Casting temperature. in degs. Cent.	Max. stress. Tons. per sq. in.	Elongation, per cent.
15	800	10.96	0.5
16	700	10.76	1.0
17	625	9.80	—

Maximum temperature in furnace, 910 deg. C.

magnesium. The bars were sand cast, tested in the "as cast" condition, within 24 hours of casting, and not subjected to heat treatment. These results are unique, being the only samples handled, in the course of several hundreds of tests, which give a decreasing tensile test with reduction of casting temperature. No yield point was visible. The bars cast at 800 deg. C. show results superior to those on the bars cast at 700 deg. C., and those cast at 625 deg. C. give the poorest results. In connection with "Y" alloy, there is distinct difficulty in casting at comparatively low temperatures. This difficulty is recognised by Rosenhain, who, in a paper presented to the Institute of Metals (Vol. I, 1923), recommends a casting temperature of 750 deg. C., and also that the metal in the furnace should not be allowed to exceed 800 deg. C. At or about 625 deg. C. "Y" alloy becomes pasty, and then sets very rapidly.

Duplicate sets of these bars were heat-treated in an electric furnace for six hours at 520 deg. C. and quenched in boiling water. They were then allowed to age for 8 days at room temperature before testing, and the tensile results are given in Table IV. These figures show a reversal of order to those in Table III; the breaking stress now increases with decrease of casting temperature. It will be noticed that the increase is the same in each case, the bar cast at 700 deg. C. gives a breaking stress exactly the mean of the other two results. Only one bar shows any evidence of elongation. From a commercial point of view, the tensile results are very low, but it is regrettable to state that in the course of numerous experiments on "Y" alloy the author has never attained anything like the remarkably high figures published by the Light Alloys Research Committee.

TABLE IV.—*Influence of Casting Temperature on Heat-treated and aged "Y" Alloy Bars.*

No.	Casting temperature. in degs. Cent.	Max. stress. Tons. per sq. in.	Elongation, per cent.
15T.	800	6.56	—
16T.	700	7.40	—
17T.	625	8.24	0.5

Maximum temperature in furnace, 910 deg. C.

Table V gives results on the same mixture but cast in chills. These follow what may be called constitutional practice, the bar cast at the lower temperature giving the best results. Duplicates of these bars were heat-treated, but unfortunately were badly distorted and useless for purposes of tensile test.

TABLE V.—*Influence of Casting Temperature on Chill-cast "Y" Alloy Bars.*

No.	Casting temperature. in degs. Cent.	Max. stress. Tons. per sq. in.	Elongation, per cent.
18	750	12.20	0.5
19	650	14.20	1.0

Maximum temperature in furnace, 910 deg. C.

Effect of Soaking Aluminium Alloy.

The results of a double experiment are given in Table VI. A batch of metal was carefully melted, and a pot withdrawn from the furnace when it had reached a temperature of 770 deg. C. The metal was allowed to cool naturally, and test bars cast in sand at 710 deg. C. and 640 deg. C., and in chills at 670 deg. C. These are the bars numbered 20, 21, and 22 respectively. The pot was then replaced in the furnace, coked up, and the metal left to soak for 1½ hours. During that time the maximum temperature reached by the metal was 1,110 deg. C. The pot was then drawn,

TABLE VI.—*Influence of Soaking on the Tensile Properties of Aluminium Alloy Bars.*

No.	Casting Temp. in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent.
20	710	8.60	9.40	2.0
23	710	6.80	8.08	2.5
21	640	8.80	9.64	1.5
24	640	7.40	10.24	3.5
22	670	8.36	10.36	2.5
25	670	7.48	8.96	2.0

ANALYSES.

	Before soaking.	After soaking.
Aluminium	85.56	86.71
Copper	3.29	3.75
Zinc	12.18	8.92
Iron	0.73	0.42

allowed to cool, and test bars cast at the same temperatures as before, namely, in sand at 710 deg. C. and 640 deg. C., and in chills at 670 deg. C. The bars are those numbered 23, 24, and 25 respectively. Looking first at the results on the sand-cast bars, one could not say definitely that any harm was apparent; in fact, bar No. 24 gives a higher breaking stress and elongation than bar No. 21. With the chill cast bars there is a wider difference, and the results are in favour of the normally melted material. It will be observed that the analyses differ somewhat, the metal which has been "soaked" being lower in zinc, naturally increasing the aluminium and copper content. This is only to be expected, but one unexpected feature was a reduction in the iron content.

In the light of this, and many other experiments of a similar nature, the author was led to the belief that aluminium alloys suffered no ill-effects by over-heating, or "burning," provided due attention was paid to casting temperature.

Table VII gives evidence which has caused a modification of these views. Repeat impact tests on an Eden-Foster machine were carried out. For this test the bar is turned down to 0.5 in. dia., with a groove 0.05 in. wide turned down to 0.4 in. dia. The bar is placed on supports 4½ in. apart, and a 2-lb hammer allowed to drop from a height of 1 in. on to the grooved portion, the bar being turned round through 180 deg. after each blow. The total number of blows required to fracture the bar is recorded. Of the two bars cast at 710 deg. C., that cast first required 18,976 blows to fracture, whereas after overheating only 10,780 blows were required. Of the bars cast at 640

TABLE VII.—*Repeat Impact Tests on Aluminium Alloy Bars Outlined in Table VI.*

No.	Casting temperature in deg. C.	Blows.
20	710	18.976
23	710	10.780
21	640	21.838
24	640	Defective bar
22	670	22.458
25	670	19.034

deg. C., that cast first stood 21,838 blows, but no results could be obtained from the bars cast after overheating, as no less than three bars were found to be unsound on turning. Of the chill cast bars, 22,458 blows were required to fracture the normally melted metal, against 19,034 after overheating. It is worthy of note that once again the better results are obtained at the lower casting temperature, as evidenced by the fact that the normal bar cast at 640 deg. C. withstood nearly 3,000 more blows than the bar cast at 710 deg. C.

It is apparent, from these results, that aluminium alloys do suffer some ill-effects from prolonged overheating, although in this case the overheating was deliberate and excessive. Similar results have been obtained on repeat experiments of this nature, and, as in automobile work, aluminium alloys have to withstand severe vibration, this point is important. Tensile tests on overheated or "burnt" metal show little depreciation, but repeat impact tests generally give lower results.

More Tests on "Y" Alloy.

Some further experiments on "Y" alloy were undertaken, and the tensile test figures are given in Table VIII. All these bars were chill cast and aged at room temperature for 14 days before testing. It will be noticed that the bars cast at 760 deg. C. and 740 deg. C. have the same breaking stress, but the second bar shows a slight elongation. There is a progressive rise in breaking stress with reduction of casting temperature, and the bars cast at 625 deg. C. show a considerable in-

TABLE VIII.—*Influence of Casting Temperature on Chill-cast and aged "Y" Alloy Bars* (Al, 92.02; Cu, 3.77; Ni, 2.36; Mg, 1.44; and Fe, 0.40 per cent.).

No.	Casting temperature. in degs. Cent.	Max. stress. Tons. per sq. in.	Elongation, per cent.
30	760	11.60	—
31	740	11.60	0.5
33	700	11.92	0.5
35	625	13.68	0.5

Maximum temperature in furnace, 790 deg. C.

crease. Of five bars cast at this latter temperature, only two were sound, the other three having cold shuts. This is a common defect with "Y" alloy, which does not cast well below 650 deg. C. Results after heat treatment are not available, as one bar broke on the shoulder on testing, one was spoiled in turning, and the bars cast at the low temperature were unsound. The result on the only remaining bar is useless for comparison.

Repeat impact tests on bars in this series are given in Table IX. It will be noticed that in the "as cast" condition they show a progressive rise in resistance to fracture as casting temperature falls, but that heat treatment apparently so alters the structure that the effect of casting temperature is lost. Heat treatment causes a large increase in the number of blows necessary to fracture, particularly in the bars cast at 720 deg. C. This bears out the statement of the originators of this alloy, that a fairly high casting temperature is needed for satisfactory results to be obtained.

Table IX.—*Repeat Impact Tests on "Y" Alloy.*

No	Casting Temperature in deg. C.	Blows as cast.	Heat treated.
32.	720	1222	42338
33.	700	1962	13126
34.	650	3862	15072

Maximum temperature in furnace 790 deg. C.

Influence of Temperature of Dies.

In the production of die castings, the temperature of the dies is an important factor for success.

Table X.—*Influence of Temperature of Dies on Tensile Strength of Aluminium Alloy* (Al., 82.04; Cu., 3.39; Zn., 13.73; and Fe., 0.65 per cent.).

No.	Casting Temperature in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent
2.	700	8.80	10.04	2.0
3.	700	9.04	11.40	3.0

Maximum temperature in furnace, 810 deg. C.

In Table X the first bar was cast in a chill at an approximate temperature of 500 deg. C., and the other bar in a chill at a temperature of 120 deg. C., the pouring temperature of the metal being the same in each instance. There is quite a reasonable difference between the two results, and it is obvious that a quicker rate of cooling (chill effect) causes the higher tensile figures.

The effect of ageing is a very important factor. If castings improve with age, so much to the good; but it is very essential that material should not deteriorate with age.

Aluminium-Copper-Zinc Alloys.

In Table XI are some results on an aluminium-copper-zinc alloy. Two sets of bars were cast in chills at temperatures of 700 deg. C. and 640 deg. C. Tensile tests were taken 4, 45 and 95 days after casting. It will be observed that the difference in tensile at the different temperatures is not very pronounced after 4 days' ageing, but becomes more marked after 45 days. A further period of ageing appears once again to eliminate the difference, yet both sets show a considerable improvement with age.

TABLE XI.—*Influence of Ageing on Aluminium-Copper-Zinc Alloys* (Al., 82.04; Cu., 3.39., Zn., 13.73; and Fe., 0.65 per cent.).

No.	No. of days aged.	Casting Temp. in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent.
3.	4	700	9.04	11.40	3.0
3A.	45	700	10.12	11.52	4.0
3B.	95	700	10.44	13.28	4.0
1.	4	640	8.84	11.44	4.0
1A.	45	640	10.48	13.84	4.0
1B.	95	640	10.12	13.72	4.0

Maximum temperature in furnace, 810 deg. C.

Table XII gives results due to ageing on an aluminium-copper alloy containing a small quantity of zinc. A delay of 31 days before testing gives considerably improved results.

TABLE XII.—*Influence of Ageing on Alloy containing* Al., 85.32; Cu., 12.45; Zn., 1.63 per cent.; and Sn., Trace.

No.	No. of days aged.	Casting Temp. in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent.
6.	6	680	—	9.64	1.0
6A.	37	680	11.0	11.20	1.5

Maximum temperature in furnace, 710 deg. C.

Table XIII deals with a die-casting alloy of aluminium and copper. In this batch the bars cast at 800 deg. C. show a reduction in breaking stress with an increased elongation, whereas those cast at 700 deg. C. and 600 deg. C. show an increase in breaking stress and elongation after 35 days' ageing. It will be noticed that the aged bars all show a small elongation, whilst the bars tested soon after casting show none. Both in this and the previous test it would have been desirable to continue the ageing effect, but an insufficiency of test bars precluded this.

TABLE XIII.—*Influence of Ageing on a Die Casting Alloy containing* Al., 87.90; Cu., 11.14 per cent.; and Zn., Trace.

No.	No. of days aged.	Casting temp. in deg. C.	M.S. tons per sq. in.	E. per cent.
10.	3	800	7.28	—
10A.	35	800	6.64	1.0
11.	3	700	8.24	—
11A.	35	700	8.84	1.0
12.	3	600	8.00	—
12A.	35	600	8.36	1.0

Maximum temperature in furnace, 960 deg. C.

In Table XIV are another set of results on aluminium-copper-zinc alloys. These were sand-cast bars, and a peculiarity of the results is that, though both bars show an increase in breaking stress after 40 days' ageing, neither of the bars then gave any evidence of yield point. It will be noticed that both before and after ageing the general rule applies, *i.e.*, better tensile tests are obtained at the lower casting temperature.

TABLE XIV.—*Influence of Ageing on Sand-cast Bars containing* Al., 85.56; Cu., 3.29; Zn., 12.18; and Fe., 0.73 per cent.

No	No. of days aged.	Casting Temp. in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent.
20.	5	710	8.60	9.40	2.0
20A.	40	710	—	10.00	1.5
21.	5	640	8.80	9.64	1.5
21A.	40	640	—	11.44	1.5

Maximum temperature in furnace, 770 deg. C.

Table XV gives figures obtained quite recently on a ternary alloy. An examination of this table shows that the yield point is much the same for all casting temperatures, but that both the breaking stress and elongation progressively increase as the casting temperature decreases. These tensile tests were made within 48 hours of casting, and the bars were chill-cast. Duplicate bars of this series have been put aside for the purpose of ageing, and tensile tests will be taken at intervals of six months. Should the author have occasion to present a further Paper on this subject, he hopes to be able to include those results.

TABLE XV.—*Influence of Casting Temperature on an alloy containing* Al., 82.78; Cu., 4.90; Zn., 11.50, and Fe., 0.60 per cent.

No.	Casting Temp. in deg. C.	Y.P. tons per sq. in.	M.S. tons per sq. in.	E. per cent.
40.	770	5.96	7.88	2.5
41.	700	6.40	8.84	4.0
42.	680	6.04	9.40	5.0
43.	660	6.44	11.04	6.0
44.	640	6.04	11.32	7.0

Maximum temperature in furnace, 770 deg. C.

Further experiments on resistance to repeated impact are exhibited in Table XVI. The differences in the number of blows required to fracture are remarkable. The bar cast at 610 deg. C. needed nearly 8,000 more blows than the bar cast at 640 deg. C., and more than twice as many blows as the bar cast at 710 deg. C. This is truly a remarkable variation for a relatively small difference in casting temperature. Before passing from this table it should be noted that, as an experiment, a duplicate set of these bars were heat treated at 520 deg. C., and quenched in boiling water. On the repeat impact test, all broke out-

TABLE XVI.—*Influence of Casting Temperature on Repeat Impact tests using an alloy containing* Al., 86.08; Cu., 2.95; Zn., 10.04; and Fe., 0.68 per cent.

No.	Casting temp. in deg. C.	Blows to fracture.
27.	710	12,252
28.	640	22,998
29.	610	30,768

Maximum temperature in furnace, 840 deg. C.

side the grooved portion. The bar cast at 710 deg. C. broke after 40 blows; that at 640 deg. C. after 72 blows; and that at 610 deg. C. after 478 blows.

Hardness of Aluminium Alloy.

Before concluding, it seems desirable to refer to hardness. This is not a very important function of aluminium castings, as aluminium is rarely used as a bearing metal, but there are occasions where a knowledge of the hardness is desirable. All the hardness determinations have been taken on a Brinell machine, with a load of 500 kilograms applied for 30 seconds. Flat strips, $\frac{7}{8}$ in. thick, were cast, and the Brinell number determined in several places. Repeat tests on the same samples were made at intervals, and as the results obtained are rather curious, it might be of interest to include some examples.

Table XVII gives the hardness on three sets of strips cast at 700, 650 and 585 deg. C. respectively. All were sand-cast. The Brinell number is given for each sample, tested immediately after casting, and also at various periods up to 85 days later. The first row shows that the bar cast at the lowest temperature is slightly harder than the other two. After 15 days there is a considerable increase in hardness in all three samples, and the hardness rises with reduction of casting temperature. This increase in hardness is maintained for a further 49 days, when there is another slight increase in the first two bars, bringing all three equal in hardness. No further change appears to take place, and it should be stated that these bars have been tested many times since at intervals

TABLE XVII.—*Influence of casting Temperature on Aged Aluminium Alloy Bars on the Brinell Hardness* (500 *kgs.*)

Days Aged.	Cast at 700 deg. C.	 650 deg. C.	 585 deg. C
1	50	50	54
15	63	65	70
29	63	67	70
36	63	67	70
64	70	70	70
85	70	70	70

Maximum temperature in furnace, 760 deg. C.

of 14 days, but no change has taken place. The time factor has apparently eliminated variations due to difference in casting temperature.

Brinell hardness tests on die-casting alloy are given in Table XVIII. There is very little difference in the hardness when tested the day following casting, but all three samples show a reduction over a period of 36 days, and then a tendency to increase. Further tests made since this table was made out seem to indicate an arrest of change in the samples cast at 800 deg. C. and 600 deg. C., but another reduction of hardness in the sample cast at 700 deg. C. It is probable that, given sufficient time, the three samples will arrive at a stable state in which there is little or no difference in their respective hardnesses.

Table XVIII.—*Influence of Casting Temperature of Aged Die Casting Alloy on Brinell Hardness.*

Days Aged.	Cast at 800 deg. C.	700 deg. C.	600 deg. C
1	70	73	70
8	65	73	65
36	63	65	57
57	73	77	65

Maximum temperature in furnace, 960 deg. C.

As a final batch of results, Table XIX gives hardness tests on "Y" alloy. These strips were cast at the same time as the tensile bars shown in Table III, and in dealing with the tensile tests it was stated that these were the only set of bars the author had tested in which the higher casting temperature gave the higher tensile. As is shown, the hardness results exhibit the same phenomenon. There was no possibility of the bars being mixed during casting, as each set were stamped immediately they were made. There appears a regular

Table XIX.—*Influence of Casting Temperature of Aged "Y" Alloy on Brinell Hardness. Composition as shown in Table* III.

Days Aged.	Cast at 800 deg. C.	700 deg. C.	625 deg. C
1	77	73	70
8	80	83	86
32	86	86	80
53	83	83	77
70	83	83	80

Maximum temperature in furnace, 910 deg. C.

increase in the hardness over a period of 32 days, when it reaches its maximum; then there is a slight decrease until a stable state is attained, after which there appears to be practically no change. Further tests on these bars, made several months later, gave identically the same figures. The bar cast at 625 deg. C. shows rather erratic results, but this is mainly due to unsoundness. As stated before, it is exceedingly difficult to cast good test bars in "Y" alloy at temperatures below 650 deg. C.

CONCLUSION.

These results are typical of many others recorded over a number of years. The conclusions drawn can now be stated. In the author's opinion, casting temperature has a profound effect on the physical properties of aluminium alloys, as typified by tensile strength, hardness and resistance to repeated impact.

All classes of aluminium alloys follow the same course, namely, the lower the casting temperature, the better the physical properties.

The difference in tensile strength due to variation in casting temperature persists on ageing, with the possible exception that with certain alloys of aluminium, copper and zinc, the difference appears to be less accentuated after ageing. As the author is engaged on further tests on this particular class of alloy, he does not feel justified in committing himself to a definite opinion on this point.

Hardness is also affected by casting temperature in the same manner as tensile strength, but in many instances ageing would appear to eliminate such differences.

Resistance to repeated impact is similarly affected by casting temperature, and in this property its influence is very marked. A reduction of 20 or 30 deg. causes an increase of approximately 50 per cent. in the number of blows required to fracture.

Prolonged heating in the furnace has apparently only a slight effect on the tensile strength, but a much greater influence on the resistance to repeat impact. This is no doubt due to the presence of oxide inclusions, as can be shown by examining unetched micrographs at 75 dias. In the ordinary coke-fired pit furnace, it is impossible to avoid an oxidising atmosphere, but in many types of gas-fired furnaces the mixture of gas and air can be so regulated that the bulk of the metal is in contact with a reducing atmosphere. Nevertheless, the difference between normally-melted and overheated metal can be detected by the repeat impact test. Overheating is never indulged in as a regular practice, but may be the accident of the moment. It has nothing to recommend it; it is wasteful of fuel and metal; and the aim of every foundry foreman should be moulds ready for the metal, rather than metal ready for the moulds.

For the production of good castings in aluminium alloys, a mould should be poured at the lowest temperature at which a sharp casting is obtained; a better practice would be to determine by the aid of a pyrometer the exact casting temperature at which the best results are obtainable for each type of casting, and standardise the use of the pyrometer as part of the regular routine of the shop.

With competition as it is to-day, and the greater demands for quality made on the foundry, chance methods of working may carry on for a time, but are likely to lead ultimately to the Bankruptcy Court.

The figures submitted, although they represent tests made at odd periods during the past seven years, touch only the fringe of the subject. The alloys of aluminium offer a wide field to the investigator, and though much has been made known, considerably more has yet to be discovered. There is no finality in metallurgical work, perfection will come with the millenium, and it is towards that happy state we must ever keep striving. Knowledge is mainly garnered in the hard school of experience, and the pleasure derived in the acquisition of such knowledge is often the only reward.

DISCUSSION.

The Chairman (Mr. J. Shaw) said they had had a very interesting Paper. It was practically the first non-ferrous Paper that they, as a branch of the Institute of British Foundrymen, had had.

When they made inquiries from the members as to the branch of the foundry trade they were connected with, they found that they had quite a number who were connected with the non-ferrous trade; hence that Paper.

Dr. Percy Longmuir, in opening the discussion, said that about 20 years ago he had carried out a certain amount of work. Unlike Mr. Hurren, he found that the intermediate, the fair casting heat, always gave the best results. That was, of course, not on aluminium alloy, but on the commercial aluminium of those days. He had been intensely interested in the ageing effect on these aluminium alloys, because, at the time he was speaking of, working on those metals, the only equalising effect that he got was on lead. Of course, the maximum stress on lead was indefinite, and one had to go on the elongation. He found that casting too hot gave a low elongation; casting from the same crucible at a fair heat gave a very fair elongation; while casting too low—by which he meant just low enough to give a sound casting—again gave a low elongation. Now, companion bars, put away for three months and tested, gave equal elongations. The ageing effect of these aluminium alloys was therefore one of very great interest, and he hoped that Mr. Hurren would follow out his work in that direction.

All his working life he had objected to what he called the stewing of any metal, and they had had good proof of that that night. He himself had found, particularly with the copper-zinc alloys chiefly, stewing to be intensely bad. Apart from the volatilisation losses of zinc, involving a change in composition, there was a decidedly bad effect, which, as the lecturer had shown, did not necessarily show in tensile, but did show in some form of a brittleness test suddenly applied.

Dr. Longmuir added that he would like to support what Mr. Hurren had said: that the casting temperature, not only of the particular alloys that he had investigated, but of all alloys, must necessarily vary with the type of casting. In his own experiments with Admiralty gun metals, with Muntz metals, and so on, he found that many American text-books were quoting him as stating that his own fair heats were the correct heats for all types of casting. But those temperatures only represented, and could only represent, the most suitable conditions for that particular type of casting. If one had, say, a 3-ft. cube and then a 3-ft. plate by ¼ in. thick, necessarily the temperatures must vary.

Professor C. H. Desch said, like Dr. Longmuir, he had always urged that stewing was a most pernicious practice, whether carried out intentionally or just as the result of careless working. To deal for a moment with another alloy, in which there was no question of volatilisation, namely, gun-metal, he had found several cases in which castings of gun-metal, prepared at roughly the same temperature, differed from one another to the extent of one giving double the elongation of the other, the better result being obtained simply by the avoiding of stewing, by pouring the metal directly the temperature was reached.

Why "Y" is Difficult to Cast.

He noticed that Mr. Hurren had some difficulty with the alloy "Y," which he believed had been the experience of very many users. It happened to be a very tricky alloy to use, and very few people, he thought, had succeeded in reproducing the results from it that had been obtained at the National Physical Laboratory, where the staff had been working on it for a long time and had acquired special skill. The order of Mr. Hurren's tests came out slightly differently, in the case of the "Y" alloy, from the order of the other alloys, and this suggested that casting at so low a temperature as 625 deg. C. did not really give the "Y" alloy a real chance, because it contained nickel. Now the nickel-aluminium compound that formed had a high melting point, a high temperature at which it fell out of solution. He had not the diagram by him at the moment but he thought that at 625 deg. C. there would actually be crystals in that alloy out of solution and in suspension, which would, of course, prevent one from getting a very good casting.

The ageing effect was of extraordinary interest—the ageing effect that was first discovered in duralumin, and was now known to be characteristic of so many alloys. That, of course, had now been quite satisfactorily explained. The work of Dr. Rosenhain and his collaborators had shown that they had there the magnesium and silicon concerned, and that it was due to the falling out of the older microscopic particles from solution and then the gathering together of those particles to form larger masses. Following up those changes, they could, as a matter of fact, account for the whole of the ageing. He should like to ask Mr. Hurren whether he made any experiments on artificial ageing. The periods of 85 days and so on were, of course, long, and made the experiments very tedious, but, as most of the alloys could be aged artificially in boiling water, or at temperatures somewhat higher, it might be of interest to know whether he obtained the increase there. The increase in resistance to repeated impact by ageing was very extraordinary. He did not remember seeing such large differences before. He took it that Mr. Hurren had not been able to follow out microscopically the difference that took place on ageing. It was an extraordinarily difficult thing and required high power work, but it would be interesting to know whether there was any visible change, giving such considerable increase in resistance to shock as was shown by those tests.

In regard to the general results of the effect of temperature, he took it that Mr. Hurren concluded that the best results were obtained by casting at the lowest really fair temperature. He thought that would be a quite general conclusion from the results if they ruled out those 625 deg. C. tests on the "Y" alloy, which, he thought, were probably not fair tests for the alloy at all.

Mr. E. H. Hill said the lecturer had spent a very considerable time in making tests on what they might term comparatively hard alloys, and the influence of the casting temperature on the tensile strength. One point which seemed to him worth consideration was, what would be the effect of casting temperature on the softer alloys, with regard to the elongation? The elongation shown by the tests which had been exhibited that night were all very small. He thought the greatest which occurred in any sample was about 7 per cent., which, for an aluminium alloy, to his mind, was very low. The ductility of aluminium was a very important characteristic of the metal, and he should be glad of some information regarding casting temperatures and ductility.

Mr. Hurren, in reply to the discussion, said he was very pleased indeed to see Dr. Longmuir there that night, as he would like to say that it was that gentleman's pioneer work, published as a Carnegie Memoir, which first started him on this idea of the casting temperature for aluminium alloys. Dr. Longmuir's work, when he read it, struck him as being of intense value, and one which might be extended to his own particular class of material. He was also glad to see that Dr. Longmuir was in agreement with him that stewing, or overheating, of any material was most objectionable. So far as variation of casting temperature for the type of casting was concerned, he might say that in their own work they cast some articles—crank cases he had in mind—always at 720 deg. C. A bearing gauge, which had a very much thicker section, they cast as nearly as possible to 630 deg. C., and they had tried to standardise different casting temperatures for different jobs. In many ways they were fortunate, as much of their work was repetition work, and once they had determined the best casting temperature for a certain job they could very often carry on for weeks at a time. If the work was what was known in foundry parlance as jobbing work they would either have to spend a considerable time in experiments or to take risks.

Dr. Desch had emphasised the difficulties which had been found with "Y" alloy, and at present he (the speaker) must confess that they had not been able entirely to overcome those difficulties. There seemed to be a particular range of temperature at which good castings could be obtained with "Y" alloy, and outside that range there was nothing but failure. The commercial difficulty with "Y" alloy also lay in the fact that in the as-cast condition only poor results were obtained, and that the castings must be heat-treated. This introduced a very serious difficulty into a works turning out a fairly heavy tonnage or a large number of articles. He was of opinion that Dr.

Desch had pointed out the cause of the difficulty of casting "Y" alloy at comparatively low temperatures, in the fact of the nickel-aluminium crystals remaining in suspension rather than in solution. They had noticed time and again that the metal was apparently liquid one second, and went pasty and had to be scraped out of the pot within a very few seconds after.

Natural Ageing.

He had made no experiments on artificial ageing at present, as he wished to determine the effect of natural ageing in view of the fact, as he stated in the paper, that they made castings one month which were in use six or sometimes eight months later. The microscopical examination of sections of aluminium had been followed out to a certain extent, but there were so many manipulative difficulties in the way that he did not feel capable of placing micrographs before such an assembly.

Dr. Desch had also emphasised the necessity of casting at the lowest fair temperature. In regard to that, he could only repeat what he had already said respecting Dr. Longmuir's remarks.

Mr. Hill inquired as to the effect on softer alloys than those he had shown that evening, and also remarked that the elongations appeared to be small. The alloys which he had shown were those which were commonly specified for automobile work, and, although the elongations appeared small, it was a matter of extreme difficulty to get an aluminium-copper-zinc alloy, or an aluminium-copper alloy, to give an elongation much over 6 or 7 per cent. They had had extreme instances where they had had 14½ tons tensile and 12 per cent. elongation, but how they did it he did not know now. The reason, therefore, why he had not dealt with the softer alloys was that at present they had no commercial value in an automobile works. His tests had all been taken during the ordinary course of production; they were not specially dressed up for the occasion, but were simply selected from tests which had been made at various periods since the early part of 1916.

Mr. Shaw, the Institute of British Foundrymen's Branch-President, asked him to give a non-ferrous paper, and, as he had known that gentleman for a number of years and always had a great respect for him, and as Mr. Shaw was in the unique position of having been president of two separate branches of the Institution of British Foundrymen, he gladly consented, but when Mr. Shaw told him that he had also arranged for that meeting to be a joint one with the Institute of Metals he wished he had not been quite so rash in promising. Frankly, he had been rather afraid of the Institute of Metals. He had always had an idea that nothing but pure physical chemistry was acceptable to them.

The CHAIRMAN said he thought they would all agree with him that Mr. Hurren had not very much need to be afraid of what he had put forward. He had put before them a certain amount of original work, done under shop conditions. When he told them that Mr. Hurren had in one of his workshops (he did not know whether he had at this moment) over 100 moulders working on aluminium, they would have some idea of the scope and size of the shops and, as a very great deal of the work was on moulding machines and was being turned out on mass-production lines, certainly Mr. Hurren had the opportunity of gauging the casting temperatures and the other things to make the success of it that he had. His paper might not be one on pure science, but it described conditions that he had obtained in actual works practice, and as such it ought to be beneficial to those who were in a like line. The temperatures that he had given were such as the ordinary man, with the use of an ordinary pyrometer, could obtain.

Vote of Thanks.

MR. J. R. HYDE, in proposing a vote of thanks to Mr. Hurren, said the paper showed that all the difficulties were not in steel foundries. He thought they were a great deal indebted to the people who tackled the problem of aluminium alloys, and so saved them the trouble of having the difficulties of the automobile industry brought to Sheffield. They had quite enough troubles of their own. But there was another point about it—that unless the aluminium castings were produced successfully there would be no great demand for Sheffield's steel or other manufactures to build up into the complete motor-car. They must all work together, and he was sure that an exchange of knowledge in this manner was highly beneficial.

Engineer-Commander Jackson seconded. He said it was always a pleasure to hear the results of a man's experience. He knew very well that that kind of thing was not done for nothing. There must have been a fair amount of work put into the paper, and they were under a debt of gratitude to Mr. Hurren for giving it. He had not had much experience himself with aluminium alloys. In the small quantity that he had melted, he had always found a sort of red oxide come on the top, and had wondered what it was and taken it off. He had found that when the red did not come, that was about the temperature to cast at.

Mr. E. H. Hill, in supporting, expressed the thanks of the Institute of Metals to the Institute of British Foundrymen for their invitation to attend that meeting. The Sheffield section of the Institute was very much interested in non-ferrous alloys, and its members were always pleased to see members of the Foundrymen at their meetings. He should like to express his appreciation of Mr. Hurren's practical work. He had had some experience of Rover cars over a period of twenty years, and the aluminium casting in them had always been particularly good.

The resolution was carried unanimously.

Mr. Hurren, in response, said he should like to tell Mr. Hyde that the steel-casting man had not all the troubles in the world. He might think in Sheffield that he had got a monopoly of them, but, even if that were so at some time or another, he thought some of them had now moved down into the Midlands. Although there might be a lot of trouble with steel, there was also a considerable amount with aluminium, and, he thought, as a matter of fact, there was considerable trouble with all foundry work.

Lancashire Branch.

THE PRACTICAL VALUE OF MODERN NON-FERROUS ALLOYS.

By S. F. Barclay, D.Sc.

Any particular alloy possesses two or more quite distinct qualities, and consequently may be employed for two or more quite distinct purposes. For example, phosphor bronze may be used purely on account of its capacity to resist corrosion or on account of its excellence as a bearing metal. It is impossible to develop in a maximum degree all the different qualities an alloy may possess, and, as a rule, any one quality can be given a maximum value only at the expense of sacrificing some of the others. The object of this Paper is to show that if the founder is to give the best service to his customers, he needs to know the exact use to which his castings will be put, so that he can bring out the relevant quality in the highest degree.

Phosphor Bronze.

If phosphor bronze is to be used for resisting corrosion, the greatest care must be exercised by the founder in keeping down impurities to a minimum. The zinc content should not exceed 0.25 per cent., and should preferably have a lower value; the lead should not exceed the same amount, and the iron and other impurities should not exceed traces. The function of phosphorus in castings to resist corrosion, is more to serve as a deoxidiser and a scavenger than as a hardening element, and it is satisfactory in such cases if the phosphorus content is about 0.25 per cent. In considering the action of impurities on phosphor bronze, it has to be remembered that in the solidified metal they are not uniformly dispersed throughout the mass, but tend to collect at the crystal boundaries, and an impurity which constitutes a small percentage of the whole may constitute quite a high percentage of the intercrystalline material. If the best results are to be obtained for resistance to corrosion, ingot metals only should be used or scrap from high-grade castings, the composition of which is known. Table I shows in a striking way the effect of what at first sight might be considered to be small percentages of impurities on the strength and ductility of the metal:—

TABLE I.—*Influence of Impurity on the Mechanical Properties of Phosphor Bronze.*

	Good quality.	Poor quality.
	Per cent.	Per cent.
Copper	89.68	87.56
Tin	9.78	9.3
Lead	0.08	1.53
Iron	0.03	0.23
Zinc	Nil	0.98
Phosphorus	0.235	0.117
Physical Properties.		
Yield point (tons per square inch) ..	9.0	9.26
Maximum load (tons per square inch) ..	20.2	12.62
Elongation on 2 inch	23.0	5.5
Reduction of area ..	27.5	6.0

If phosphor bronze is to be used as a bearing metal, the composition may be quite different from that previously described. This alloy owes its merit, as a bearing metal, to the presence of a hard skeleton framework of phosphor-tin with a soft filling of the other constituents. The harder the phosphor-tin eutectoid and the softer the filling, the more effective is the alloy as a bearing metal; the phosphorus content should thus be high, not less than 0.5 per cent., and with advantage it may be 1 per cent., and lead to the extent of 6 or 8 per cent. should be introduced deliberately to increase the softness of the filling.

Phosphor bronze is influenced profoundly by the casting temperature, as is shown by the figures given in Table II.

In all cases where ductility of the alloy is of importance the temperature of casting must be carefully controlled. For bearing bushes, however, with which a low coefficient of friction is everything and ductility of minor importance, there is a distinct advantage in casting a metal somewhat cold.

Gun Metal.

The Admiralty specification is 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc, with a maximum permissible lead content of 0.5 per cent. If castings are to be subjected to an elevated temperature such as is encountered with fittings for superheated steam, there is no question of the wisdom of limiting the lead content to the value fixed by the Admiralty. The lead in gun-metal is not diffused uniformly throughout the mass, but exists in the form of localised globules. At elevated temperatures the strength of the lead globules falls to zero, and their presence constitutes an important element of weakness. If, however, the gun-metal is to be used at ordinary temperatures, there is a distinct advantage in raising the lead content to 1 per cent., and there is nothing detrimental in employing as much as 1.5 per cent. The influence of lead on Admiralty gun-metal is clearly shown in Table III.

Table II.—*The Influence of Casting Temperature on Phosphor Bronze.*

	Cast at		
	1,180 deg. C.	1,110 deg. C.	1,032 deg. C.
Yield point (tons per sq. in.)	10.2	9.0	1.48
Maximum load (tons per sq. in.)	11.60	20.2	00.0
Elongation on 2 in. ..	3.0	23.0	5.4
Reduction of area	3.8	27.5	5.2

Table III.—*The Influence of Lead on Admiralty Gun-metal.*

Lead per cent.	Casting temp. deg. C.	Y.P. (tons per sq. in.)	M.S. (tons per sq. in.)	Elong. per cent.
0.19	1210	8.8	17.0	14.8
0.88	1215	10.1	17.6	16.8
1.50	1210	9.3	17.6	20.0
1.7	1220	8.2	16.4	13.7

It is clear from the above figures that if the founder is to produce the best gun-metal, he must know if it is to withstand an elevated temperature or if it is to work at normal temperatures.

In common with most alloys, gun-metal is very sensitive to the temperature at which it is cast. If the metal is too high when poured, porosity is almost certain to result; if too cold, the metal will be weak and unsuited for withstanding pressure. For gun-metal to be sound and strong, it is necessary to have the interlaced type of structure, which can be secured only by casting at the correct temperature, which is approximately 1,200 deg. C. When poured at this temperature, the microscope shows that the interstices of the copper-rich mass of the metal are filled with small land-locked seas of eutectoid, and thus soundness results. Fig. 1 shows the structure required to give a strong metal. If poured at an appreciably

FIG. 1.—STRUCTURE OF GUN-METAL AT 100 DIAS. TO BE ASSOCIATED WITH A GOOD METAL.

lower temperature, there is a quick uniform contraction of the metal, which is more of a solid solution on account of the different constituents not having had the chance of separating out, and inter-crystalline pores develop as microscopic holes throughout the metal. If gun-metal is to be subjected to liquid pressure, annealing is of great value in causing dispersion of the eutectoid and the filling-in of the shrinkage interstices between the eutectoid and the filling.

Brass.

If any cold work is to be done on ordinary brass castings, it is desirable to increase the copper content and to keep down the impurities, iron, lead and bismuth, to very low values. If a higher tensile strength is required than can be secured by the plain 60/40 mixture, the 70/29 mixture with 1 per cent. tin gives good results. It has to be remembered that tin is only slightly soluble in 70/30 brass, and the addition of more than 1 per cent. is strongly to be deprecated. Further, it is most important that all castings of this alloy should be annealed very thoroughly if they are to have any work done on them. Table IV shows the influence of annealing on the elongation and ultimate strength of naval brass:—

TABLE IV.—*Naval Brass* (62 : 37 : 1) *Annealed for* 30 mins.

Annealing temp. deg. C.	Method of cooling.	M.S. (tons per sq. in.)	Elon. per cent.
450	Quenched	29.0	19
550	Slowly cooled ..	28.0	30
550	Quenched	28.5	36
700	Slowly cooled ..	26.6	42
700	Quenched	25.6	50

If brasses containing a small percentage of tin are required to have good tensile properties, the lead content should be restricted to a low value. Frequently, however, alloys of this kind are specified with the essential requirements that they shall be "free cutting," have a good appearance, and be left with a clean, smooth surface after machining. For any metal to be "free cutting," there must be an absence of toughness and a marked tendency for the turnings to break off short. Excellent results of this kind are obtained by adding from 1.5 to 2 per cent. of lead to the brass. This serves as another striking illustration of the importance of the founder being given the exact information with regard to the metal quality required.

Castings for Electrical Conductivity.

There is now quite a big demand for copper castings for electrical work; the essential requirement is high conductivity, and mechanical strength is usually of minor importance. The founder should thus aim at securing sound castings with the highest possible electrical conductivity. Some deoxidising agent must be employed, otherwise the castings would be honeycombed with small holes. Boron is possibly the best deoxidiser, in view of its effectiveness and at the same time small influence on conductivity. It is of vital importance that all impurities be eliminated, as even very small amounts have an extraordinary effect in lowering the electrical conductivity; electrolytic copper in all cases should be used. Table V shows the effect of impurities on the electrical conductitvity of copper castings.

TABLE V.—*Influence of Impurities on the Electrical Conductivity of Copper Castings.*

	Added element. Per cent.	Electrical conductivity. Mathieson Standard.
Tin	0.38	73.0
Zinc	0.35	73.4
Nickel..	0.19	79.0
Iron	0.15	59.2
Manganese	0.12	71.0
Silicon	0.18	54.0
Chromium	0.04	91.5
Phosphorus	0.07	63.2
Aluminium	0.08	84.1
Magnesium	0.012	98.7
,, ...	0.024	94.0
,, ...	0.038	89.5
No addition	—	97.2

Another very important class of castings for electrical work is the slip ring used on rotary converters and other alternating-current electrical machinery. The slip rings are used for conveying the electric current from the windings of the machine to the electric cables and blocks of graphite or graphite associated with copper press against the ring under the action of springs. The demand of the electrical designer is that the slip ring temperature shall be as low as possible. There are two tendencies at work causing heating: the passage of the current through the ring and the frictional loss between the ring and the brushes. The ideal material would thus have high conductivity and low frictional loss. So far no alloy has been produced combining these qualities, and a compromise between the two has to be made. If pure copper is used, the heating due to the flow of current is small, but due to frictional loss, is unduly great on account of the unsuitability of the soft metal to withstand abrasion. If, on the other hand, a nickel-copper alloy is used, the frictional loss can be reduced to a small value, but due to the high resistance, the heating caused by the flow of the current is unduly great. Phosphor bronze is sometimes specified for this purpose, and, in fact, it is important for the founder to see that it is very pure in order to ensure high electrical conductivity, and that the phosphorus content does not exceed 0.05 per cent. in order to ensure that there is a minimum of the tin-phosphorus eutectic which would lead to undue resistance loss. Admiralty gun-metal is more frequently specified on account of its more favourable micro-structure. Lead should be eliminated altogether, and the zinc should not exceed the 2 per cent. specified, and preferably should be reduced to 1.5 per cent.

Castings to Withstand High Temperature.

Engineers often overlook the extraordinary way in which some non-ferrous alloys lose their strength when subjected to even small increases of temperature. Most brasses have less than one-half their original strength if heated to 350 deg. C., and at 450 deg. C. the tensile strength has fallen to one-eighth the normal value. Table VI shows the relationship between temperature and strength of some of the better-known alloys:—

TABLE VI.—*Relationship between Temperature and Strength of some Non-ferrous Alloys.*

Alloy.	M.S. (tons per sq. in.)			
	200 deg. C.	250 deg. C.	350 deg. C.	450 deg. C.
Muntz metal ..	31.6	23.1	12.7	3.9
Cast manganese brass	33.1	23.2	12.8	4.2
Drawn manganese brass	35.1	23.1	12.2	2.8
Delta metal, 4 E.	23.1	28.4	19.1	17.5
Cast gunmetal ..	16.1	15.2	10.1	5.4
Cast phosphor bronze	15.3	14.8	10.9	10.2
Nickel copper ..	16.7	13.3	11.6	11.1
Monel metal ..	39.2	36.1	35.8	31.3

The aluminium alloy piston for internal-combustion engines well illustrates the importance of the founder knowing the use to which the castings will be put. An aluminium alloy is not used for pistons, purely on account of its low weight; in fact, for the medium-speed motor-car engine, the greater weight of cast iron in itself is an advantage, although such is not the case for very high-speed engines of the type used on racing cars and aeroplanes. The most important reason for using aluminium pistons, however, is the better heat conductivity as compared with cast iron. If the correct alloy is used, it is possible for the heat conductivity to have over double the value of that is very rapid falling-off in strength with increase of temperature, but special alloys have now been produced which retain a fair measure of strength at the working temperature. Another important of cast iron. With most aluminium alloys there feature of alloys for this purpose is that the thermal expansion shall be as low as possible.

Sheffield, Birmingham and Coventry Branches.

THE CYLINDER PROBLEM.*

By O. Smalley, Member.

The scope of this Paper is confined to the cause and elimination of the commoner defects encountered in the manufacture of cylinder castings. Of the problems confronting the engineer and the foundry to-day, the manufacture of sound cylinders and cylindrical castings is possibly the most intense. 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.

To attempt to arrive at the basic principles essential to the production of sound cylinder castings is deplorably difficult; published literature offers little or no solution, and presents such an overwhelming mass of conflicting data that one might be excused in regarding their manufacture as a somewhat hopeless process. Discuss a failure with a skilled moulder, and you find either that he is not responsible for the defect, or that his is an art that has accumulated so many traditions that the possibility of obtaining a sound casting is dependent upon either his past experience or chance. So old is his art, and so saturated is the moulder by his beliefs and opinions unsupported by any actual proof, and so deep-rooted is his conservatism, that science or any innovation is deeply resented. It is a rare thing to find a skilled artisan who has any knowledge of natural science or who understands the fundamentals of his art.

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* A Paper read before the Sheffield, Birmingham and Coventry Branches of the Institute and also the North East Coast Institution of Engineers and Shipbuilders.

This is the cancer at the root of the cylinder problem. The unenviable position of the foundryman to-day becomes more embarrassing with the restriction of his responsibilities. The construction of the cores or of the mould is being split up into two trades, the moulder and the core-maker. They have little or no voice in the selection of their raw materials, whilst the method of running the casting and the melting of the metal is out of their province. In many instances the work of the skilled artisan resolves itself into purely mechanical labour, but, carrying the traditions of their trade, they are able to bewilder those uninitiated in their art. In some instances, particularly in loam moulding, where the moulder sketches out his own strickle plates and grids, and perhaps constructs his own pattern, a more intricate knowledge of his raw materials and the construction of the mould is essential. Considering the equipment employed by such men, and the class of work they turn out, one cannot but feel a deep respect for their skill. They represent the backbone of the foundry industry.

The manufacture of cylinders is divided into three distinct operations:—(1) Preparation of mould and cores. (2) Melting of the metal. (3) Pouring. The materials used in the construction of the mould comprise moulding and loam sands, facing materials, and the necessary tackle to contain the sands and give it the support and sufficient strength to withstand the temperature and pressure of the molten metal.

The principal defects directly attributable to the mould and core are: Scabbing and flaking, buckling, blow-holes, open grain, mechanical weakness.

(1) *Scabbing and Flaking.*—This results from incorrect venting, incapacity of the mould to withstand the flow of hot molten metal, incorrect drying, low bond value and poor refractory properties, all of which are traced either to the use of inferior sand or to careless moulding.

(2) *Buckling.*—Due to the use of too fine sand or loam, incorrectly prepared sand, too rapid drying, method of construction of mould, too rapid running or beating of the metal in one place.

(3) *Blow-holes.*—Due to incorrect venting, careless preparation of the sand, incorrect drying, patching up, rust or moisture from chills or chaplets and method of running.

(4) *Open Grain.*—Too warm mould or core, low heat conductivity of the moulding sand, method of running.

(5) *Mechanical Weakness.*—Use of wrongly designed chaplets, incorrect adjustment of rate of cooling at change of section, casting of blocks of metal in heavy portions to unify rate of solidification.

Raw Materials.

Moulding Sand.—In general engineering practice it is customary to purchase raw materials to a rigid specification suitable to requirements. In the foundry the prevailing custom, in Great Britain at least, is to order the same as before, or, in the case of sands, to test by feel and by bond, gripping a handful and breaking and examining the fracture by eye. It is with the greatest reluctance that the foundryman will change his raw materials if those in use are giving satisfaction, whilst the potential advantages to be gained from a new material would be difficult to estimate owing to the numerous uncontrolled variables involved elsewhere.

The requirements of a satisfactory mould and core are that it shall form a structure strong enough to handle, resist the temperature, fluxing action and pressure of the molten metal, yet at the same time permit of a free passage of the gas generated in the mould and give to a contraction of metal, and yield smooth and well-finished castings.

The following is an endeavour to formulate the essential properties required of moulding sands for cylinder castings:—Bond, permeability, refractoriness, texture, longevity, heat conductivity, and water content.

Bond.—This is a measure of the cohesion of the sand particles after pressing together in either the green state or after baking. It is best measured by means of the transverse test. The test bar is made in a skeleton core-box 8 × 1 × 1 in. The sand is gently rammed up on a flat steel plate, and any excess is carefully removed. The corebox removed, the test piece is dried and baked at 400 deg. Fah. (205 deg. C.) for two hours and broken over 4-in. centres.

Permeability.—This is the property of allowing the gases to pass through pore spaces. The principle of the apparatus is to determine the time in seconds to draw a known quantity of air through a unit mass of sand. The test piece used is 2½ in. long by 1 in. dia. This is moulded in a suitable core-box, air dried and gently heated to 400 deg. Fah. and baked for two hours at this temperature. When cool it is immersed in a mixture of stearic acid and paraffin wax just molten. Two rapid immersions are recommended, allowing the first to harden before dipping a second time. When the second coat has set hard, the bottom ¼-in. is removed. The test piece is set in a glass funnel with plastic wax and molten wax run in. When firmly set, the top of the test piece is cut open with a specially shaped tool. The funnel is connected to an aspirator of 600 c.cm. capacity, filled with water and the time taken to empty in seconds is recorded as the "permeability" figure, *i.e.*, it is the time taken to draw 600 c.cm. of air through the test piece.

Refractoriness.—This is best determined by heating 5 grams of the dried sand in an electric carbon-resistance tube furnace for 30 minutes at 1,200 deg. C., and then examining under a hand glass or low-powered microscope. Sands showing any signs of fusion or fritting should be rejected.

Texture is determined by a simple mechanical grading using a set of sieves, including a number 20, 30, 60, 90, 100, 120 and 200 with punched round holes.

Heat Conductivity.—This property is closely associated with grain size and the pressure applied in ramming. The smaller the grain and the more compactly rammed, the more rapid the extraction of heat from the metal. It is a property on which little systematic investigation has been published.

Water Content.—The uncombined water is determined on 10 grams drying for four hours at 110 deg. C.

Practical Interpretation.

Table I details the properties of three well-known sands of different geological characteristics,

Table I.—*Testing of Sands for Dry Sand Moulding.*

Source.	Physical condition.	Temperature and time of baking.	Permeability to gas in secs.	Transverse tests ozs.	Moisture content of sand before use.	Mechanical Grading.						
						Per cent. by weight retained on sieves mesh passes						
						20	30	60	90	120	200	200 to the inch.
Belgian Yellow ..	Tempered ..	400° F. 4 hours.	55	132	10.2	10	2	14	47.5	3	8	15.5
	Milled 5 min. ..	,,	72	136	9.6	—	—	—	—	—	—	—
Birmingham Cemetery	Tempered ..	,,	45	53	7.9	0.13	0.08	5.62	63.58	3.25	16.48	10.86
	Milled 5 min.	,,	76	199	8.4	0.14	0.06	5.45	65.48	1.03	16.96	10.98
	Milled 30 min.	,,	440	608	8.9	0.01	0.08	5.03	56.18	4.70	16.88	17.12
Lenton ..	Tempered ..	,,	46	160	10.5	0.05	0.60	29	41	4	14	11
	Milled 5 min.	,,	60	270	10.9	—	—	—	—	—	—	—

as received from the mine and after milling five minutes. These are self-explanatory of the importance of strict control at the mill.

Belgian Yellow.—A highly refractory open sand of good bond, which is not appreciably affected by a light milling.

Birmingham Cemetery Sand.—Well-known red sand. When lightly milled, it is strengthened without seriously affecting the permeability figure. Owing to its nature, however, over-milling should be studiously avoided, because the sand readily disintegrates, and although accompanied by an increase in strength, there is a marked fall in the permeability.

Lenton.—An open red sand, highly suitable for cylinder work. It will be observed that milling does not disintegrate as in the case of Birmingham Cemetery Sand, but unlike Belgian Yellow, its value is improved by a light milling.

Green Sand.—In modern foundry practice green sand moulding is a lost art, and for cylinder castings dry sand moulds are almost universal. On the Continent and in America automobile cylinders are made in green sand moulds, but the contour of the castings is formed from a series of hard-baked cores, a practice which can scarcely be styled "green sand moulding."

If we are to revive this branch of the industry, which is essential if moulding costs are to be reduced under present economic conditions, either more men must be trained as green sand moulders or a "sand" must be found which is "foolproof" and does not require the individual skill of the trained moulder. High cost of labour and mass production militate against the revival of the highly skilled artisan. A green sand mould, made by unskilled labour, therefore, must have the properties of a dry sand mould; it must be hard and compact so that crushing and erosion by the hot metal are avoided; it must be rigid and resist the expansion of the solidifying metal, be freely venting and have a low moisture content.

In normal practice the bond value of green sand, measured by the dropping test, varies between 1¾ to 2¼ in., the permeability to gas 60 to 100 sec., and the water content 6 to 7 per cent.

In the old days this sand was prepared by the moulder himself, who was usually a man of long experience. The modern tendency is to confine the moulder's time to moulding; sand preparation is considered out of his sphere. *If prepared with an understanding of the real requirements of the sand, centralised sand preparation is a step in the right direction.* If done for the purposes of economy, placing in the hands of unskilled labour —which is the common practice of to-day—green sand moulding will always be the uncertain art it is to-day, and a costly method of making castings.

Given a sand of higher bond value than is average, or ramming brick hard, the moulder fears blowing or scabbing, such sand in the past having been proved to be dense and impermeable to gas. In the early stages of development of a "synthetic green sand" which would eliminate dry sand moulds, the dropping test aimed for was 3¾ to 4 in.; that is an exceedingly strong and tough sand, water content 4 to 5 per cent. and permeability figure 50 seconds. A green sand core 8 × 1 × 1 in. could be handled with ease in this sand, and it was more freely venting than the ordinary green sand, which crumbles to the touch.

The first tests were carried out on 100 valve bodies, a design which had given trouble when previously made in green sand. Moulding was done, two in a box, on a jolt ram machine. *The time of moulding was reduced* 40 *per cent.* The moulds were well-finished, strong and rigid. Touching up and sleeking were unnecessary. When the moulder was requested not to use a vent wire for artificial venting, doubt was cast upon the sanity of the project. This batch of castings came out so successfully that it at once established the value of *sand testing* to the untutored mind and achieved the original object, viz., *to produce a green sand mould by unskilled labour equal to and as foolproof as a dry sand mould.*

The effect of water in the dampening down or tempering of the moulding sand, and the effect of ramming on the venting power, are shown in Tables II and III respectively. Table II shows the effect of varying percentages of water on the venting properties of Mansfield and Erith Loam when made into dry sand moulds. Table III details the effect of ramming on the venting qualities of the same two sands. These tables demonstrate the necessity of rigid control of the water content, and show that, if it is under control and due care has been exercised in the selection and in the preparation of the sand in the first place, the venting power is not materially affected by excessive ramming.

TABLE II.—*The Effect of Varying Percentages of Water on the Permeability of Mansfield Sand and Erith Loam when made into Dry Sand Moulds.*

Sand.	Percentage of H_2O	Permeability.
Mansfield	3	48 secs.
,,	6.71	48 ,,
,,	13	110 ,,
Erith Loam	6	47 ,,
,,	12	80 ,,
,,	15	82 ,,
,,	25	216 ,,

TABLE III.—*The Effect of Ramming on the Venting Qualities of Mansfield Sand and Erith Loam for Dry Sand Moulds.*

Sand.	Ramming.	Percentage of water.	Permeability figure in seconds.
Mansfield	Light	6.7	41
	Normal	,,	48
	Heavy	,,	61
Erith Loam	Light	11.2	Too friable to test.
	Normal	,,	85
	Heavy	,,	110

Loam.

Loams may be placed in three general categories:—(1) Building loams; (2) mould loams, and (3) core loams.

Each is a clayey sand milled with floor sand to a slurry containing 20 to 25 per cent. water, opened by means of sea-sand, coke, ashes, sawdust, cow-hair or horse-dung.

The commonest troubles with loam moulds and cores are flaking of the face on drying or on casting, scabbing or buckling, blowing, contraction cracks, too high bond.

The essential properties required of loam are: (1) Low shrinkage on drying; (2) strength; (3) porosity; (4) permeability; (5) refractoriness; and (6) property of rubbing. The fundamental importance of these and the precise control in the preparation of loam should be patent to all, and yet it is no uncommon practice to have loam prepared as a builder does his mortar. Table IV shows the effect of milling on the strength, permeability to gas and volume changes, of one of the most commonly used loams, viz., Erith. It shows that little mechanical action is necessary to obtain the desired combination of properties, and that hand milling almost doubles the strength. In ordinary practice, mechanical milling for five minutes gives the best combination of strength and permeability, any longer time than this merely grinds the loam into a finer state of division, reduces the permeability to gas, increases the contraction on drying, and renders it more suitable for use as a cement than a foundry loam.

TABLE IV.—*Effect of Milling Erith Loam.*

Time.	Water. content.	Transverse strength baked 4 hours at 400° F.	Permeability to gas in secs.	Volume changes after baking at 400° F. 4 hours.
Tempered over night.	21.9	276	730	4.47
Hand milled ..	23	492	927	6.62
Milled 5 mins.	22.8	547	1,700	7.67
,, 15 ,,	21.9	579	1,945	8.25
,, 30 ,,	22.7	604	2,528	8.43

Table V details the effect of varying the percentage of water on the physical characteristics of loam. It demonstrates broadly the progressive effect of increasing quantities of water, and emphasises the high importance of its accurate control.

Effect of Rate of Drying.—That the elimination of 20 to 25 per cent. of water from a loam must be conducted with considerable care and without undue haste is quite evident from the volume change figures given in Table V. It is an everyday practice, however, to find a moulder disregarding these precautions. He will sweep a job and have it in the stove within a few hours, and yet is surprised to find it badly cracked or flaked, or lifted bodily from its bricks or plate. Often this is scarcely discernible and difficult to detect, but no matter how slight, the result is a buckled casting.

TABLE V.—*Effect of Varying Percentages of Water on the Physical Characteristics of Erith Loam.*

Treatment.	Per cent. water.	Transverse.	Permeability.	Volume change.
Milled 5 mins. ..	11.4	148	72	1.3
Water added and milled 2 mins.	19.8	530	690	6.62
Water added and milled 2 mins.	21.5	650	2,200	8.31
Water added and milled 2 mins.	28.97	448	1,095	8.67

Construction of Moulds and Cores.

In this Paper it is impossible to treat fully the defects resulting from wrong construction of the mould or cores. Starting from a basis, however, that the physical characteristics of the sands used are known and are under control, and that the moulder possesses an elementary knowledge of physics, mechanics and sound practical sense, the commoner defects such as scabbing, flaking, buckling, blow-holes, shrink holes and draws will be greatly eliminated, and the construction of the mould will lend itself to standardisation.

For the purpose of this Paper, we will consider the construction of a large l.p. marine-engine steam cylinder. Figs. 1 to 6 show the cores and method of construction of a cylinder with a dished crown weighing 23 tons. The pattern consisted of a few simple strickles, skeleton core-boxes and the necessary wood trappings. The mould was made in sand, the cores in loam. This complex structure was erected with little or no knowledge of the properties of the raw materials used, or of the strength and rigidity of the cores. Yet it had to withstand the strain and stress of 23 tons of molten metal poured into it in 2½ minutes. The metal must flow uniformly throughout the sections without agitation and overlaps, and the gases must pass freely through the vents arranged for them. Neither the sand nor loam must spall, nor must the metal wash away any corner or details of either mould or core. Suffering mass influence, and undergoing a chemical change

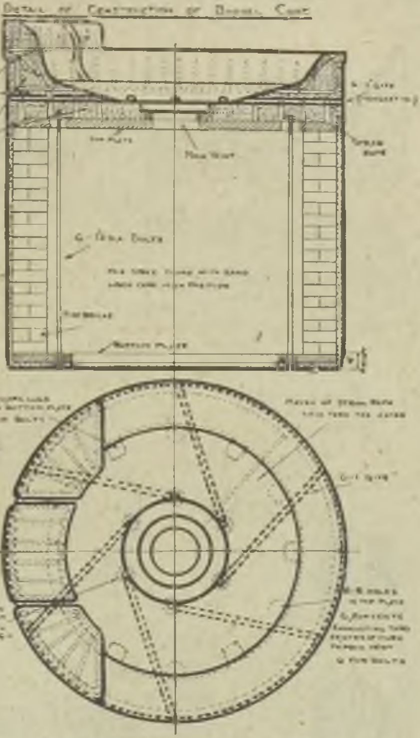


Fig. 1.—Illustrating Difficulty of Running a Cylinder Due to the Barrel Core Buckling.

until completely solid, uniform freezing conditions must be sought, compensations made for both liquid expansion, liquid contraction and solid contraction—which may operate at the same time—and arrangements made to remove the products

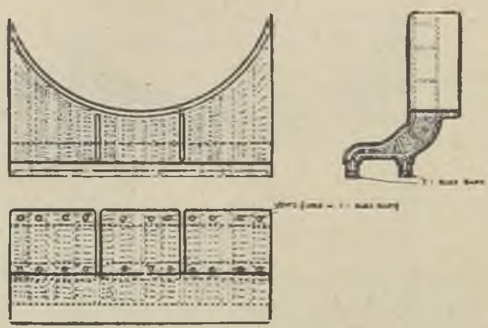


FIG. 2.

FIG. 3.

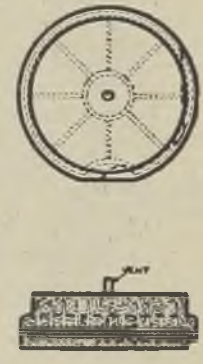


FIG. 5.

of chemical action in the metal during solidification.

The mould for such a casting in its details and complications calls for the science and understanding of any mechanical construction of the engineer. Yet the fate of such castings hangs upon the uncertain knowledge that certain iron and brick supports, and certain sand mixtures might have proved suitable for a similar type of casting in the past. That good castings are still being produced from such empirical data is

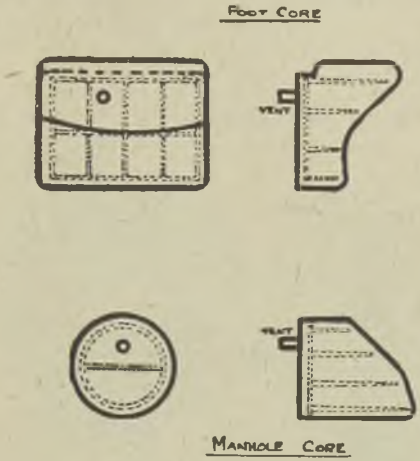


Fig. 4.

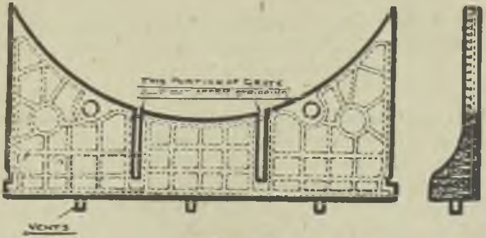


Fig. 6.

remarkable, and speaks highly for the skill of moulders who are able to make these castings commercially. At the same time, very few managers or foremen will guarantee their castings, and their successive emergence from one foundry to another is very discouraging.

The cylinder under consideration was cast crown up. The first cylinder was lost through the barrel core buckling and a part of the crown breaking away. The diagram of the barrel core, Fig. 1, shows the difficulties of construction and of running the metal so as to prevent the breaking away of the upper portion of the core and of producing a clean, sound casting. In the second casting, ingates through the crown were made through the top of the barrel core as shown, in order that the metal on rising to the lower level of the crown would gently swirl on to the centre of the top of the barrel core, and the whole rise together. At the same time, it was realised that without an intimate knowledge and control of the properties of the loam used—strength, permeability to gas, shrinkage on drying and refractoriness—which must be such as to enable it to endure the flow and pressure of the molten metal, permit free escape of the gases generated and yield to the contracting metal, this procedure was risky, and the second casting would follow the first.

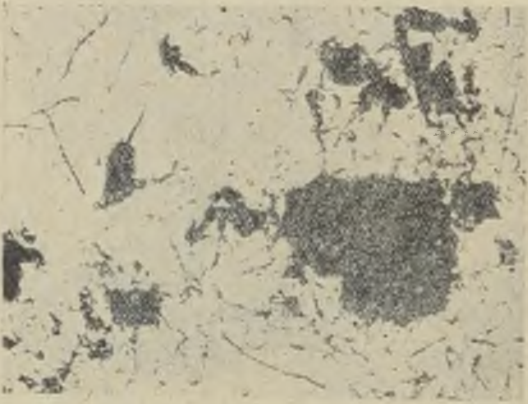


FIG. 7.—PHOTOMICROGRAPH TAKEN FROM THE DEFECTIVE ZONE OF THE STEAM CHEST OF A LOCOMOTIVE CYLINDER.

Similarly do these remarks apply to the *construction of the moulds and cores of all castings,* *for unless they can be prepared from day to day with a* CERTAIN ASSURANCE *that similar conditions are being reproduced, production of sound castings becomes an uncertain and harassing business.*

Fig. 7 represents photomicrograph of a locomotive cylinder taken from a section of the defective zone, proves the defect to consist of entrapped sand and oxide, suggesting that a portion of the mould or core was washed by the metal, and was trapped in this portion of the casting. Close examination of this and other cylinders presenting a similar defect, traced the origin of the defect to the collapse of a small core inserted in the lower portion of the mould which had been burned in drying.

FIG. 8A.—SHOWS A PORTION OF A CYLINDER REJECTED FROM CHAPLET TROUBLE.

Chaplets.—It is not uncommon for an otherwise good cylinder to be rejected on account of leaking at the chaplets or for the foundry to lose a casting because the chaplets gave way. Scientific design of chaplets, however, presents much the same difficulties as scientific control as a whole. The requirements of a chaplet are that it must (1) sustain a given load for a definite period of time, (2) fuse in the shortest possible time and form a perfect weld with the adjoining iron. The ideal design for strength is that which enables the chaplet to withstand direct compressive stress, when the entire load is concentrated on the central support, and a bending moment when the direction of the load does not coincide with the axis of the support.

Consideration of the relative value of the cylindrical, rectangular and corrugated supports leads to the conclusion that structurally a suitably designed corrugated support is the best, in that it gives the highest ultimate buckling strength, presents the greatest surface to the molten iron, and does not depend for strength on the efficiency of the joint between the support and top, which is particularly the case with the rectangular and circular supports.

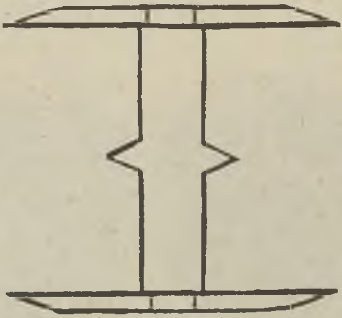


FIG. 8a.

Unfortunately the foundry does not possess suitable facilities for making its own chaplets, and whilst the designs at its disposal may be strong enough, the problem of obtaining a weld is left in the hands of the moulder. At the best this can never be more than a poor compromise, and the result is that the chaplet is often loosely attached to the casting. Photograph A, Fig. 8, shows a portion of a cylinder rejected because of trouble with chaplets. In this instance they could be pulled away from the casting with the hands.

The two principal objections to the common form of chaplets sold to-day are (1) that they are made in the same section of mild steel irrespective of whether for use in ½- or 2½-in. section, or whether they are for use at the top or bottom of the casting; and (2) that the central support for one particular section of casting may vary more than 20 per cent. in diameter. The foundryman endeavours to get over the difficulty of obtaining a weld by using his chaplets tinned or galvanised, or by treating with a mixture of red lead and turpentine. Evidence is still required to prove that these increase the fusion between the chaplet and the casting, although we have proof to show that oxides or metals having low boiling points, are a prolific cause of blowholes and spongy places.

FIG. 8B.—SECTION THROUGH CHAPLET USED IN A LOCOMOTIVE CYLINDER.

Where a chaplet is necessary, the author uses the form shown by Fig. 8a. This does not differ radically from the standard chaplet sold, but is modified to present easy fusion at the centre of the stem without reducing its strength, and also at the faces of the chaplet as an additional safeguard. Such chaplets thus enable a perfect weld to be produced whether used at the top or bottom of a casting. To remove any oxide and ensure a clean skin in use, these chaplets are pickled in acid and protected in store by means of oil. Photograph B, Fig. 8, shows a section through such a chaplet when used in a locomotive cylinder. Photomicrograph C, Fig. 8, shows the depth of carbon penetration and the efficiency of the weld between the edge of the chaplet and the cast iron.

Numerous instances of moulding defects may be cited, but they only go to demonstrate further the high importance of technical control of raw materials and of every operation in manufacture, if any measure of security against defective castings is to be guaranteed, and if cylinder losses are to be eliminated by any other method than the costly one of risking the casting. Apart from the commercial value of such a control in reducing scrap losses, cost of drying, etc., sand costs and its preparation are brought to an economical basis, whilst the reductions effected in handling charges, which represent a capital investment, are enormous. Some idea of the possibilities in this direction may be gathered from the fact that in the manufacture of 1 ton of castings under normal rule-of-thumb conditions, no less than 6 tons of sand may be used, which is often handled 8 times (incidentally a fertile field for the equipment engineer).

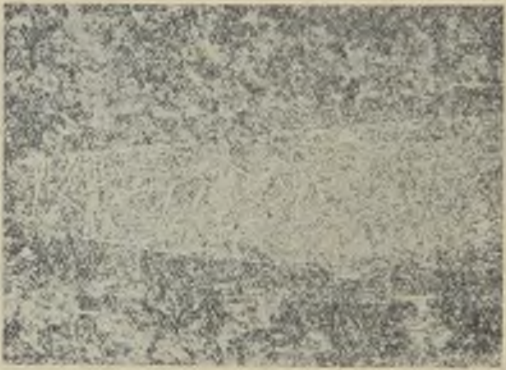


FIG. 8C.—ILLUSTRATING DEPTH OF CARBON. PENETRATION AND EFFICIENCY OF WELD BETWEEN CHAPLETS AND CAST IRON.

Metal.

The principal metallurgical defects of cylinder castings are low test figures, open grain, draws, porous patches, variations of grain in bore, shrink-holes, blow-holes, mechanically trapped foreign matter and cracks. It is not meant to imply that these defects are traced directly to the use of defective iron. The fact that they are common to land and marine-engine cylinders rather suggests that cylinders as a class present similar difficulties of manufacture, and that the fundamentals of design, metal or organisation are not really understood. Owing to the wide scope of the paper it is impossible to give the detailed study that the subject demands, and the author's comments must be confined to the simple metallurgical principles necessary to a better understanding of both manufacture and design.

FIG. 9A.—GRAPHITE IN HOT-BLAST SAND-CAST PIG.

Melting.—As a melting furnace, the cupola is subject to constant criticism. Some cylinder manufacturers find it profitable to instal the more costly open-hearth melting equipment, whilst on the Continent and in America the electric furnace alone, or as a refining and super-heating unit in conjunction with the cupola, is finding wide favour.

The difficulties of the cupola resolve themselves into melting hot, control of the fluid life of the molten metal and of the ordinary chemical elements, viz., carbon, silicon, manganese, phosphorus, sulphur. Under scientific control, however, these difficulties are not insuperable, and as a commercial melting unit, the cupola will not be easily replaced under the present conditions of high cost of fuel and labour.

Cupola-melted grey iron is a material of unknown thermal stability. It is because of its anomalous behaviour in this respect that the selection of pig-iron on a basis of chemical composition has not altogether displaced the old-fashioned rule-of-thumb method of grading by fracture.

The texture or grain of cast-iron, which determines the physical properties, and on which the serviceable life of any cylinder depends, is controlled primarily by the graphite content, its physical form and mode of distribution. The influence of the element in this direction may be judged from the fact that in cylinder castings in general, the quantities range from 2 to 3.5 per cent. and may occupy as much as 10 per cent. of the total volume of the casting. Assuming a tiny worm-like formation, and being a soft friable and combustible substance of different co-efficient of expansion and contraction from the metal matrix, a slight variation in either the quantity or form exerts a profund influence on the serviceable quality of the iron. This is intensified by the graphite assuming various physical forms under different temperatures and pressures, its density ranging from 1.2 to 3.5 per cent., whilst its refractory and lubricating values are a function of temperature, time and rate of cooling.

These facts emphasise the supreme importance of precise control, if consistent production of sound castings is to be obtained. Unfortunately it is the substance over which, under ordinary conditions of manufacture, we have least control. Some eminent chemists assure us that it is a simple decomposition product of the carbide, and is directly under the influence of the other elements present, temperature and time. In ordinary practice this is erroneous, for it is quite common to obtain from two irons of similar chemical composition cast under identical conditions widely different mechanical properties, due mainly to the form and mode of distribution of the graphite.

The chemical composition of cast iron in itself is of somewhat similar value to the chemical composition of a moulding sand or of any other complex structure. It indicates the principal elements present, without giving any idea of the chemical or physical constitution of the compounds formed or of their relation to one another. For this reason, the better practice in the preparation of cupola mixtures is that based upon chemical composition and the appearance of the fracture. This method, however, is unscientific, for whilst some claim to understand graphite and its behaviour in the manufacture of castings of any texture from the appearance of the fracture, the majority of metallurgists do not. To overcome this difficulty, the author prepares a special pig-iron melted at a controlled temperature and to a precise chemical composition, which is cast in chill moulds. This safeguards the quality of the iron and retains much of the carbon in solution, whilst the remainder is disseminated in a fine state of division.

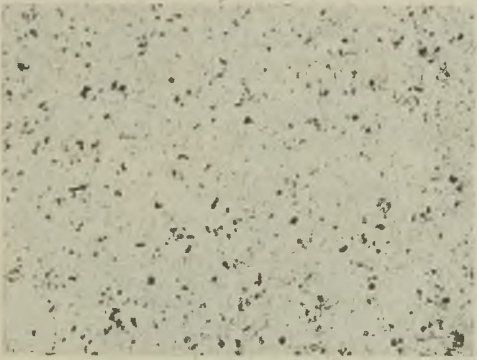
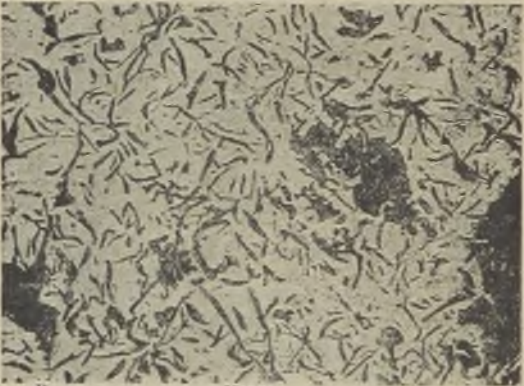


FIG. 9B.—GRAPHITE IN SPECIAL CYLINDER IRON.

Photomicrograph A, Fig. 9, shows the graphite of ordinary sand-cast pig made in a hot blast furnace, and B of the same figure the graphite of a specially prepared cylinder iron. Both irons have practically identical compositions with the exception of the total carbon content, which is

3.5 in A and 3.08 in B. The use of this special iron, for all practical purposes, solves the pig-iron problem and facilitates the preparation of cylinder mixtures from a basis of chemical composition alone.

A Outside.



B Middle.

Fig. 10.

Cylinder Mixtures.—Having established a control of the quality of pig-iron, the selection of a suitable chemical composition for any particular class of cylinder rests with the *service conditions* *required, our knowledge of the metallurgy of cast iron and the design of the casting.*

Service Conditions.—The engineer does not give much practical assistance. His requirements are but vaguely expressed, and his design often evolved from accumulated practical engineering experience does not consider metallurgical principles. Taking, for example, the test bar, which is now engaging the attention of a committee of eminent metallurgists and foundrymen: within recent experience, it was common practice to cast a 1-in. square bar and break over 5 ft. support by means of a weight suspended at the middle. Rupture of this bar at once or over night, as might be demanded, would condemn the casting. Crude as this method was, it laid the foundation of the present-day methods for the testing of cast-iron, which have advanced in detail only, and extended by the application of physical tests which have been found useful for other materials of construction, although serving a different purpose. For cylinder castings, for instance, the Brinell hardness test is frequently specified and cylinders are accepted or rejected on a certain hardness figure. Yet the Brinell test does not measure tenacity hardness as is generally under-

FIG. 10 C.

stood; nor can a standard Brinell figure be used universally as a standard measure of the life of

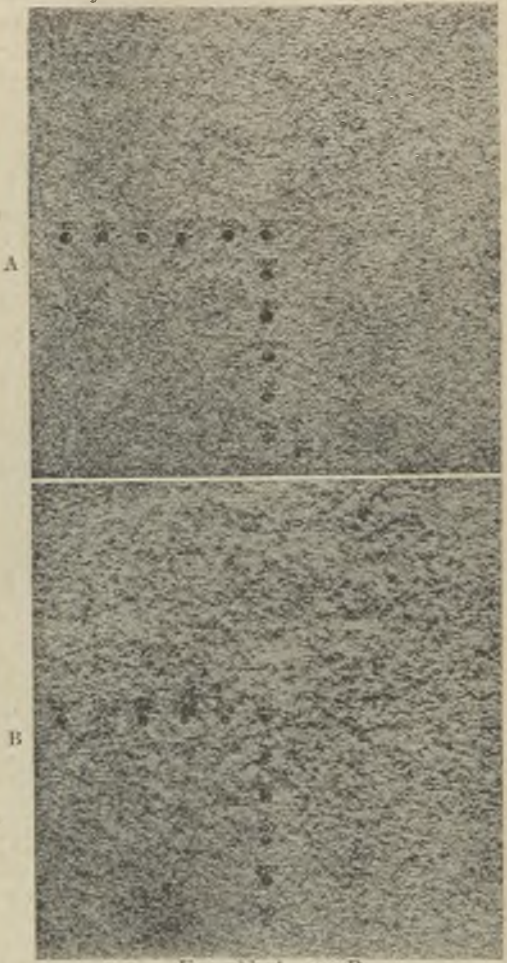


Fig. 11 A and B.

the cylinder. Similarly, the tensile and compression tests rarely measure the simple stress indicated, for if the graphite flakes happen to take a particular dimension or form, fracture occurs by shearing. Again, it is not uncommon to find that the cross-sectional area of the transverse bar does not correspond to the section of the casting. Such a bar can give little indication of the real strength of the casting.

The original idea of test bars in early history was to measure the quality of iron going into the casting and nothing more. They furnish valuable information of the conditions operating in melting and the temperature of pouring. They are certainly supposed to convey something more than this to the engineer, and it is not uncommon to see an otherwise good cylinder rejected on low test figures; yet when these are satisfactory, he guardedly reserves the right to reject on grain or water test, both of which are ambiguous and subject to personal prejudice in their decision. An

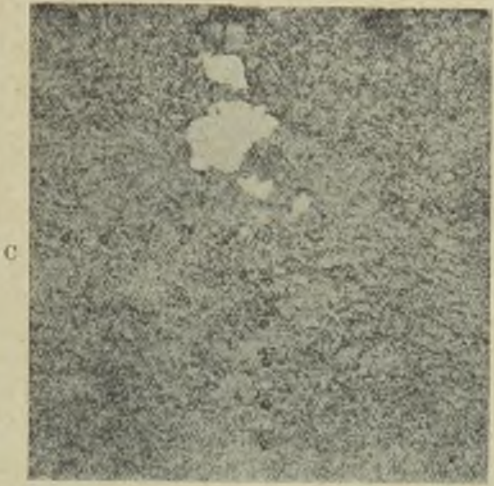


FIG. 11—*cont.*

FIG 11.—The composition of A is T.C., 3.40; Si., 1.03; Mn., 0.63; P., 0.09; and S., 0.063 per cent. B is T.C., 3.27; Si., 1.15; Mn., 0.62; P., 1.54; and S., 0.086 per cent. C is T.C., 3.38; Si., 2.30; Mn., 0.60; P., 0.78; and S., 0.063 per cent.

instance of this may be cited in the rejection of nine locomotive cylinders. These were considered to be open and did not pass the water test satisfactorily. After transferring the patterns to another foundry, the results were unfortunately worse. To alleviate the situation, the contractors recalled the original cylinders, which this time not only passed the second water test, but after a light

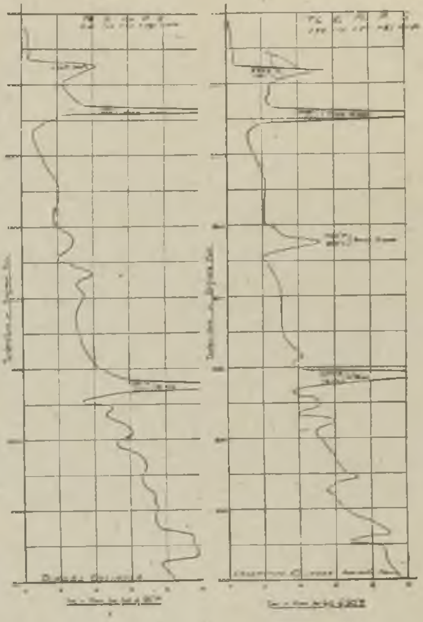


FIG. 12.

finishing out were held up as examples of close-grained cylinders to other manufacturers. Rejections of this nature, justified or unjustified, incur losses to both the foundry and machine shop, and create an unwholesome atmosphere in the two departments.

Open Grain.—Fig. 10 represents a series of micrographs taken through the section of a cylinder that was rejected on account of open grain in the bore. The tensile, transverse and Brinell tests were to specification. This is obviously a metal defect resulting from the use of an iron too high in total carbon and silicon contents, and from too slow cooling.

Fig. 11 shows the effect of mass on the solidity or texture and on the Brinell hardness of three irons made under similar conditions in ordinary sand moulds. The three photographs suffice to demonstrate "solidity" of cast iron as a function of chemical composition, and show that for ordinary sand castings the minimum section permissible to uniform solidity from a cylinder iron may range from 1 in. to 6 in., according to its "solidity penetrating power." Expressed in terms of actual strength, they show that by further increasing any section beyond the limits of the "solidity penetrating power" of the iron used, there is a corresponding decrease of strength. Assuming, for example, that a tensile figure of 15 tons is obtained from a cylinder iron whose solidity penetrating power is 2 in., at 4 in. this may fall to 9 tons; at 6 in., 3 tons or less. Yet it is not uncommon to meet with specifications of a chemical composition, without regard to either section or dimension of the casting.

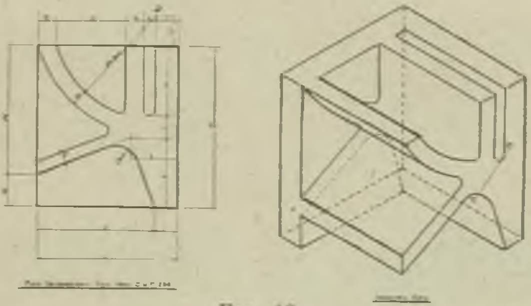


FIG. 13.

This simple illustration is presented here to demonstrate that under ordinary conditions of manufacture of sand castings, weight and mass do not necessarily mean either increased strength or longer life in service. Heavy sections, bosses,

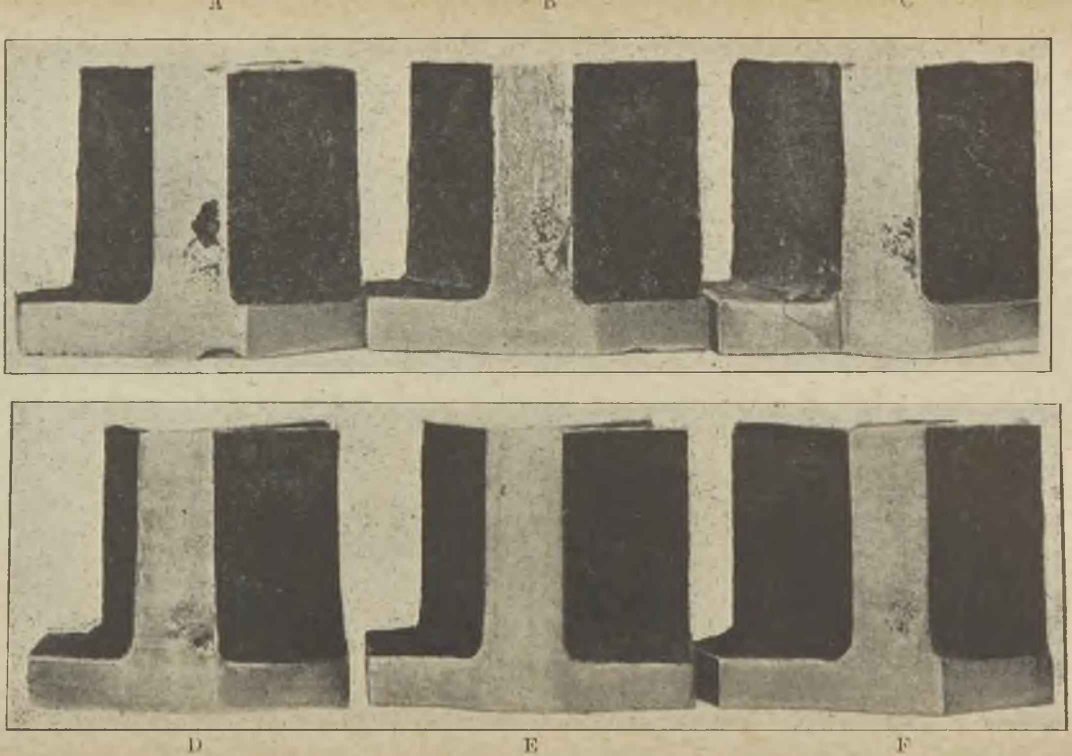


Fig. 14.

large fillets and strengthening ribs not only increase the cost of manufacture and reduce the chance of the production of sound castings, but weaken the structure as a whole.

Mechanism of Solidification of Cast Iron.

The cooling curves taken from a Diesel-engine-cylinder iron and from an ordinary locomotive-cylinder iron, reproduced in Fig. 12, show the essential difference between these two irons on solidification to lie in their range of freezing temperatures. In the former solidification commences at approximately 1,240 deg. C., and is complete at 1,160 deg. C.; in the latter it commences at 1,231 deg. C. and continues to 935 deg. C., *i.e.*, the freezing range of the former is 80 deg. C. and of the latter 296 deg. C. There exists the same difference between the process of solidification as between mild steel and Admiralty gun-metal. Because of its long freezing point, ordinary cylinder iron thus presents the same defects of crystallisation and liquation as ordinary gun-metal, and

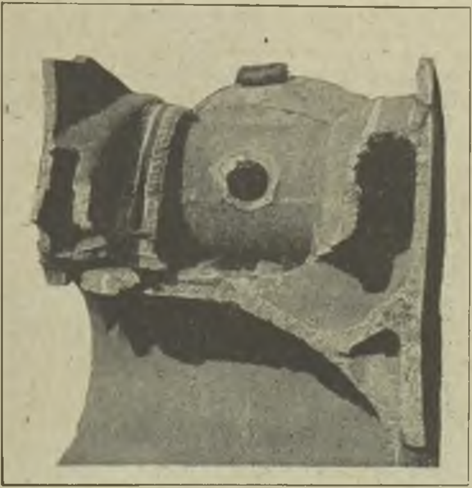


Fig. 15.

consequently presents similar difficulties in the manufacture of solid castings.

To demonstrate the difference between these two irons in the manufacture of solid castings of varying sections, where ample opportunities exist for the manifestation of the ill-effects of differential freezing, the casting shown in Fig. 13 was designed. This represents a portion of a port of a cylinder that gave trouble in manufacture from "internal draws" at the heavy section. The sections range from ½ in. to 2½ in. The castings were made with the heavy section at the bottom and without risers, running from the bottom so as to represent as faithfully as possible the actual conditions of freezing operating in complete cylinder castings.

Each casting was sectioned through AB, the position of drawing according to the isothermal lines of the casting.

In Fig. 14, A, B and C show the result obtained from three soft irons of the following chemical compositions:—

	Total Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.	Molybdenum.
A ..	3.27	2.20	0.72	0.91	0.096	—
B ..	3.27	2.20	0.72	0.91	0.096	0.20
C ..	3.34	2.50	0.56	1.83	0.044	—

D, E and F show the results obtained from three cylinder irons:—

D ..	3.41	1.41	0.60	0.90	0.072	—
E ..	3.49	1.25	0.68	0.20	0.089	—
F ..	3.51	1.10	0.68	0.53	0.085	0.25

These experiments show that the wider the freezing range and the softer the iron, the greater the tendency to draw. B suggests that molybdenum is of value in reducing drawing of an iron of long freezing range, whilst C shows that by increasing the phosphorus to an abnormal figure so that excessive quantities of the low-melting-point phosphide predominate, drawing is slightly reduced.

D, E and F show an all-round improvement, whilst E, a low-silicon and low-phosphorus iron of high solidity penetrating power and short freezing range, is equally solid throughout. These results indicate the influence of chemical composition as a factor in eliminating the trouble of leaking ports. Other factors which also influence solidity are temperature of pouring, rate of cooling, and rate of running. This form of test piece could be applied to investigate each of these and to any design of cylinder giving trouble, modifying the form or sectional dimensions accordingly, instead of using the cylinder itself as an experiment. Such a test bar, incidentally, provides the engineer with direct information on the solidity of the various sections throughout his castings.

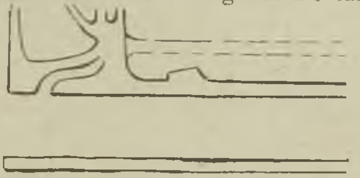


Fig. 16.

Fig. 15 shows a fracture through a defective port of a locomotive cylinder. At this position five sections, ranging from ½ in. to 1¼ in., conjoin. Comparative analyses from a solid and defective portion of this cylinder are given below :—

	Total Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
Sound ..	2.93	1.29	0.57	0.091	0.53
Drawn Port	—	—	—	0.176	0.17

Fig. 16 represents a diagrammatic section, and Fig. 17 a fracture through the port of this cylinder. This is even more complicated than the standard section first considered (Fig. 13), and apart from the ill-effects of selective crystallisation and liquation, such an arrangement of cores will act as scum traps for the oxide, slag and dirt from the mould accumulating on the surface of the rising metal. Chemical analysis is not the best means to demonstrate this point, although it will be observed that the sulphur content at the draw is 0.176 against 0.091 obtained from a sound portion of the cylinder. Apart from functioning as scavengers, however, cores presenting little or no cooling surface prevent free dissipation of heat from the solidifying iron. Conservation of heat in this way is equivalent to mass influence, and for

Fig. 17.

this reason alone the design of the port is a common cause of sponginess and general unsoundness. Any form of design, therefore, that presents these features is not only bad for the foundryman, increasing his difficulty and also his cost of manufacture, but produces finished castings that will always be a source of trouble to the engineer.

Fig. 18 shows a section through a port of a cylinder made by a recently patented process of casting on suitably formed steel sheet. The efficiency of the weld is apparent from the photograph, the steel could be pulled away readily from the casting. The objections against the general adoption of this process are the uncertainty of attachment, blow-holes and mechanical defects from misplacement. It is a palliative, not a remedy of " draws " in ports of cylinder castings.

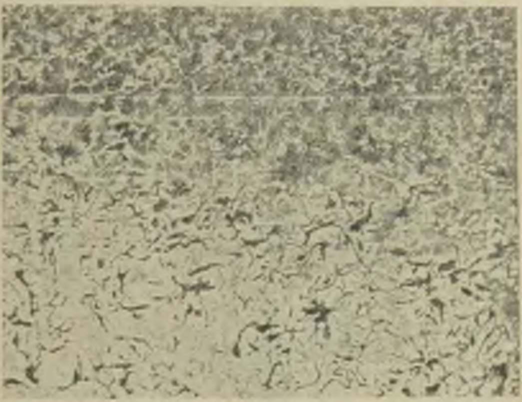
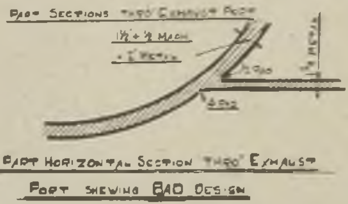


Fig. 18.

Fig. 19 shows a section through the exhaust port of a 14-ton marine-engine steam cylinder of simple form, which gave considerable trouble. Here three sections ranging from 1½ in. to 2¼ in. merge into a mass of metal 3¾ in. across, whilst the main core at this position running almost to a point presents little or no cooling surface. The defect encountered was a draw at the heavy section, and in one port 170 lb. of cement were pumped in ineffectively. Permission to modify the design was not granted, but the alteration shown by Fig. 20, which safeguarded the cylinder against rejection under water test and foundry losses, by no means ensured sound metal at this position; and owing to the form of the port and the metal contracting on the chill, the removal of the sections was both risky and costly. Fig. 21 shows another marine-engine cylinder which presented similar difficulties. Fig. 22 shows the change in design permitted to ensure a more uniform distribution of the heat. A sound casting



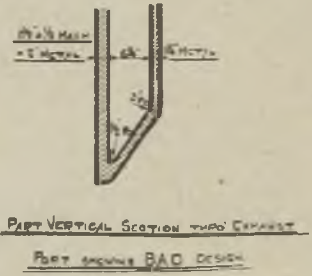
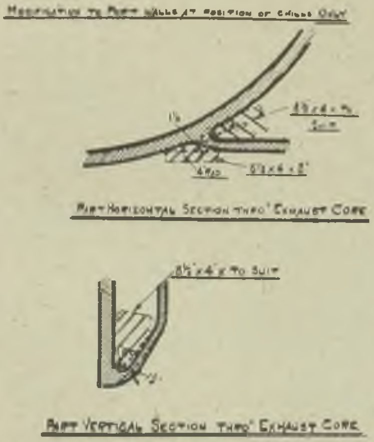


FIG. 19.

was obtained without radically altering the design or dimensions.

Porous or Spongy Patches in Cylinder Bore.

Fig. 23 shows sections through defective i.p. marine-engine steam cylinders which were rejected on account of local patches of open texture in the

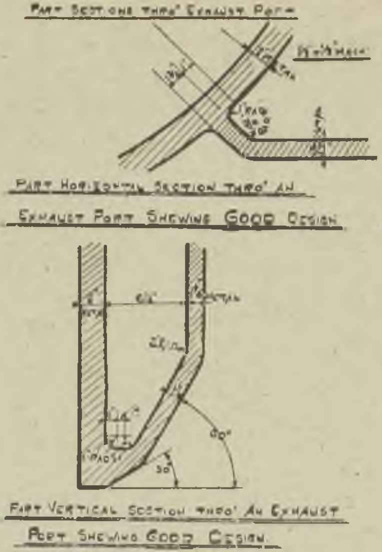


Modification to Port Walls at Position of Chills Only

Part Horizontal Section thro' Exhaust Core

Part Vertical Section thro' Exhaust Core

FIG. 20.

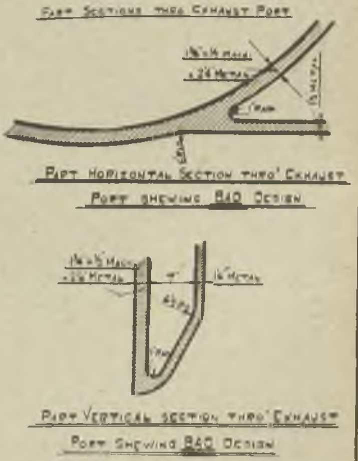


Part Sections thro' Exhaust Port

Part Horizontal Section thro' an Exhaust Port Shewing GOOD Design

Part Vertical Section thro' an Exhaust Port Shewing GOOD Design.

FIG. 22.



Part Sections thro' Exhaust Port

Part Horizontal Section thro' Exhaust Port shewing BAD Design

Part Vertical Section thro' Exhaust Port Shewing BAD Design

FIG. 21.

bore. The defects manifested themselves in the final machining operation at positions in the cylinder where heavy sections merge.

There are instances where the problem of design was aggravated by the moulder, who, in endeavouring to give a good finish to his mould, unwittingly increased the dimensions of the fillets. To remedy the former the fillets were removed from the pattern, and an iron of shorter freezing range and high degree of solidity penetrating power was used.

Other causes of porous or open patches in the bore are: Melting cold, low pouring temperature, method of running, temperature of mould and wrong metal. To control the temperature, the author uses an immersion thermo-couple. The temperature of the pouring is adjusted according to the types of cylinder, their dimension and the metal used. Hard and fast rules cannot be laid down. The temperature figures range from 1,310 deg. C. for a large l.p. steam cylinder to 1,380 deg. C. for a small automobile cylinder or a Diesel cylinder.

Equally important with temperature is the dimension of the pouring dish and the method of running factors determined by the dictates of experience. The safer practice is to use a deep pouring basin made in hard baked loam, which holds approximately one-third of the weight of the metal required for casting, and to run as slow as possible by means of both bottom and top runners, the former to ensure a steady filling of the mould with clean undisturbed metal and the latter to lift any scum adhering to the moulds and cores, and provide a supply of hot metal at the top of the casting.

These remarks apply whether the casting is poured horizontally or vertically. Generally it is preferable to cast vertically, with the closed end up to ensure a good flow of metal through the barrel. Where casting vertically is not convenient, running off one or more risers is recommended. Such practice achieves two ends: it washes out any scum adhering to either the cores or mould and brings about uniform conditions of crystallisation.

Porous patches resulting from entrapped scum are easily differentiated from those caused by selective crystallisation. The former exhibit a bright silvery appearance, and on close examination appear to consist of numerous minute blow-holes, whilst the latter appear crystalline. Confirmation of a decision may be obtained by means of a sulphur print. If due to entrapped scum, the high sulphur is shown black; if due to selective crystallisation the sulphide is normal and uniformly distributed.

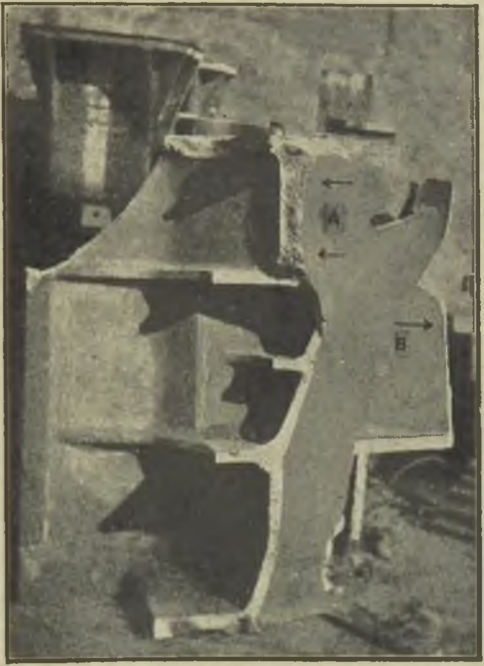


Fig. 23.

As a rule, porous patches from entrapped scum may be traced to the metal having been rushed into the mould through bad pouring, or from the use of a too shallow pouring dish, from pouring cold, the use of dirty metal, or from too much steel.

Porous Patches from Selective Crystallisation.

Carbon.—Photomicrographs A and B, Fig. 24, show the microstructure of normal and open texture of a cylinder made from pig-iron containing a high total carbon content, which was rejected on account of a porous patch in the barrel.

Phosphorus.—Phosphorus considerably extending the freezing range of cast iron is, however, the worst offender, and its presence even in small quantities is the commonest cause of porous patches. The effect of phosphorus on the process of solidification of a cast-iron cylinder may best be followed by the aid of a transparent cylindrical mould and

FIG. 24.

some prepared coloured molten wax which freezes through a range of temperature. The surface of the vessel may be rough or highly polished, but if it is a poor conductor of heat, crystal growth will be observed to commence from within and from the surface at the same time. The slower the rate of cooling, the greater the chances for internal crystallisation and of floating crystallites, preventing uniform crystallisation and distribution of the lower melting point eutectic. For the same reason any condition operating in the manufacture of an iron casting of cylindrical form which results in such a mode of crystallisation—whether due to the composition of the iron, a reduced cooling surface, the use of hot or warm cores, or of cores bonded with a combustible heat-generating substance such as linseed oil, or method of pouring—will assist in the formation of local patches of open and weak texture.

Blow-holes.

Blow-holes arise from the phenomena of solution of certain gases in melting, from the dissociation of certain chemical compounds and from chemical reactions. They may, therefore, be located to occluded gases, mechanically contaminated oxide, or to a simple chemical reaction in the metal itself, or between the scum or oxidised surface of the iron and the main body of metal

When resulting from poor melting conditions their origin may be traced to the use of low-grade pig-iron, scrap or steel, badly dimensioned stock, inferior coke, low coke bed, too low coke ratio, too high blast pressure, wrong fluxing or any condition which tends to oxidise the metal or melt cold. On the other hand, semi-steel or iron, high in sulphur, if poured cold, will blow as a result of dissociation of the sulphur compounds. These, however, cannot be directly attributable to bad melting, their elimination being a question of shop organisation. Such blow-holes usually exhibit a bright skin. They are accompanied by a general unsoundness of the casting and in some instances free oxide of iron may be found.

Blow-holes resulting from overlaps in running or from a reaction between the scum and the metal, are local to some particular portion of the casting, and exhibit a tinted or blackened skin. These are caused by wrong gating, the use of a too small pouring dish, careless skimming or entrapped foreign matter such as may be lodged in some portion of the cylinder which does not permit of a free flow of the metal.

Fig. 25 shows an etching taken through a section of a cylinder casting barrel at a defect of the blowhole type. It shows the extent of sulphur segregation in the immediate vicinity of each blow-hole, whilst in the rest of the cylinder it is normal and uniformly distributed. Photomicrograph A, Fig. 26, shows the microstructure at the position C of etching B, Fig. 25. Photomicrograph B and C, Fig. 26, show the nature of the iron in the vicinity of the blow-holes, the pale granules and brownish-black patches being sulphide of manganese and oxide of iron respectively. The actual sulphur content at the segregation of this sample was 0.67 per cent. against 0.063 in the rest of the cylinder.

FIG. 25.

This examination points to the entrance of scum from the ladle into the mould, entrapped by port cores functioning as skim gates. The remedy is self-evident, and lies either in the use of bottom pouring ladles or a larger and deeper pouring dish which will permit the scum to rise to the surface, or by casting vertically and flowing some metal off through one or more risers.

Design.

Having considered design in its relation to moulding principles and the metallurgy of cast iron, we may now proceed to the general aspects of the subject.

A well-designed casting might be said to be one that can be made commercially and whose sections are no thicker than is essential to the desired unit of strength and which are evenly proportioned so as to avoid local slow cooling.

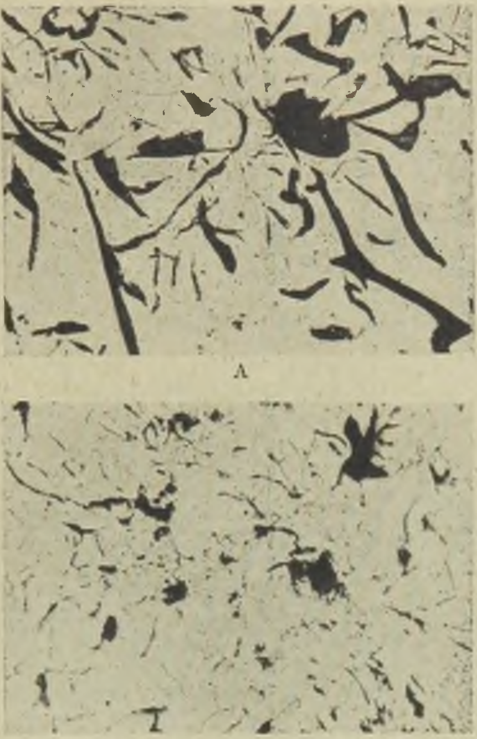


Fig. 26.

Design and Economy.—From the engineer's point of view, a design that will save machining, fitting, handling and weight is desirable, but considered without a knowledge of the metallurgy of cast iron, moulding methods, difficulties and cost, defeats its own end and may prove more costly in the long run. The cheapest design is that which presents least difficulties and risks in manufacture. Cylinder castings, however, are never simple, and cut prices do not assist in the successful production of sound cylinder castings. After deducting establishment charges, cost of metal and profit, the common procedure with cut prices is to barter with the moulder and core-maker to accept that figure which may be left for them. Cylinder moulding requires a consummate skill and conscientious workers who will give the closest attention to the minutest details. These qualities are not to be obtained from either dissatisfied or incompetent men.

C

Fig. 26—*cont.*

Design and Evolution.—One cannot overemphasise the importance of a closer active co-operation between the engineer and the foundryman. Where old designs have been modified to meet new and more stringent conditions, overhaul in the light of recent foundry research would well pay for the time and trouble expended. Recently the author was consulted in the manufacture of a superheated steam locomotive cylinder of a somewhat complex design, which gave trouble to all the foundries that attempted manufacture, whilst some of the cylinders that passed inspection cracked after short service. The cylinder design was old and had evolved to meet modern conditions. After modifying the section of the ports, removing unnecessary ribs, bosses, drain-holes, flanges and an anti-vacuum valve passage, which was attached to the steam chest, but which was not used, commercial manufacture of reliable cylinders became possible.

Modern Design.—Freaks of this nature, however, are still encountered in new designs, and castings are requested daily in which no consideration has been given to strength (other than that of assuming cast iron to be an unreliable material of construction) or to venting and removal of cores.

Grey cast iron is a material that may either expand or contract on solidification, but which under normal conditions of manufacture expands. The placing of large masses of metal, therefore, at the top of the casting for feeding purposes—a desirable feature in the designs to be made in steel, brass or other freely contracting alloy—is to be avoided. Cast iron cannot be fed in the same way that steel can, and feeding heads placed on thick sections of iron castings to attempt to eliminate draws aggravate rather than minimise the defect. For this reason, heavy masses of metal or various sections conjoining, if essential in the design, should be placed somewhere within the casting, proportioning the sections so that there is a gradual change in their thicknesses, and so that a free flow of metal will be obtained. Where the sectional changes are abrupt and not uniformly proportioned, one portion of the metal will remain fluid and feed those sections which freeze first. These designs necessitate the free use of mechanical chills, which, setting up undue stresses through cooling strain, are a common cause of premature cracking in service.

Conclusion.—In concluding, the author wishes to state that this Paper has dealt only with one phase of the cylinder problem. It has essayed to show that successful practice of the art of cylinder manufacture can only be expected when the scientific principles involved are understood, when there is the right combination of art and science in manufacture, and when the foundryman and engineer understand and recognise each other's sphere in the production of the casting.

DISCUSSION AT COVENTRY.

The President (Mr. C. Dicken, M.I.M.), said Mr. Smalley was a well-known figure in the metallurgical and foundry world, and had given them a most interesting lecture on foundry and cylinder problems which was particularly practical and instructive.

A visitor remarked that Mr. Smalley had mentioned the use of steel shot for overcoming porosity. Could he give details as to how the shot was to be used? He took it that the lecturer meant it was used in facing sand in some way, and an explanation of the point would clear up some doubt in his own mind as to the method of dealing with shot in sand.

Mr. F. H. Hurren confessed that he had learned much from the lecture, and, referring to steel shot in sand, asked if Mr. Smalley had ever found any difficulty with the shot owing to its uniting itself with the casting. That was to say, the heat of the metal caused the shot, at any rate on the surface of the core, to adhere to the casting. He had some painful recollections of trying chills on cast iron on several occasions, and at times the chill became an integral part of the casting, with the result that the entire lot had to be consigned to the scrap heap. The figures that Mr. Smalley gave on the screen as to the effect of moisture on the bonding of sand somewhat astonished him. Very often it was the practice in foundries to allow the labourer to wet down the sand, but it appeared to him to be a job for scientific application, as the lecturer had plainly shown. The very small differences in the percentage of moisture were, he noticed, accompanied by a marked difference in permeability, and he thought that if anyone worked on the lines indicated by Mr. Smalley, they would find that a green-sand mould could be made which would stand up a great deal better, and, as the lecturer said, save the trouble and expense of drying. If he understood Mr. Smalley rightly, there was one point on which he did not agree with him, for he gathered that he said Brinell hardness was no indication of the life of a cylinder. For many years they had taken at his firm's foundry Brinell hardness numbers on different portions of the casting for cylinders, and they always took particular Brinell numbers on particular parts. The result was that they found two things: first, that the Brinell number was an indication as to whether the machinist was coming down to grumble about the casting being too hard; and, secondly, that when the Brinell number was low, they would probably meet with a complaint from the customer some months later that the cylinder was wearing badly. They endeavoured from years of test experience to keep their Brinell numbers within a certain range, and whilst they did this they invariably found that they could obtain a cylinder with a fairly long life. He would not say the test was a complete indication of the life of a cylinder, but it did give some knowledge as to what one might expect.

THE AUTHOR'S REPLY.

Mr. Smalley informed his audience that the use of steel shot had been confined to cores only. The quantity necessary is determined by the rate of cooling desired. Where a small hole is to be cored out of a large mass of metal, the core should be made entirely from steel shot, bonding with any well-known core oil such as linseed oil. Where such rapid cooling was not necessary the steel shot may be mixed with sea-sand or a moulding sand in any desired proportion. He could not give definite heat-conductivity figures for the varying proportions, but some idea could be readily formed by assuming the heat-conductivity of the steel shot to be 12 times that of sea-sand. In the use of this material it is important to keep it free from rust. It may be separated from the sand by passing through a magnetic separator or by jigging. Answering Mr. Hurren, the lecturer said he had not experienced any difficulty from the metal burning on to the steel shot or on to the ordinary solid chills. He recommended the use of a graphite, or graphite-china-clay mixture as facing mixed with kerosene. Chills should never be made from a low melting-point phosphoric iron, or trouble will be encountered from seizing.

The Brinell Test.

Possibly, Mr. Hurren had misunderstood his remarks regarding the Brinell test. He did not say that the Brinell test was of no value in determining the life of a cylinder, but that it was not a measure of tenacity hardness or hardness as is generally understood by the term. It was not a test that could be used universally as a standard measure of the life of a cylinder in service. It was, nevertheless, useful for control purposes in individual foundries. It afforded useful information on the texture, solidity and machinability of cast iron. In reply to Mr. Judd, regarding the design of a pyrometer for measuring the temperature of cast iron, he would refer him to a pyrometer, full particulars of which were given in the "Proceedings of Institute of British Foundrymen," 1921-22, page 698. This pyrometer had been in daily use for three years, and the total cost of upkeep was less than £10.

DISCUSSION AT SHEFFIELD.

The President (Mr. John Shaw) mentioned that Mr. Smalley's position as a technical adviser to a large concern made it necessary that he had not only to discover defects, but he had to put them right.

Aluminium and Blow Holes.

Mr. Robinson said he (Mr. Robinson) had encountered blow holes which were not blamed on to the sand. He would like to know whether the lecturer had ever come across blow holes in castings which were ascribed to a small percentage of aluminium in the iron. At the present time this was a thing in which he was particularly interested. The percentage had only been about 0.04 of aluminium in the iron. The lecturer had mentioned the structures of cylinder irons, and he had also given the compositions. Recently he had been in conversation with a fairly high authority in the Midlands with regard to cylinder irons for motor work, and he recommended a fine-grained cylinder iron, but if they had to produce such a structure by reducing the phosphorus content by using hematite it would be difficult to make them mix thoroughly and at the same time to give the fine grain necessary for cylinder castings. During the war foundrymen were all more or less up against a specified phosphorus content in the composition of cast iron supplied for war measures. In order to get that down it was always necessary to use either a certain amount of steel or hematite in the mixes. This question had cropped up, whether by mixing a large quantity of coarse-grained iron in the shape of hematite with a cylinder iron which had a higher phosphorus content than was required, it would mix and produce a suitable cylinder grain. A lecturer at Coventry had stated that between 0.3 and 0.8 per cent. phosphorus gave a greater danger zone than when it was below 0.3 and above 0.8 per cent. With regard to one of the specimens shown of the running of locomotive cylinder castings, he once had charge of a shop where they were making locomotive cylinders, and they were all cast on the flat. They never had one returned. He was very much more in favour of running them straight down, and not, as the lecturer said, running part in at the bottom and part at the top. Mention was made with regard to milling sand and permeability. Had Mr. Smalley any experience with regard to the milling of sea sand and oil? Did he consider there was any damage done by milling it, and would it have a detrimental effect on the permeability?

Strength to be Associated with Thin Sections.

Mr. Evans, referring to the question of design, pointed out that getting a thicker casting did not strengthen it. In fact, in many cylinder castings they could take off 30 per cent. of the weight and get a stronger casting. If some of the difficulties of the foundryman were understood in the drawing office much of their trouble would be overcome. He thought the castings were better run through quickly.

Mr. Edginton, speaking of L. P. marine engine cylinders, thought that slow running would be detrimental. With regard to the chaplets, views of which the lecturer had shown them, he thought it was a question of the temperature of the metal run into the mould, whether they obtained a proper weld of the chaplet. If the metal was run fairly cold, one could never hope to get a tight welding round the chaplet. The lecturer had shown a slide of a locomotive cylinder which had been run horizontally, with the trouble that dirt gathered round the port cores. That trouble occurred when they were run vertically, the only difference being that the trouble appeared lower down in the bore.

Mr. Green thought that slow running and dull metal was one of the worst things that the foundryman had to deal with.

Flat or Vertical Casting for Cylinders.

Mr. Webster said that, so far as cylinder making went, casting them on the flat, he would be inclined to say that with hot melting and hot pouring there was not very much more risk than there was in any ordinary engineering casting that required to be of good finish. Had Mr. Smalley had anything to do with 20-in. dia. piston valve loco. cylinders? If he had, which way would he cast them, how would he run them, how would he propose to feed them, and what were the common difficulties generally met with?

Co-operation.

Capt. Didden, speaking more as an engineer than a foundryman, said he would like to see more co-operation between engineers and foundrymen. His own experience, both in Europe and in America, had been that there had not been anything like the co-operation between the two that there should be. It was rather interesting on this point to recall a Presidential address by Sir John Durance a few weeks ago, in which he made that same remark. Coming from a man of the calibre of Sir John, and being mentioned that night by Mr. Smalley, it showed the tendency to-day that engineers and foundrymen were beginning to realise that there should be greater co-operation. One thing that Sir John mentioned was that most of the apprentices in the engineering trades to-day did not go into the foundry as much as they should do. They worked by rule of thumb laid down by their predecessors, and they knew very little of the actual foundry conditions. A boy in the engineering trade had a superficial knowledge of what was going on in the foundry, but 99 per cent. of the apprentices could not answer if they were asked the reason certain things were done. In the future it should be laid down as part of the curriculum that engineer apprentices should have a course in the foundry. This would give them a sound knowledge, so that as engineers they could appreciate the many difficulties which foundrymen had to meet.

Casting Temperature for Loco. Cylinders.

MR. PEMBERTON remarked that Mr. Smalley had told them some of the methods of eliminating difficulties, but he was not quite sure whether they were altogether practical of accomplishment in the foundry. One of the points raised was with regard to the Brinell hardness test. He understood Mr. Smalley to say that this did not indicate the life nor the hardness of the casting. What did it indicate? He would like to know the correct temperature at which to run a locomotive cylinder.

THE AUTHOR'S REPLY.

In reply to Mr. Robinson, MR. SMALLEY said he did not see how 0.04 per cent. aluminium could be blamed for the blow-holes referred to. Until further information was forthcoming with regard to the composition of the iron and the mixture used in the cupola, it was impossible to make any further remark. With regard to the milling of sea sand and core-oil, his experience was that, provided a light mill was used—the time of milling was less than five minutes—there would be no ill effects.

Permeability and Strength of Moulding Sands.

In reply to Mr. Evans regarding moulding sand tests, *permeability to gas and strength should* go hand in hand. It was usual to find the bonding strength was increased at the expense of the venting power. The only method to obviate this and obtain the desired combination of bonding strength and permeability was by testing the sand in the manner outlined. As to "rate of running," he thought Mr. Evans had misunderstood him. He did not advocate either slow or quick running of cylinder castings. The terms permitted too wide a latitude in their expression. He had shown them on the screen certain results obtained from a complex casting when every variable had been eliminated, as far as was practical, except the "rate of running," which is an important factor in the control of the "solidity or soundness" of cylinder castings, one that must receive due consideration. Without taking precise examples, it was very difficult to say whether a cylinder mould should be filled quickly or slowly.

Vertical Casting Preferred.

Answering Mr. Edginton, the lecturer said that casting cylinders vertically was, on the whole, preferable to casting flat, owing to metal having a freer flow and to there being less chance of trapping scum. Should any difficulty be encountered with the latter he advocated bellying the barrel core at the ports, or passing a riser through the port to the head of the casting. Neither of these should be necessary if the metal is melted correctly, poured hot, and the casting is suitably run. If with these precautions the design is such as still to give trouble, he recommended the use of a bottom-poured ladle.

Answering Mr. Green, Mr. Smalley said that he used chill-cast pig-iron for the reasons outlined in the Paper. Such iron is also cheaper than sand-cast pig-iron, and is more economical in use.

Science—Not Chemistry.

In reply to Mr. Webster, the lecturer said that unless the moulds could be prepared from day to day with a certain assurance that similar conditions were being reproduced, he could not see how it was possible to avoid making bad castings. He had suggested sand tests and a control of other factors to this end. If Mr. Webster had such a control of those factors, although he could not figure it out in technical terms, then his castings were assured, and he had in his foundry *scientific control. Science is too commonly associated with the chemist*, a being often learned in many theories which have not been proved. *Science is knowledge*, *and the aim of science is to reduce manufacture to a precise basis.* With regard to the cylinders referred to, he always cast that type vertically, running from the bottom quickly until the mould was nearly full, then he opened three top jets, spaced equally round the flange. He did not advocate a feeding rod but preferred to adjust his risers so that they could automatically feed or counteract any draw that might occur. At the heavy section above the ports he used chills. He agreed with the remarks made by Capt. Didden with regard to the training of apprentices, and considered it to be one of the most serious problems of to-day. In reply to the question by Mr. Pemberton as to the best temperature for casting locomotive cylinders, he said that the range he used was 1,325—1,340 deg. C. With regard to the Brinell test, he suggests that this measures solidity and not hardness as is ordinarily understood by the term.

A resolution of thanks was accorded Mr. Smalley.

Joint Discussion at Newcastle with the N.E.C.I.E.S.

Mr. Harold Thomson (the Chairman), opening the discussion, touched upon the necessity for further scientific investigation into the art of producing sound castings, and said he thought that Mr. Smalley's Paper had gone a long step in that direction both with regard to cylinders and other castings. He supposed that the experience of most people was with the castings after they had been delivered to the shops, but now they had heard the foundry side of the question. He would like to know what the lecturer would suggest, from the foundryman's point of view, as a substitute for the Brinell hardness test.

Mr. A. D. Bruce (M.N.E.C.I.E.S.) agreed with Mr. Smalley that, in a certain sense, the engineer did not give much practical assistance. In looking at the question from the engineer's point of view, however, he felt that perhaps Mr. Smalley had given the designer a subordinate position. In the case of marine-engine-cylinder castings, he thought that many of the improvements in reliability had resulted from alterations in design, but he had no doubt that much of the inspiration that the designer had got had come from the metallurgist and the foundryman. Mr. Smalley had mentioned that a well-designed casting was one whose sections were no thicker than was essential to the desired unit of strength, and he (Mr. Bruce) would like to know what the desired unit of strength was. He would like to have the author's views upon Muirhead metal and to know its composition, and he would also be glad to have his opinion upon the value of annealing.

Is Special Pig Necessary for Good Castings?

Mr. W. J. Paulin said that the author naturally endeavoured to make a good case for the scientific control of the foundry, but one wondered whether it was any longer necessary to press that point.

Mr. Smalley had mentioned the milling of sand for dry sand moulds, but was that not rather an uncommon practice, and did it not tend to diminish the ventilation?

He did not understand Mr. Smalley's remark that very few managers and foremen would guarantee their castings, because, of course, the firm must guarantee the castings, and it was difficult to see how the foreman could escape doing so, at least by implication.

In speaking about cupola-melted grey iron, Mr. Smalley had referred to the selection of pig on the basis of chemical composition, but he (Mr. Paulin) presumed that it would be impossible to analyse every pig, and therefore they must judge by the relative appearance of the fracture of the neighbouring pigs at the time of analysis.

Mr. Smalley had stated that he prepared a special pig-iron in chill moulds, but did he consider this necessary to the production of good castings? He (Mr. Paulin) thought that it would be difficult, in these days of keen competition, to secure work on such lines.

The lecturer had shown some varying tensile strengths obtained from the cylinder iron of different thicknesses. The most important feature controlling the tensile strength was undoubtedly the variations in rate of cooling, for would it not be more uniform throughout with approximately simultaneous cooling?

Mr. Smalley had said that mechanical chills were a common cause of premature cracking in service.

His own experience, however, was different from Mr. Smalley's, and he had used chills with perfect confidence in the knowledge that he could secure great freedom from porosity and open grain. They now used semi-steel for the production of small cylinders, and it had been markedly successful on account of its close grain and the good polish that could be obtained, and also because they could use chills on heavy bosses and get good results. It would be interesting to hear Mr. Smalley's views upon the use of semi-steel for cylinders.

American Locomotive Cylinders.

Mr. J. W. Hobson (M.N.E.C.I.E.S.) said that American locomotive cylinder designs were much more complicated, but he could not say definitely that they had less rejections than the British. He understood that the American cylinders were softer than the British, being cheaper in machining operation but not having the lasting qualities in service.

The author had referred to his experience in the case of a certain cylinder of old design which had been altered to meet modern conditions. He (Mr. Hobson) also had had experience with that design, but, fortunately, they had not experienced the extreme difficulties described by the author, although the additions to the original design undoubtedly added to the difficulties of founding. Their usual procedure in the case of new designs or modifications was to bring the designer, the patternmaker and the founder together for a discussion before issuing the working drawing and making the patterns, and he thought that this fact might be responsible for their success.

On the motion of Mr. C. Waldie Cairns (Vice-President, N.E.C.I.E.S.), a vote of thanks was unanimously accorded to Mr. Smalley for his Paper.

The Moulder and the Scientist.

Mr. H. J. Young (member) wrote:—The major difficulty of anyone whose duty it was to apply science was that of expressing his opinions in such terms and in such manner as to make them forceful and, at the same time, palatable to those whose education and experience had been in other directions or upon a lesser scale.

It was unfair to blame the moulder for a failure if there was no convincing evidence that the fault was his. The possibility of obtaining a sound casting did depend, and ever would depend, partly upon past experience and partly upon chance. What success in this world did not depend more or less upon these two factors?

It was untrue, as a general rule, to say that science or any innovation was deeply resented by the moulder, and resentment of this kind was generally due to the scientific man's lack of understanding and appreciation of the practical man's point of view and personality.

The author complained that the foundryman was very reluctant to change his raw materials if those in use were giving satisfaction. That was an extraordinary charge, because, even if a material was no better nor worse than another, it did not follow that the man accustomed to working with the one would meet with equal success when he changed over to the other. The reluctance complained about by Mr. Smalley therefore was often a blessing in disguise, and prevented the indiscreet adoption of " gambles."

After criticising the empirical methods of the moulder, the author said:—" It was remarkable that good castings were still being produced from such empirical data, and (it) spoke highly for the skill of the moulders." It spoke just as highly for the empirical data as for the man using it that good castings were so produced. Mr. Smalley condemned the methods devised and used successfully by the man he applauded.

The moulder's experience was not founded upon sand, even though the castings were, and nothing Mr. Smalley might say could detract from the wonderful methods built up by the moulder on empirical reasoning. Much remained for science to do, but it must have respect for the knowledge of the practical man, and it must be willing to co-operate.

Do Two Similar Irons Exist?

Whilst agreeing with what the author had said about graphite, he (Mr. Young) could not, for one moment, agree that it was common to obtain from two irons of similar chemical composition, cast under identical conditions, widely different mechanical properties, because he had seen no proved instance of this phenomenon in any two normal grey irons. Out of thousands of analyses of test bars, taken over years of practice, he possessed but one or two bars of precisely similar composition, and his records went to prove that when two bars were almost alike in composition and in cooling conditions, so were the tests almost alike. He was not referring to pig-irons or crucible irons, but merely with regard to cupola metal as used in commerce.

The two pig-irons shown in Fig. 9 had very different carbon contents, and therefore would behave differently. If the author's contention is that the difference lies in the fact of one being a sand-cast hot-blast iron and the other a cupola-melted chill-cast, then he could not agree with him. Two equally clean pig-irons of similar composition would give similar results, no matter how the pigs have been produced—but possibly the author holds the same views.

Mr. Smalley's remarks about phosphorus in cylinder castings were interesting and valuable, and what he said about scum and its identification confirmed what had been pointed out by Mr. Wood and the writer.

The author knew full well how much he (Mr. Young) had appreciated his work in the past, and it was with regret that he now criticised adversely Mr. Smalley's attitude as a works chemist dealing with men of lesser education than himself—men who made no pretence of a knowledge of science, who did not know what science was. It was up to the chemist to show him, not to fight him.

Mr. Mills wrote referring to Mr. Smalley's remarks as to a superheated steam loco-cylinder, and expressed the view that it was true that the design was in need of improvement, but successful castings had been made without the modifications suggested by Mr. Smalley.

Some locomotive specifications demanded that the metal to be used in casting cylinders must be seven times poured. Will Mr. Smalley give his opinion as to whether this would break up the large graphitic structure shown in Fig. 9 (*a*), or whether chill moulds were essential? Also would the use of chill moulds eliminate the expense of the specified procedure? The author appeared to have been very successful with metal cast to the American specification; indeed, local experience of American cylinders suggested that he had been more successful than the American manufacturers themselves.

THE AUTHOR'S REPLY.

Mr. Smalley, in reply to Mr. Harold Thomson, said that the Brinell hardness number of cast iron did not bear a direct relation either to the chemical composition or rate of cooling during solidification. It was questionable whether the test gave any information as regards the wearing properties of cylinders or liners. It was of value in individual foundries running certain known mixtures from day to day, and afforded useful information on the texture, solidity and machinability of cast iron.

A test used by the author for measuring the wearing properties of cast iron was to run a small cylindrical test piece—cut from the casting—in contact with a hardened steel plate, which was made to revolve at a speed bearing some relation to the running speed in service. The test piece may be loaded on to the rotating plate to any desired pressure.

In reply to Mr. Bruce, Mr. Smalley said that Muirhead metal was a refined pig-iron which was supplied in various grades. The following was a typical analysis:—Graphite, 1.21; comb. carbon, 0.65; silicon, 1.32; manganese, 1.31; phosphorus, 0.091; and sulphur, 0.072 per cent. The principal feature of this iron was the low total-carbon content. In this respect it differed from ordinary hot-blast pig-iron, and enabled a better control of the graphite content in the finished castings. For melting in the cupola the ordinary cold blast iron was favoured because of the superiority of its property of blending with other irons and because it would carry greater quantities of domestic scrap.

Annealing Cast Iron.

The strength of cast iron should not deteriorate by annealing if that was correctly performed. An investigation into the question showed that ordinary cast irons retain a good strength at temperatures up to 900 deg. F., and that the strength was little affected by annealing the casting at about this temperature, which was sufficiently high to remove casting strains.

An annealing temperature of 1,100 deg. F. was urged by some authorities. The fall in strength, after soaking at this temperature, would be determined by the time factor. If the period of time be extended or the furnace temperature not under accurate control, the cylinder might lose more than half its original strength and increase considerably in size. The growth of cast iron was however, closely related to the rate of cooling; for this reason annealing should always be followed by a slow cooling.

In reply to Mr. Paulin, the author insisted that science must help the foundryman to find out the physical properties of his raw material, but this did not imply that good castings cannot be made without technical control.

How to obtain Maximum Strength in Cast Iron.

With regard to the milling of sand for dry sand moulds, most foundries did this. Over-milling was certainly derogatory to the venting capacity, but sand, like steel, was a raw material whose best properties could only be obtained after correct treatment.

In reply to Mr. Paulin's reference to the guarantee of castings, there were few foremen who were able to guarantee the first casting of a new design. It was not uncommon to see the first few castings scrapped, and yet the company must guarantee a specified number of sound castings. It was the difference between the number of castings made and the number delivered that determined the efficiency of a foundry.

Mr. Paulin's experience with the variation of the composition of ordinary hot blast iron confirmed general experience, and, as he remarked, one cannot test every pig; moreover, fracture was not a reliable guide. It was for these reasons that the author found it profitable to prepare special cylinder irons to a precise chemical composition. The extra cost incurred in manufacture was more than counterbalanced by the saving effected from consistent production of sound castings.

With regard to Mr. Paulin's query about varying tensile strengths obtained from iron of different thicknesses, the author referred him to his Paper "Cast Iron and Mass Effect." In this research it was shown that there existed for each grade of cast iron a minimum rate of cooling, which yielded, within practical limits, the same grain or density, regardless of section or dimension of the casting when poured with a suitable degree of superheat. Consequently, by speeding up solidification to this critical rate of cooling, the tensile strength would be more uniform throughout, irrespective of the dimensions of the section.

Behaviour of Chills.

In part, this answered Mr. Paulin's query regarding the use of chills. Where chills could be arranged so that the rate of cooling of the heavy section was speeded up to that of the lighter, chilling can neither cause internal strains nor machining difficulties. In many designs the change of section was abrupt, and iron or steel chills on the heavy sections were fraught with danger. If slightly over-chilled at the junction of the heavy and light sections, the iron was white and liable to sudden cracking in service. If the chills were placed so that a uniform rate of cooling was obtained, stresses would still be set up at the junction of the chill and sand. Experience with chilled Diesel liners had proved costly.

On the other hand, irons having a wider margin between the white and grey conditions permitted a wide latitude in the use of chills. For instance, the central core of the ordinary marine-engine piston may be made in iron or steel without risk. The chilling effect of this core was such as to closen the grain without affecting the machining properties, whilst there was little or no danger from casting strains.

Defects of Semi-Steel.

In reply to Mr. Paulin's query regarding the value of semi-steel for cylinder castings, semi-steel was a material that could be claimed to have gained international reputation. Its successful use seemed to be restricted to those familiar with the fundamentals of scientific melting, who understood its casting peculiarities and who were not beset by foundry prejudice. The principal difficulties with semi-steel were its ready oxidation during melting, affinity for sulphur and short fluid life.

For cylinder castings 5 to 40 per cent. of steel might be used, according to the result desired and the class of cylinder made. For castings of complex design the author found that the best results were obtained from 15 to 20 per cent. The quantity, however, was a variable determined by the cupola practice and pig-irons used. Phosphoric irons low in manganese, and basic irons should be used sparsely; hematite and pig-irons low in total carbon and phosphorus and high in manganese were preferred.

In reply to Mr. Hobson, the author said that the assertion made by older railway engineers "that owing to softer castings they could not get as long a life out of cylinders as used to be obtained," surely requires some modification. The higher steam pressures and service conditions of the modern locomotive scarcely permitted a comparison of the cylinder of to-day with that of, say, fifteen years ago. It was true, however, that little was known of the relative wearing qualities of cast iron, and it was here that the engineer could assist the metallurgist.

The Bureau of Standards in America had already done much good work on these lines. So far the results showed the harder cylinder to have a longer life than the softer, but from the high percentage of softer cylinders which had given better service and had a longer life than the harder, no definite conclusions could be drawn.

The procedure adopted by Mr. Hobson with regard to new designs of co-operation of designer, patternmaker and founder before issuing the working drawing and making patterns, presented the solution to many of the common troubles of cylinder castings, and was the safest method for economic production.

The Roll of the Skilled Moulder.

In reply to Mr. Young's correspondence, Mr. Smalley wrote that the contention that the manufacture of a casting must always depend upon the moulder's experience and chance was the surest way to bring a foundry into the bankruptcy court that he knew. According to Mr. Young, if the moulder had not the experience, he must take the chance, and the chance would be a bad casting.

Mr. Young's comments on sand testing were unfair. Sand tests had a practical value. Mr. Young referred to a gamble in the changing of raw materials for something better and cheaper. Unless a foundryman testing those raw materials, and knew what they were capable of and how they were to be treated, how could their economic value be determined? Sand is a raw material whose best properties were not obtained in the raw state, and it required special treatment. To make a casting without a knowledge of those physical properties was surely a gamble. To understand and control the properties ot sands was the only way he could suggest to place manufacture on a sound basis.

In a certain foundry in America 8,000,000 cylinder castings were made per annum without the assistance of any skilled moulders. In this foundry the sands were specially prepared, tested and controlled in a department for that purpose. Many more examples could be given both from this country, the Continent and America, of castings made without "the aid of the wonderful methods built up by the moulder upon empirical reasoning."

When are Test Bars Alike?

In regard to Mr. Young's criticism on the chemical composition and the physical properties of grey cast iron, if Mr. Young had made so many thousands of test bars and never met the phenomenon referred to, it would be futile to quote figures that he had obtained to convince him. He wrote: "The whole of my records went to prove that when two bars were almost alike in composition and in cooling conditions, so were the tests almost alike." The word "almost" is vague. If he had not met the phenomenon, why were the tests not exactly alike?

To prove mechanical suspension of graphite in molten cast iron, Mr. Young should investigate the effect of casting temperature on graphitic irons. If, as the carbide theory suggests, molten grey cast iron was a true alloy, *i.e.*, all the graphite was in solution, then the bars cast hottest should be the weakest. In normal cupola practice he would invariably find that casting hot gave the best test results

In reply to Mr. Young's final paragraph, he had never occupied the position as works chemist in a foundry. Mr. Young, however, was quite correct in saying that the works chemist must not fight the moulder, his duty being to test raw materials and deliver good metal.

Multiple Remelting Inefficient.

In reply to Mr. Mills, Mr. Smalley wrote that at this juncture of the foundry industry the fact must not be lost sight of that perfect metallurgical control was not yet accomplished in all foundries. It was admitted that any casting could be made solid without assistance from the designer, but such practice would prove costly to both the founder and the engineer. Valuable assistance might be rendered by the designer's avoiding abrupt changes in section by proportioning his sections so as to obtain a uniform rate of cooling, and by appreciating the fact that the thickening of a section did not necessarily add to the strength.

In reply to the query regarding the use of cylinder iron that has been seven times poured, this is a practice which could not be recommended because of cost and uncertainty of the results. If melting was repeated seven times the original characteristics of the iron might be so changed that the process might prove more injurious than beneficial. As 6 per cent. by weight of the total quantity of iron melted was lost each time the iron is melted in the cupola, and as the desired chemical composition could be produced from a single melt there was nothing to be gained by repeating the process. If the iron was prepared to such a specified chemical composition, chill cast pigs were not essential. It was only when high proportions of a soft iron having a coarse graphite structure were used in the preparation of a special cylinder stock iron that chill cast pigs are recommended. Apart from the physical form of the graphite, however, chill cast pigs recommended themselves because:—(1) The preparation of a chill bed costs less than half that of the sand bed; (2) the absence of sand and oxide ensures a cleaner and more fluid iron; (3) they save labour in breaking and handling; and (4) being uniform in form and of small dimension, it is possible to increase the cupola capacity and reduce the coke consumption without affecting the temperature of the metal.

He was at a loss to understand Mr. Mills' reference to the American cylinder specification. He neither referred to this in his Paper nor did he use or advocate American cylinder mixtures.

Birmingham Branch.

SOME NECESSARY ADJUSTMENTS BETWEEN THE FOUNDRY AND DRAWING OFFICE.

By E. Ronceray, M.I.Mech. E., Hon. Member, Paris.

[The Branch-President (Mr. J. B. Johnson), before calling upon M. Ronceray to give his lecture, expressed his pleasure at seeing so large an attendance in honour of their distinguished visitor. There was no man in the ironfoundry world, he said, whose name was better known. From time to time M. Ronceray had provided them with original ideas on certain aspects of their industry, from which they had derived great benefit. The results of his researches had been freely placed at their disposal. They were also honoured by the presence of Sir William Mills, the pioneer of aluminium founding in this country. He would ask Sir William to supplement the welcome which he had expressed to M. Ronceray.

Sir William Mills said those who had had experience of aluminium casting would appreciate his difficulties as the pioneer of the industry in England. His difficulty was with the men, who wanted to do the work in exactly the same way as though they were dealing with iron or brass. Some of the patterns he received were almost impossible to cast, and he was told by many steel casters that they could not be done. But they made the castings somehow in aluminium. In some instances he asked for a slight modification in the pattern, and occasionally his request was acceded to, but in most cases he was told that if he did not cast what had been designed the orders would be placed elsewhere. During the war his firm produced nearly all the Puma engine castings, which amounted to a very large number, and they had great success with them. The explanation was that Mr. Siddeley used to submit the tracing and ask what alterations they desired to make, so that there should be no trouble after the castings were made. That was a practice that might very well be generally followed.]

The title refers to a very broad subject, and it is impossible to survey it completely in the course of one Paper. However, there are a few points that can be usefully discussed for the common interest of both foundryman and engineer.

Their respective claims tend to show that they are not quite satisfied with each other. The foundryman maintains that the engineer, who has no knowledge of the foundry trade, designs unnecessarily complicated shapes, badly proportioned, difficult to turn out in sound and strong castings at a reasonable price.

The engineer complains that the castings he is supplied with are unsound, full of blow-holes or porous, rough in appearance and expensive.

Both are right to a great extent, and it is a curious fact that when an attempt is made to adjust the differences it is very difficult to bring either of them to proceed from the general to the particular; in other words, both of them maintain that the other is wrong, but are unable to say how and where, and to make definite suggestions for bringing about improvement.

The following is an attempt to make a small step in the right direction. It is the result of a few years' study of other peoples' researches, also of personal deductions and experiments of a modest engineer who has become a modest foundryman. It is a great pleasure to him to bring the earliest communication of his work to the Institute of British Foundrymen in Birmingham where he has so many friends, and where he delivered two years ago a lecture which started the ball rolling for the international study of new methods of testing cast iron and where he had the honour of being elected honorary member of your great Institute.

The Requirements of the Engineer.

In short, the engineer wants an abundant supply of sound and strong castings, of good appearance at a reasonable price. To give this to the engineer the foundryman requires from him a good design, simple forms, and equal thicknesses.

It is when the details are worked out that the differences start, the exact requirements not being defined. The common knowledge necessary to both engineer and foundryman will probably be scheduled some day, and the author is doing his utmost to start the work in the Paris Foundry High School of which he has the honour to be the Director of Studies.

But this work, similar to what Monge did in laying down the rules of descriptive geometry from the information he obtained in studying the practice of the builders of past centuries, will take a long time.

To be satisfactory, a casting must *primarily* be *sound*. It is rather easy to make it of strong iron, but it is useless if it is not sound. On the other hand, being sound and made of strong iron, it is useless if there are *internal strains* that bring some parts of it near the breaking point. So there are three main points to consider:—Internal strains, soundness and strength.

Internal Strains.

It is a great pity that there is up to now no practical way to detect internal strains in castings. There are perhaps hopes that this will come one day; however, this day is not yet in view. But there are at our disposal several ways to reduce internal strains to a minimum, some of them by the engineer, others by the foundryman.

To reduce strains the engineer can design his castings with thicknesses as regular as possible, avoiding abrupt changes. He can also, when he requires different thicknesses, have the castings cast even and machined out to get reduced thicknesses where he wants them.

In view of the same results, the foundryman can put his runners so as to pour the metal in the thinnest parts, thus reducing their tendency to cool quicker than the thicker parts; to fill the same purpose, he can put chills or denseners against the thick parts. He can also heat-treat them after pouring, or cool them slowly from a given temperature similar to the American chilled wheels which are remarkably strong.

He can also use when there are enclosed cores a special material, resin for instance, for avoiding undue resistance to shrinkage or else break the moulds and cores shortly after pouring.

But the engineer then must be expected to understand that these processes entail an increase in price. He must accept it and not try to cut down the cost price by starving the foundryman, but rather by judicious design and collaboration. He must also accept or even suggest chills or denseners at certain points of his castings providing they can be machined.

Soundness.

Unless they are very apparent defects the unsoundness of a casting is not generally detected until machining has brought it to light. Sometimes it is only found after complete finishing when a pressure test is made, and sometimes it is never found except when the casting is broken, either in service or when it is withdrawn from service.

The Real Object of Making Castings without Feeding Heads.

Unsoundness of a casting in many cases condemns it, especially when it occurs in a vital part. Where it occurs it renders useless the attempt that has been made to use a strong metal. It may be accepted only at unimportant points, and always casts suspicion on the other parts of the casting when it is discovered. The author has devoted much time to and has made some personal researches on this point, and his conclusion is that, in most cases, unsoundness in castings is more due to gas effect arising from insufficient permeability of sand rather than to the so-called draws, especially with iron castings. Previous Papers by the author on related subjects raised a good amount of interest even in Birmingham, where they have been discussed. Unfortunately, the question has not always been understood from the right point of view.

When advocating pouring without feeding heads it was not thought to promote any improvements by simply doing away with feeding heads or risers, the point being that the common use of feeding heads is almost always to correct a defect of the mould unknown to the moulder. In other words, it is supposed to feed a draw in a casting while in fact it fills quite another purpose. It masks the real trouble and provokes the use of wrong methods of curing it. Those interested may perhaps have read the author's Papers in the "Proceedings" of the Institute or in the FOUNDRY TRADE JOURNAL.

"Effet Leonard."

M. Joseph Leonard, Past-President of the Liège Foundrymen's Association, has thrown light on some very interesting points in several Papers and lectures. The defects mentioned are due to an intense production of gases at certain insufficiently permeable points of moulds which are highly heated by hot metal with the result that these gases, not being able to escape through sand, find their way through metal in leaving various sorts of defects: black spots, blowholes, porosities, etc. The author has called this phenomenon "Effet Leonard," and it is quite typical though very little known. As a rule, it is misunderstood, and taken as a draw. These conditions are shown in Fig. 3.

Finding black spots in motor-cycle cylinders of design shown in Fig. 4, M. Leonard thought they were due to gas effect of the type mentioned. To prove it, he used at the point under consideration, core sand, and took special care to vent it, when the trouble disappeared. He reproduced the trouble in a specially-designed casting of the shape shown in Fig. 2. The black spots appeared in the congested and unvented place and not in other places. It is easy to reproduce them or to avoid them by proper means.

There are very often faulty designs which could be improved by slight alterations resulting in increasing considerably the chances of getting a better casting.

For instance, a lathe foot or a bed plate (Fig. 10) which has a round flange (A) can be altered with great advantage to that shown at B.

On loco. cylinders bosses should be avoided where there are bolt holes (Fig. 9). When there is a loose boss on the side of a frame the design should be altered to make it one piece with the pattern, as a loose piece is always liable to move.

Definite Examples.

The author has fully demonstrated by numerous experiments how many defects that are usually attributed to other causes can be very simply cured by special attention paid to ramming and venting of restricted points. The troubles reappear again as soon as this *special attention* is no longer practised.

(A few samples were shown at this point.)

The conclusion of the above will be that the designer will do well to avoid such restricted points in his design. For instance, in a locomotive cylinder, instead of having a sharp-nosed piece of sand, shown at A, Figs. 1 and 11, the design should be altered to flatten it as at B, Fig. 11.

In a bed-plate or a surface-plate, ribs instead of meeting at an acute angle as at A, Fig. 5, the design should be modified to give that shown at B or C, Fig. 5.

In an automobile cylinder it is preferable to eliminate the acute angles rather in order to suppress the thin angle of sand, as shown in Fig. 6. Again, in an automobile piston instead of thin ribs meeting at different angles it is better to cut off all the ribs and round the corners, as shown in Fig. 7.

In castings having thin cores it is sometimes more advantageous to avoid such cores as they are strongly heated and difficult to vent properly.

When there are angles, as in Fig. 8, formed by a flange at the end of pipe, it is always advisable to round the corners and to form them with leather fillets rather than to let the rounding be at the discretion of the workman.

When there is an enclosed core the designer must provide for openings, if possible, at several places. When the moulding of a casting with such an enclosed core is to be made one must, whenever possible, provide the core print at the top, as it is always easier to protect it, and the escape of gases is much easier by the top of the mould than by the bottom.

The fact is now well-established, that for many metals there is no need for avoiding draws by

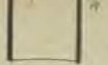


Fig 1

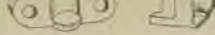


Fig 3

Fig 5

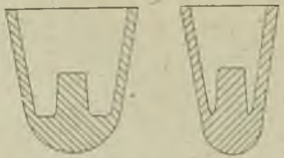


Fig 2

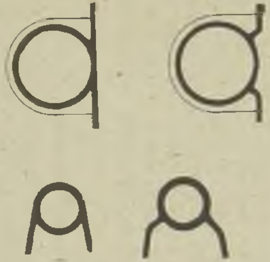


Fig. 4

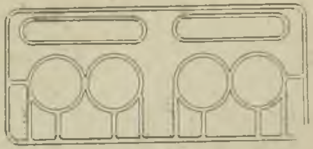


Fig 6

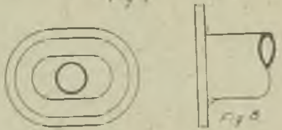


Fig 8

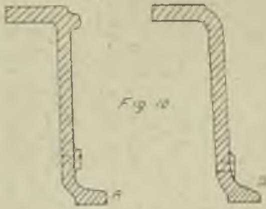


Fig 10

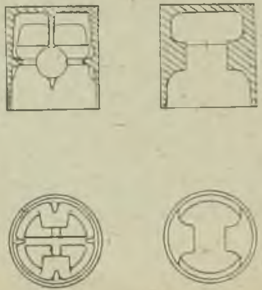


Fig 7

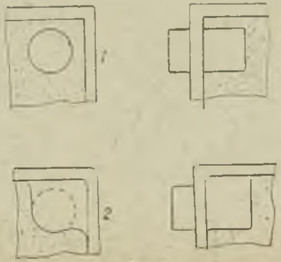


Fig 9

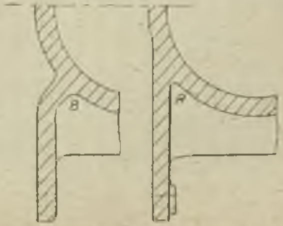


Fig 11

special feeding, and above all, there is no need of churning or pumping, especially for the ordinary thicknesses. That, as will be seen later, the engineer must try to conform to. A proper design and correct moulding are all that is necessary, and if such a course is followed there are more chances to get a sound casting than by processes involving the blind use of a remedy to poor design and poor work.

Other Factors.

Metal is not always clean when in the ladle, and attempts to clean it before pouring are unsuccessful in skimming every particle of slag. Slag in a mould introduces blow-holes where it stops, so that steps must be taken to prevent its entrance into the mould as much as possible.

There is always the necessity of avoiding the introduction of air with metal in the mould, otherwise what the author called "Custer effect" will take place. Custer has proved that when air is entering in a mould with sulphurous iron a reaction takes place which produces SO_2 (sulphur dioxide), causing blow-holes especially when the metal is not very hot.

The Importance of Runners.

On the other hand, speed of pouring must be regulated according to different cases. There are many ways of taking care of these necessities. Plug pouring is one of them. It is rather a common practice in this country. The use of tinned strainers is another one, and is very convenient on repetition work where the thickness of the strainer can be selected by experiment. These strainers and strainer cores used in America are satisfactory; however, the author prefers what he has called the "filter cores." They are simple discs of core sand, about $\frac{1}{2}$ in. thickness, in which a few holes about $\frac{1}{4}$ in. dia. are provided. These cores are simply laid down in the mouth of the runner with the cover and can be seen by the foreman. If the casting is a heavy one, several of these filters are used, one on each of the several runners fed by same basin. It is recommended to cover each of the filter cores with a disc of strong paper.

When the metal is poured the paper prevents the first drop, which may be slag, entering the mould. The metal fills the basin, slag rising to the top. The paper burns and the filling of the mould proceeds through the small holes of filter cores. No air can be drawn into the mould, thus avoiding "Custer effect." Of course, the metal must be very hot to use such a process, and this is a good help towards a sound casting.

Too much care cannot be taken to provide a clean runner. This point is very important and is rarely considered sufficiently carefully. Special attention is paid to the mould and much less to the runner, which, however, is the more important. The gates and runners must be exceedingly clean and special attention must be paid to avoid their scabbing and washing, and a stronger and more permeable sand must be used for this purpose. The filter cores, followed by large runners, go a long way towards the avoiding of sand washing as the speed of metal stream is reduced.

Whenever possible, the gating must be so made that the metal flows down in a well where the first metal is accumulated. The first metal protects the sand and prevents washing.

The design and patterns must be made so that whenever possible the machined parts are cast down and when a machined part is at the top of a mould it is always safe to leave at least ⅓ in. machining allowance. The reason is that particles of sand and blacking which may be washed up by the iron, and little drops of slag are always collecting at the top, where they are liable to make dirt and provoke blow-holes.

Strength of Iron.

Cast iron being the most commonly used material in engineering and the most affected by improper design will only be considered. In a written communication on Mr. J. Cameron's Paper* on Semi-steel, the author showed a graph representing Keep's curves as they appear in his book, "Cast Iron," with the only difference that the origin of ordinates is brought to zero, which makes it more intelligible than the graph of Keep, which started at 160. These experiments were suggested, it is thought, by the work of Pro-

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* See F.T.J., August 17 issue, 1922.

fessor Thomas Turner, who made the first researches on the influence of silicon on cast iron.

Though rather old now, Keep's curves are very interesting, and it is not thought that all useful conclusions have been drawn from them. On careful examination it will be seen that under the best conditions for each case, the strength of cast iron diminishes very quickly as the thickness increases; in other words, the thinner the casting, the stronger it is, or what is equivalent metallurgically, the quicker its cooling speed, the stronger it is. Transverse strength passes from 440 lbs. for ½ in. thickness to 260 at 1½ in. and 200 at 4 in., which means that a ½-in. bar is 2.2 times stronger per unit of weight than a 4-in. one (under the best conditions).

The first conclusion is that engineers must design their machines with thin walls instead of thick ones. When compelled to use thick walls foundrymen will know that by speeding up the cooling, for instance, by chills, they will increase the strength.

It is common knowledge that the lower silicon percentages would give white iron in thin sections. If, at the same time, it is realised that the strength of higher percentage silicon irons are the strongest for thin sections, then foundrymen will insist upon high percentages of silicon for such castings; 2.00 to 3.00 per cent. is adequate, as it will at the same time give softness and strength.

On examining the curves further, a knot between 1 in. and 2 in. is noticed, which implies that at 1½ in. thickness all percentages of silicon give about the same strength. Consequently, there can be no inconvenience by using in the foundry the same quality of metal for all thicknesses of metal up to what corresponds to a 1½-in. bar. Above that, the strength increases slightly when silicon diminishes for a 4-in. bar, there being a difference of about 20 per cent. between the 1.0 and 3 per cent. silicon iron, but obviously chills will help, and consequently one must be prepared to use them extensively when dealing with thick walls.

Estimating the Strength of Cast Iron.

Every country seems to have its different ideas, and while the British Committee adheres to the separately cast test-piece, other countries prefer the resolution of International Paris Congress, which have been voted unanimously:—

"That the International Congress of Foundrymen, assembled in Paris, recommends that the testing of cast iron be differentiated into the testing of the quality of the iron entering the castings, from the testing of the quality of the castings themselves.

"That it is recognised that *in no case* will the testing of the quality of the iron give reliable information as to the quality of the castings made with it.

"That a joint committee be appointed from the nations here represented, to make suitable recommendations carrying this proposal into effect."

From what has been said, it seems that this is quite reasonable and that the test piece must be taken from the casting itself, and, moreover, from various vital points of the casting if reliable information is expected. It would only be in the case that such a test is very costly that it would not be reasonable to adhere to it.

In his Paper to the Paris Congress Dr. Moldenke mentions that "The Fremont method would be nearly ideal from the scientific standpoint, though rather expensive from the practical one." The author felt constrained to mention in the discussion that it was quite a mistake. The Fremont test that he advocated in Birmingham two years ago consists of the shearing on a very small and cheap machine of a small test piece, less than ¼ in. dia., which is drilled out of a casting by a small hollow drill. [This was exhibited.] The hollow drilling for obtaining the test piece can be made either at the place of a bolt hole of the finished casting or in a place to be plugged afterwards, and when this is not possible in sacrificing one casting, but in all cases it is much cheaper than any other kind of test, while it is much more reliable. In a small test piece 1 in. long, four or five tests can be made. This test does not give any information as to the soundness or internal strength; but so far it appears to the author to be the most reliable ever designed.

Conclusion.

From this hasty survey it cannot be pretended that all points between the foundryman and engineer have been adjusted, but in summing up perhaps it can be considered that it has done some useful work.

The engineer, who requires strength and lightness, will do well to reduce the thicknesses of his castings as much as he can in spreading over the material rather than using heavy masses. He must make simple designs with round corners, avoid restricted places and enclosed cores, which are difficult to vent. Further, he will accept chills where heavy parts are unavoidable and insist upon soft, high silicon metal, so long as he knows that under above conditions it is stronger than hard iron. If the casting is liable to have strains, he will ask and pay for heat treatment.

The founder must spare no effort to produce sound, clean and smooth castings, supply good soft iron and improve his practice by every means.

The engineer will also do well to discuss with the foundryman the method of moulding, and will be agreeable that the pattern is made according to the latter's recommendation; he will supply the foundryman with as good and strong a pattern as is consistent with the number of castings to be produced. It is to be expected that by a confident collaboration, new progress will be made for the good of the industry.

DISCUSSION.

The Cumulative Ill-Effect of Non-Co-operation.

Mr. F. C. Edwards congratulated the Birmingham Branch upon having secured the presence of a gentleman of such world-wide experience and reputation as M. Ronceray. The lecturer had covered considerable ground, some of which was no doubt very debatable, especially the references to gas troubles. Confining his remarks to the co-operation between the draughtsman and the foundryman, Mr. Edwards said he had had some years as an intermediary between the two, and he believed there was great and pressing need for an adjustment of the relations between those two departments. On the one hand, the requirements of the foundry were seldom, if ever, realised by the drawing office. On the other hand, the foundry itself was notoriously inarticulate in voicing its own legitimate requirements. They thus produced a condition which amounted to a sort of mutual reserve, which was not good for either the draughtsman or the foundry, and was certainly detrimental to the well-being of the engineering industry as a whole. Everyone present had heard the hackneyed remark: "You can never depend upon cast iron." The inference was, he supposed, that there was something inherent, something prejudicial in cast iron, which they could never control and which was liable to produce scrap castings at any moment. Many draughtsmen believed that it was impossible to depend upon cast iron, and acted upon that belief. Take an example. Certain parts of many castings were required to take a heavier load than other parts. What was the ordinary procedure of the draughtsman in those cases? He simply increased the metal at those points. The draughtsman increased the metal locally, the result being that, unless the moulder resorted to internal or external denseners or feeding—and these remedies could not always be resorted to—there was very frequently a scrap casting. The draughtsman then utilised that as a further piece of evidence that it was impossible to depend upon cast iron. Of course, they could never depend upon cast iron if they allowed a multiplicity of variables to usurp rational control in their methods of manufacture, for was there any manufactured article or naturally produced product under the sun upon which they could depend unless in its making the conditions of sound and reliable production had been fulfilled? Not one, he ventured to say. Was it too much to ask that in the sound production of castings the conditions should be favourable and not prejudicial to such production? Since both theoretical and practical foundrymen agreed that design played a fundamental part in determining the soundness of castings, was it too much to expect that the draughtsman should place the foundry point of view at least in the front rank of consideration, if not entirely first, when he was designing castings? That he should do so was, in his (Mr. Edwards') opinion, dictated not only by commonsense, but by the most elementary principles of economy, for they might safely say that a well-designed casting made of the worst metal could be expected to be stronger as a whole than a badly-designed casting made from the best metal obtainable.

Piston Design.

Mr. W. J. Molyneux referred to the automobile piston to which reference had been made by M. Ronceray, and expressed the opinion that they would experience great difficulty in persuading designers in this country to forgo the four supporting ribs. They regarded it, he thought, as a very important matter to connect the piston boss with the cylinder head, especially in a piston of 96 up to 120 mm. diameter. Did the lecturer think that it was possible to get the weight of the piston down by sacrificing the ribs?

A Metallurgical Reminder.

Mr. A. Marks said it was quite easily possible to obtain the same strength in a 2½-in. test-piece as in a 1-in. test-piece. He thought it should be kept in mind that strength was a function of the graphite. While the strength of cast iron might be an indirect function of the silicon, it was a direct function of the graphite.

Reinforced Cast Iron and the Use of Metallic Paints

Mr. E. Longden expressed his pleasure at finding that M. Ronceray practically endorsed all the conclusions that he (Mr. Longden) arrived at as a result of various experiments a short time ago. He called attention to an article recently published in The Foundry Trade Journal describing a new process for the production of cylinder castings which amounted to the actual metallising of the moulds and cores, especially in those parts prone to defects, and the conclusion arrived at was that the chilling effect created the soundness. He did not agree that that was the real effect. Why, in such thin sections as motor-car cylinders, should they get drawn places? There was no real bulk of metal to contend with. He considered that by more quickly freezing the metal they would reduce cavity, because they reduced the amount of time the gases could play off the awkward projecting sand corners. He also thought that possibly a much easier method would be to carry out experiments, as he was doing at the moment, in the direction of painting the corners of the awkward sections with a paste of ferro-manganese to accelerate the rate of cooling.

Vote of Thanks.

Proposing a vote of thanks to M. Ronceray, **Mr. J. G. Pearce**, the Director of the British Cast Iron Research Association, said, in his opinion, there was an enormous amount to be gained by an interchange of ideas on an international scale, and that was a particular reason why the visit of M. Ronceray was so welcome. He thought the Institute was to be congratulated upon the steps that it had taken during the last few years to promote the interchange of ideas with other countries by the exchange of Papers with America and the Continent, by visits and international congresses and by the promotion of international standards for testing. By these means he thought the Institute was giving a remarkable lead and a fine lead to other institutions in this country. One thing evident from the remarks of M. Ronceray was the necessity for knowing more about the production of castings, the material that they used in the cupola, melting practice, methods of moulding and design, and methods of after-treatment and testing.

Mr. W. J. Flavell, in seconding, agreed that it was very desirable that there should be a closer understanding between the designer and the man who had to carry out the work. Week after week they met with the difficulties due to design that had been outlined in the Paper. Recently his firm had received a pattern for a valve, one end of which was 1½ in. thick, the other side 1 in., and in between there was a plate of metal ⅜ in. thick. It was necessary to have a talk with the engineer, and he could at once see the difficulty arising from contraction. He had seen designs for the rear axle case of a motor-car where the strengthening ribs inside were put in diagonally. That meant to say that they had to be worked loose in the core box, which obviously involved considerable trouble. On inquiry it was found that, if put in at right-angles to the centre, they would serve equally well. Such an understanding took a considerable amount of expense off the job, both as to the moulder and the pattern-maker. In the lecture of M. Ronceray they had learnt much that would be beneficial to them in their trade.

The resolution was heartily endorsed by the meeting.

The Author's Reply.

Replying upon the discussion, M. **Ronceray** said there was no doubt in his mind that most of the difficulties experienced in the foundry were due to gas. The gas was not produced in the metal itself; it was caused by hot metal in contact with sand. As to the valve of the automobile pistons, he agreed that the weight could be reduced and still give satisfactory pistons. He was convinced that in cutting out the ribs they obviated defects. He did not say that silicon affected the strength of cast iron. He simply took Keep's curves as they were. The silicon effect on the strength of iron in that case was not purely the effect of silicon; it was a question of structure. He denied that the amount of graphite was of great importance, but the state of the graphite was. American black heart malleable was much stronger than cast iron, because the graphite was in a very fine state of division, and there were no flakes of graphite which cut the strength of the metal. It was not a question of metallurgy there; it was a question of metallography. It might be that some day foundrymen would find the correct texture. In fact, some work had been done in that direction, with pearlitic cast iron as a result, which he thought was a very big name for a very small thing. He, too, was glad to find Mr. Longden in accord with his conclusions. Referring to black points in flat plates, he attributed them to the absence of care in pouring the plates, with the result that small pieces of slag were incorporated in it. In his opinion, a test of an actual casting was more interesting than a test of a test-piece, especially in cast iron.

Sheffield Branch.

METALLURGICAL CONTROL IN AUTOMOBILE FOUNDRY PRACTICE.

By A. Harley, Member.

Modern Conditions and Tendencies.

In recent years the author has been much impressed by the fact that the scope of the foundry is being seriously curtailed by other methods of manufacture. The engineer is inclined to look upon the foundry as a necessary evil. He seems to have a distrust of cast metal, particularly castings made in sand. One cannot be blind to the fact that stampings are preferred to malleable iron or steel castings, and are introduced wherever possible. This attitude of the engineer may be quite justified, but foundrymen must do their best to establish more confidence in their work.

Even on the non-ferrous side, brass pressings are displacing castings to a considerable extent, and in aluminium alloys, die castings are displacing the sand-cast article. It is not so much cheapness (although some of these processes are competing seriously with the foundry even on this count), but reliability that the engineer is after. In fact, the word " reliability " hardly covers all that he wants. In a Paper published a few years ago an automobile engineer summarised his requirements for castings to be as follows:—

(1) Produced to close physical specifications; (2) of high physical properties; (3) sound and free from defects in all parts; (4) correct to size and shape, having a fine surface finish—preferably produced in permanent moulds; (5) produced at low cost; (6) having the properties of the steels by so arranging the casting conditions that the impurities are rendered inert or non-existent; (7) produced in light alloys having strength and other properties approximating to those of steel; (8)

produced in light alloys, but with bearing or other surfaces possessing special properties suitable to the needs of the design, obtained by casting in, chilling, or local hammering; (9) produced by die casting processes close to size in order to eliminate machine work; and (10) having special properties for special purposes.

On behalf of the foundry, the author submits, by way of reply, the following points to the engineer and designer for his consideration:—(1) That the physical tests specified shall have some relation to the actual service the casting has to perform; (2) that the strength of a casting is seldom represented by the strength of the test bar, either "cast on" or separate; (3) that all cores should have some visible means of support; (4) that failure in service is due more often to bad design than bad metal; (5) ease of machining is not necessarily the hall-mark of excellence in a casting; and (6) if an error is made in machining, the casting should not be carefully re-examined for foundry defects.

In the past there is no doubt that foundries have not been built, equipped and staffed to meet the demands that have been made upon them. At the same time, it is really amazing to find what has been accomplished in some old foundries. This refers particularly to jobbing foundries, and the results were due chiefly to the high skill and accumulated practical experience of the individual moulder. In the quantity production of motor castings, however, this type of man does not find the scope he requires. Uniformity of production, not only in quality, but quantity, has brought about an organisation resembling more or less a machine shop. At the Daimler concern, the foundry, which is only part of a large organisation, has to work to a schedule, and this comprises hundreds of patterns, with a definite quantity to be delivered from each every week, if not every day. Failure to maintain these deliveries causes serious dislocation throughout the entire works. There are obvious reasons also why it is unwise for the production of castings to be much ahead of the machining. With all its precautions the foundry is still quite capable of making bad castings. Much has yet to be done, but the organisa tion should be capable of preventing trouble reaching that epidemic stage which every foundryman dreads.

To meet these conditions, therefore, the foundry has developed along certain lines, and these may be stated briefly as follows :—

The laboratory and pattern shop are vital and integral parts of the organisation. While their responsibilities should be clearly defined, their activities should be under one control, that of the foundry manager.

The pattern-shop foreman is a very important man. He is responsible for the dimensional accuracy of all castings, and supplies all the jigs and gauges required in the foundry. He is also the link with the drawing office, and must convey foundry ideas as to the method of moulding, and secure any modifications of the design which will facilitate production.

The laboratory, of course, checks all raw materials received and the castings produced, to see if they are up to specification. The author has found it convenient also to make a chemist responsible for keeping the standard furnace mixtures correct, but not for the working of the furnace. All melting, moulding and coremaking should be under the foundry foreman.

Organisation of Labour Conditions.

Personally, the author encourages both pattern-shop and laboratory staff to take an interest in the foundry part of the job. The knowledge they acquire gives them a better grasp of their own side of the business, its exact relative importance, and in the case of the chemist, he learns how scientific data should be applied in practical production.

Practically all the Daimler castings are machine-moulded. The machine is of the pneumatic jarring type. The compressed-air piping is carried overhead, as leakages are more quickly discovered. The bulk of the labour employed is what is known as semi-skilled. The conditions render necessary a considerable sub-division of this labour; for example, the moulder does not assemble his boxes, nor does he make his cores. Moreover, separate men do the casting. Even in coremaking there is a certain amount of sub-division. There are special men who make all the core wires, whilst others do any jointing that is required. It is the same with fettling The operations of sand-blasting, cutting off the gits and runners, bobbing and dressing are performed by different men. This sub-division of labour means a system of inspection which rather resembles machine shop practice; for example, every core made is passed into stores after drying. In these stores the cores are carefully inspected and important cores are checked with special gauges for dimensional accuracy. Accurate records are also kept of all cores rejected, by whom made, and of all issues.

Practically all these castings are machined to jigs, which constitutes another reason for precautions to ensure accuracy. Another feature which has to be considered is the question of machining speed, and this is a point which has its influence on metallurgical practice.

The standardisation of machining speeds in conjunction with piece work or bonus system of payment, calls for uniformity from day to day in the physical condition of the metal in the castings. The desire of the engineer to increase machining speeds is one which the foundry must support in principle. There is a danger, however, that castings may be seriously stressed by excessive speeds. This applies particularly to cast iron of a hard. brittle nature. Such castings, if the design is at all complicated, may already possess latent strains. Fine cracks may be caused in this way, and these are not easily detected unless the casting happens to be one which is tested under water pressure, such as a cylinder. Instances have been found where very close-grained metal has failed under the pressure test, and comparatively open-grained, but tougher iron, has withstood it.

Cast Iron.

With regard to the melting of cast iron, the cupola, in spite of its limitations, is still supreme. The great virtue of the cupola is that it can produce hot molten metal cheaply and continuously. Its great defect is that it is impossible rigidly to control the total carbon and sulphur. The percentages of these increase during the melting operation, and, generally speaking, the author would desire a reduction in the amount of these elements. In regard to tuyeres, he has come to the definite conclusion that one row is best.

The question of the most suitable metal for automobile cylinders is very important. Much has been written on this matter, and the general practice is to produce close-grained iron of approximately the following composition:—T.C, 3 to 3.5;

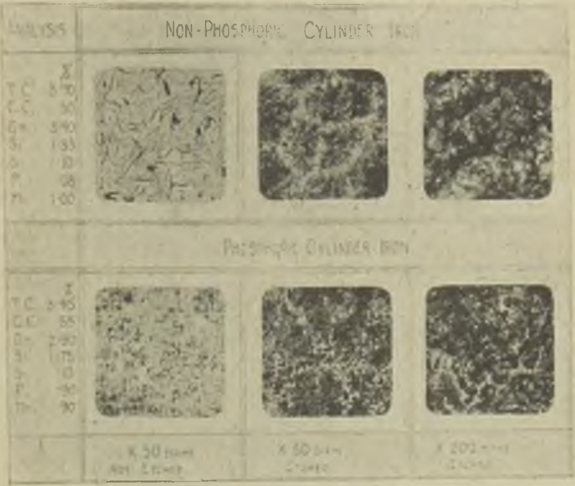


Fig. 1.—Microstructure of Phosphoric and Non-Phosphoric Cylinder Iron.

Si, 1.5 to 2.0; P, 0.8 to 1.0; S, 0.12 maximum; and Mn, about 1.0 per cent.

These figures are to be taken with reserve, as so much depends upon the type and design. This kind of metal is in favour because it gives a higher tensile and transverse test, and is supposed to give a good surface when machined, with good wearing qualities. There is one quality in cast iron, however, which is usually absent from metal of this composition, and it is a property of cast iron to which the author associates much importance. For the want of a better term he calls this the quality of toughness. If a bar of close-grained high-grade cylinder pig-iron and a bar of open-grained soft hematite pig-iron are broken with a sledge-hammer, what is found? The former breaks easily, and the latter does not. Is this quality of toughness or resistance to shock negligible? It is not thought so. To what is it due? Obviously, it must be due to the low-phosphorus content, and this toughness is retained in spite of large graphite plates. It may be objected at once that phosphorus is essential to obtain the necessary fluidity required in running a large automobile cylinder, where the sections are, in some cases, exceedingly thin. The answer to this is that phosphorus is not necessary, provided the metal is sufficiently hot.

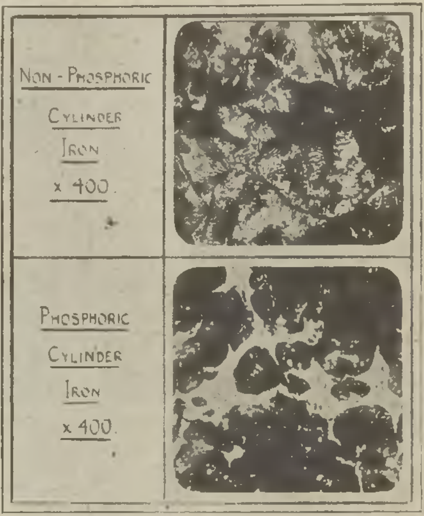


Fig. 2.

A possible second objection that may be raised is the expense of hematite pig-iron; but, as a matter of fact, hematite iron is usually cheaper than the special brands of phosphoric iron sold for cylinder work. A third objection may be the interior wearing qualities of the low-phosphoric iron, owing to the structure being comparatively more open. However, the author has not known of any excessive wear taking place with such metal, although he has made tens of thousands of cylinders, and hundreds of thousands of other castings which are subjected to the same wear as a cylinder barrel.

In fact, he is rather changing his views in regard to cast iron for this class of work. From the foregoing it will be concluded that he has not much use for phosphorus in cylinder work, and he is rather inclined to stipulate the same conditions for sulphur. Apparently, many of the difficulties with cast iron arise from its complex composition. Conversely, the author is of the opinion that many of these difficulties would be overcome if its composition could be simplified by eliminating as far as possible phosphorus and sulphur. It would take much to convince the author that the compounds which these elements form in cast iron are really beneficial. With cupola melting one cannot, of course, eliminate sulphur, but it is thought that the electric furnace will play its part in the production of metal free from this impurity.' Further, with the aid of the electric furnace, qualities will be imparted to cast iron which will widen the value of its usefulness, and what is equally

Fig. 3.—Influence of Steel Additions on the Graphite Structure of Semi-Steel Cast Iron

important, make it a much more reliable material for the engineering industry than it is at present.

With the manipulation of the elements remaining, that is, carbon, silicon, and manganese, most of the desired qualities can be obtained, but in this connection it is not forgotten the possibilities opened out by the introduction of special elements, such as chromium, to impart special and particular properties.

Both high and low phosphoric irons are used by the author for cylinder work. The former is chiefly employed in the production of motor-cycle cylinders. Figs. 1 and 2 show the microstructure of these two irons, and the analysis of each.

In engineering castings, the speed at which a casting can be machined is a very important factor in production that requires consideration. If hardness is essential, there is no help for it, but if not essential it appears to be uneconomical to employ hard metal. The foundryman, as well as the engineer, must study the actual service which the castings have to perform. With this information, his metallurgical knowledge would be of immense value, both on matters of design and the kind of metal that would be most suitable. There is another point in production which should be mentioned also, and this is a purely foundry consideration. A low-phosphoric metal does not "draw" to the same extent. Percentages from 0.8 down to about 0.4 are often recommended, the object being to strike a happy medium. In other words, to reduce the quality of brittleness which phosphorus imparts, but to have sufficient present to obtain fluidity. These medium percentages are not good for cylinder work unless very special precautions are taken to prevent "drawing." On the other hand, many of the troubles are entirely eliminated by reducing down to 0.15 per cent. or under.

It is common knowledge that the transverse and tensile strength of this low-phosphoric iron could be increased by lowering the total carbon. In certain classes of work this is necessary, and very fine iron it is, combining strength and toughness, but the chilling of corners or light projections, particularly where the metal may become stagnant, has to be guarded against.

Semi-Steel

This metal is being referred to as semi-steel, because one can never be quite sure what the latest name is. The old term is good enough for the author. Many important motor castings are made in this metal. The author has not developed the cupola-mixed metal very much. The Daimler concern has several different metals going through the furnace each day, and the conditions, therefore, are not very favourable for the uniform production of cupola-melted semi-steel. The molten steel is added to the molten iron in the ladle, and it has been found that 20 per cent. gives about the best all-round results. Above this percentage the very fluid slag, formed on the surface of the metal, is rather pronounced, and this slag is a danger to clean work. Semi-steel made in this manner has very fine physical properties. The castings produced are definitely uniform, and there have been remarkably few returns from the machine shop. It has been noticed, however, that this metal is

C.T.	C.C.	C.G.	Si.	S.	P.	Mn.
·28			·26	·022	·031	43

U.S.	YIELD.	%E.	%C.	H.	Imp.	Batch No.
32·23	23·18	8·59	23·42	150	13	
31·8	21·75	11·00	41·00	132	39	

FIG. 4.—MICROPHOTOGRAPHS AND MECHANICAL TEST FROM CONVERTER STEEL.

rather susceptible to chill. Semi-steel is simply an attempt to improve the quality of cast iron, and if proper care is exercised its use by the engineer will become more widespread. For this purpose also low-phosphorus iron is preferable, as the high-tensile strength is associated with real toughness. Fig. 3 shows the effect of varying steel additions on the physical properties.

Malleable Iron.

As to the unsuitability of malleable iron for automobile castings there is, in the author's opinion, no question. It is a fact that this material is not considered reliable by the automobile engineer, and the process of production very often means vexatious delay in deliveries. Castings are often too hard to machine, and painfully lacking in the ductility and toughness which enables the part to withstand shock.

There is no doubt that American practice has made great strides in this industry. Is this partly due to the use of metal which is radically different in composition from ours, or simply to improvements in the methods of manufacture? With British high-sulphur iron the process of annealing is really very difficult. With thin sections, and with everything carried out properly, it is realised that very fine metal can be produced, but with sections of ¾ in. and over it is hardly possible to anneal the metal thoroughly throughout. With thick sections it is only by raising the silicon that the structure can be broken down at all readily, but good malleable iron is not thus produced. There is one peculiar feature about malleable of which the author has had experience, and which was referred to in The Foundry Trade Journal quite recently. In a Paper issued by the American Bureau of Standards entitled "Embrittlement of Malleable Cast Iron Resulting from Heat Treatment" it was stated that when the iron was heated to within a critical range of between 250 to 480 deg. C., and then quenched or cooled rapidly, the metal became brittle. It was also found that if the iron was heated to a temperature of 110 deg. above the critical range and quenched from that temperature, it was more resistant to shock, and also rendered immune to embrittlement as a result of subsequent reheating to within the critical range.

This phenomena came to the author's notice many years ago when engaged in the production of malleable castings, although he was not aware of the method of heat treatment by which the metal could be rendered immune. He is still inclined to doubt whether this immunity would be permanent. What he did find out, however, was that the composition of the metal had an important bearing on the matter. Putting it very briefly, easily annealed metal, *i.e.*, metal with the silicon fairly high, was liable to embrittlement in this manner. Metal low in silicon, properly annealed, was not.

As most foundrymen are aware, malleable castings are largely used in the production of motorcycles and ordinary cycles. Many of these castings have to be brazed on to the different parts of the frame. During this operation they are heated to about the critical temperature, and then thrown on the floor to cool. If the metal happens to be the high silicon variety embrittlement ensues if the cooling is rapid. Many cases of failure in service could be traced to this cause. It was rather interesting to find that American "Blackheart" malleable was also subject to deterioration under the conditions described.

Table I shows the mechanical tests of samples of English Blackheart and English Reaumur malleable iron.

TABLE I.—*Mechanical Strength of English Blackheart and English Reaumur.*

	T.C.	C.C.	G.C.	Si.	S.	P.	Mn.
A	2.57	Tr.	2.57	0.66	0.034	0.11	0.40
B	2.60	Tr.	2.60	0.62	0.038	0.11	0.39
C	2.33	0.85	1.48	0.67	0.42	0.059	Tr.
D	2.20	0.86	1.34	0.65	0.44	0.066	Tr.

	M.S.	Y.P.	E%	R.A.%	H.	Imp.
A	13.93	11.70	5.0	10.75	131	7.5
B	15.90	12.09	13.39	11.64	90	6.5
C	22.60	—	—	—	156	2
D	25.77	17.0	8.93	3.64	156	1

Samples A and B are Blackheart, and C and D Reaumur.

Cast Steel.

The production of good steel castings is perhaps the most difficult branch of the foundry trade, owing to the high temperature of the metal and its comparatively high shrinkage. The average composition of the steel is as follows:—C, 0.2 to 0.25; Si, 0.2 to 0.3; S, 0.05 maximum; P, 0.05 maximum; and Mn, 0.4 to 0.6 per cent.

The furnace used at the Daimler foundry is the Stock converter of 12 cwts. capacity, in which the melting is carried out in the same vessel as the conversion. Whilst the experience of users have somewhat varied, in this foundry it has given great satisfaction, producing metal of regular composition and ample fluidity for pouring light work. With this type of furnace the vessels are easily and quickly changed. During the last year or two the use of the special fire brick lining has been discontinued, and a semi-plastic ganister, which is rammed in, is now used, and which, while costing less, gives more heats per lining. Fig. 4 shows a sample of converter steel and its tests,

Fig. 5.—Influence of Heat Treatment on the Structure of Steel Castings.

whilst the effect of heat treatment on converter steel is shown in Fig. 5

Moulding Sands.

The question of sand for steel castings is, of course, important, but for automobile work the difficulties are somewhat lessened by the fact that practically all the moulds can be cast in green sand. Such a mould has less resistance to shrinkage pressure, and consequently there is less trouble from cracks.

No specially prepared sand is bought, nor is any Belgian material used, although it is thought very good results can be obtained from the latter. At the same time, good results are obtained from the use of English sands, and some of those used by the author came from Yorkshire.

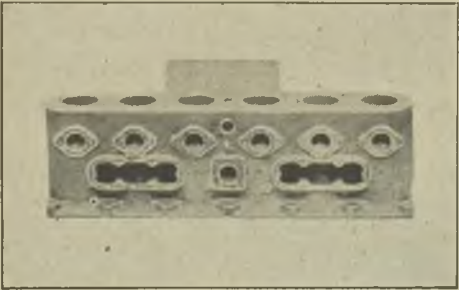


FIG. 6.—THE EXHAUST SIDE OF A SIX-BORE CYLINDER.

In a discussion that took place on a Paper given by Mr. Bradley, of Sheffield, at the Birmingham convention, the author took the opportunity of pointing out that a mistake was sometimes made in having the facing sand for steel castings too refractory, and the Daimler concern had found it the best practice to use a sand which was just on the border line of fusing. The measure of refractoriness depends, of course, on the section of the casting being dealt with, but if this is varied so that the sand just cakes in contact with the molten metal, a nice clean casting is produced so far as the skin is concerned.

Satisfactory mixtures for light steel castings can be ascertained by anyone who takes the necessary trouble, and without using any special binders. In this class of work, however, the proper milling of the sand is essential to give it just the requisite temper. The question of the use of chills in steel castings is very important. Their use in light work is often essential. Additional risers and runners add to the cost of production. It is not a question as to which is the better. The sole end in view is to produce a sound casting. In automobile castings there is no prejudice against the use of chills, but it is realised that great care and judgment is necessary. Assuming this, their use is a much more convenient method of securing soundness in a casting than the use of heavy risers, which very often defeat their own ends. The correct disposition and shape of runners and risers is vital to successful production, and is a matter for close scientific study. This is the crux of the foundry problem, and should not be treated in a casual manner.

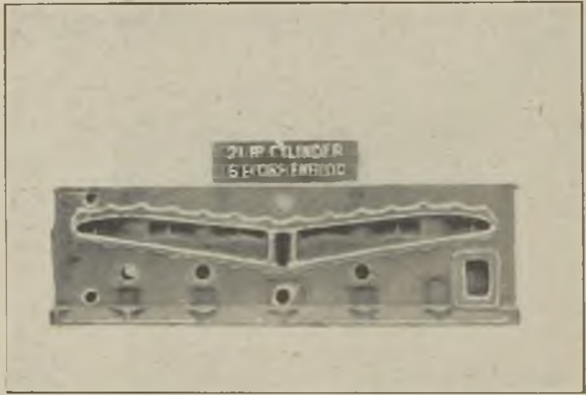


Fig. 7.—The Induction Side of the same Casting.

For the production of a steel road-wheel—a fairly complicated casting—very little chilling is done, and there is only one runner.

The Daimler foundry has an electric furnace as part of its equipment, but this is not in such regular use for steel castings as the converters. To be quite candid, the author has not been so successful in producing reliable and consistent metal for light castings, and if any foundrymen have any special experiences of this kind it is hoped they will publish their experience. Why is it that electrically-melted steel is comparatively sluggish as compared with converter steel at the same temperature? For those who are interested in this question it is pointed out that this furnace is basic lined, and that the chief trouble is porosity in the castings, although from similarly prepared

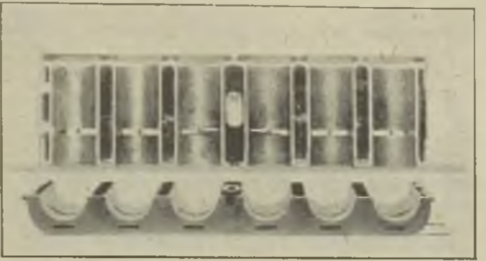


FIG. 8.—A SECTION THROUGH THE BARRELS.

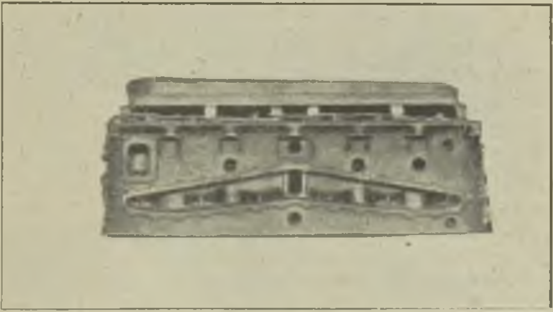


FIG. 9.—THE CASTING READY FOR FETTLING.

moulds we can produce sound castings with converter metal.

It is not to be understood that the author is condemning the electric furnace, as he must admit that problems connected with the job may not have received adequate attention. The consistent results obtained from the converters perhaps made him feel rather lukewarm, especially when the price of current was so high.

Non-Ferrous Metals.

The well-known " Y " alloy has been experimented upon by the author, and the heat treatment he has developed may be summarised as follows:—The metal, " as cast," broke at 11.2 tons per sq. in., and had a Brinell hardness number of 65. After heating at 530 deg. C. for 6 hrs., quenching in boiling water and ageing for 5 days, it gave 12.3 tons per sq. in. maximum stress, and the hardness number increased to 74. The next treatment was to heat to 530 deg. C. for 6 hours, quench in boiling water, temper at 200 deg. C. for 6 hrs., and cool down in the oven. This gave 18.8 tons maximum stress and 109 hardness number.

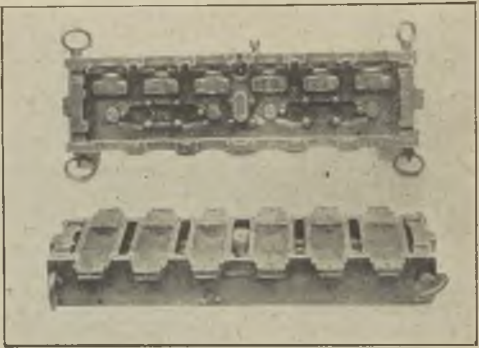


FIG. 10.—THE TOP HALF SHOWS THE JACKET CORE BOX AND THE LOWER HALF A SET OF DRIERS.

Table II shows some representative contractions found by the author.

TABLE II.—*Shows the Contraction of Metals used in Automobile Castings, the length of Test Bar being* 12.069 *in. or* 306.55 *mm.*

Material.	Contraction.
Average gun metal	1 in 64.8
Admiralty gun metal	1 in 73.5
Brazing metal	1 in 53.8
Worm wheel bronze	1 in 76.8
Phosphor bronze	1 in 74.9
L 5 Aluminium	1 in 66.3
Cast iron	1 in 80.0
Semi steel, 20 per cent.	1 in 60.3
Converter Steel	1 in 42.1

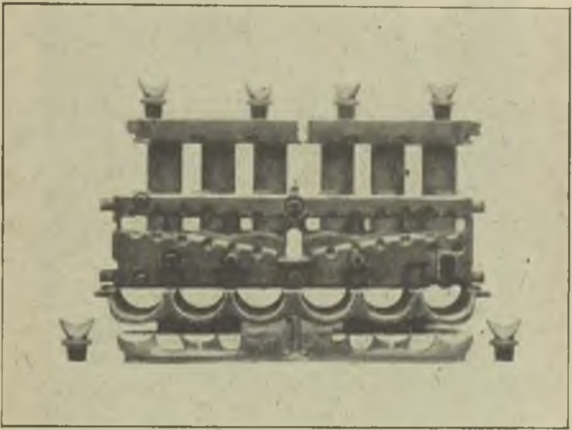


FIG. 11.—SHOWS A COMPLETE SET OF CYLINDER CORES.

Production of a Cast Iron Cylinder.

Fig. 6 shows the exhaust side of a 21-h.p. 6-bore monobloc cylinder; Fig. 7, the induction side; Fig. 8, a section through the barrels; and Fig. 9, the cylinder as delivered to the fettling shop.

The successful production of a cylinder calls for the close co-operation of the designer, pattern-maker, foundryman and metallurgist. To emphasise the importance of the foundry point of view on the question of design, a few points that had to be brought forward before the drawing for this casting was finally approved will be mentioned.

In the first arrangement the induction of this cylinder was enclosed in the water jacket, but the designer was persuaded to leave one side open to make it possible for the mould to be made horizontally. The following points were settled at this stage:—(1) The pattern to be in halves, jointed

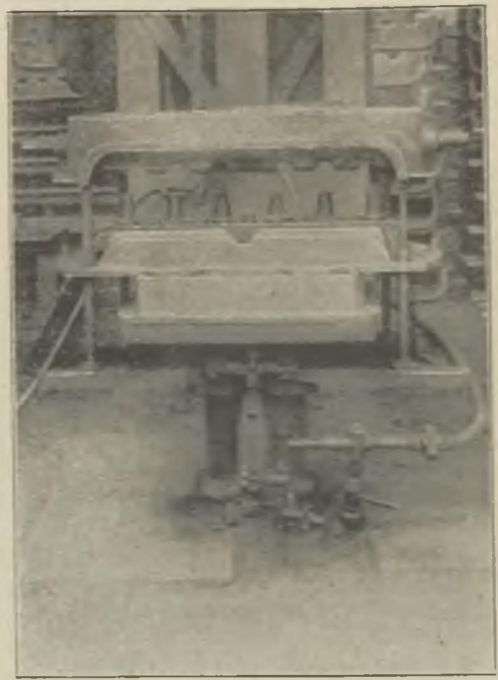


FIG. 12.—SHOWS A SIX-BORE CYLINDER MOULD ON THE MACHINE.

through centre of bores; (2) jacket core to be in halves, also jointed through centre of bores: (3) the barrel cores to be made in two parts, each part containing three barrels; (4) induction bore-core to be made in one piece up to the joint of the mould. The other part of this core to be dowelled on the top and gummed; and (5) six separate exhaust cores to be used.

As a matter of principle, the designer wishes to have as few holes in the jacket as possible, but certain requirements of the foundry and machine shop have to be met. The machine shop as a rule wants a small round hole on the centre line of each bore in order to locate from the barrels. The foundry also requires certain holes, so that the jacket core can be supported, and also for venting purposes. The foundry prefers these holes between the barrels where there is the largest body of sand, so that a compromise between the foundry and the machine shop on this matter has to be effected. In the present instance two oblong holes were made.

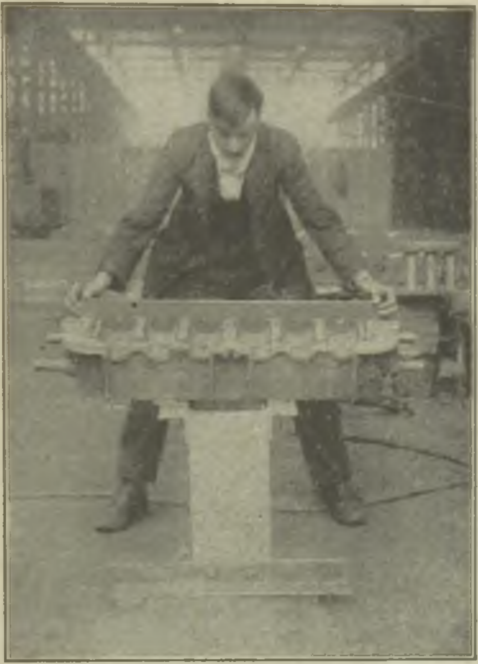


FIG. 13.—SHOWS THE GAUGING OF THE JACKET CORE.

Fig. 9 illustrates the method of running the casting. There is an ample well from which the metal runs down the barrels. The small auxiliary runners which may be noticed in the figure are for the purpose of ensuring that the outside walls are run. The author favours casting with very hot metal and casting quickly.

Fig. 10 shows the jacket corebox, one half showing the driers in position and Fig. 11 a complete set of cylinder cores.

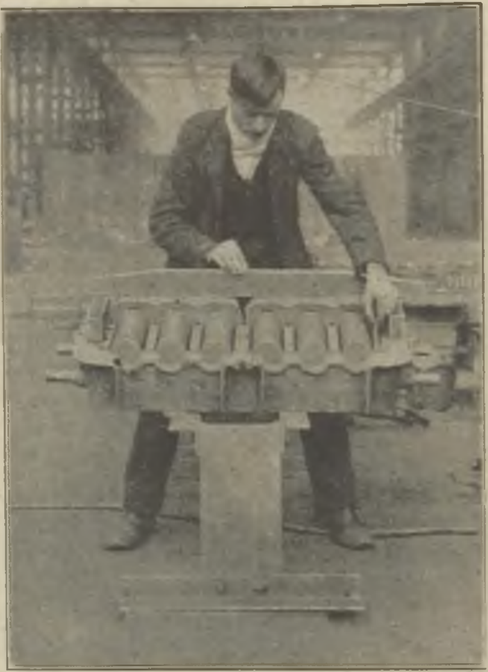


Fig. 14.—Shows the Gauging of the Barrel Core.

The jacket coreboxes are made in cast iron. The use of silica sand has one disadvantage; it wears away wood coreboxes in a very short time. Several sets of barrels to form the outside of bores are fitted in each box, and when the core is turned out of corebox on to machined plates these barrels are left in until core is dried. These driers are really an integral part of the corebox, and enable the men to handle the core and get it dry without any risk of damage or distortion. The two sides of the corebox are loose, and the whole corebox is held together by two bolts. Bushes are inserted in the corebox to form small round projecting cores.

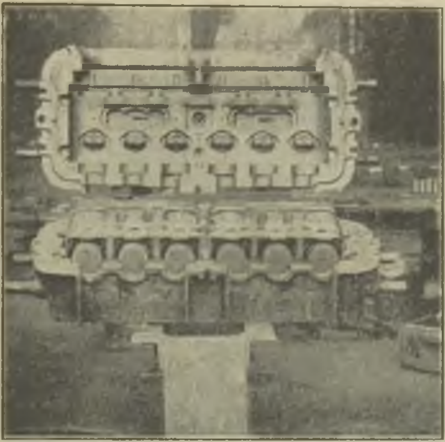


Fig. 15.—The Cored-up Mould ready for Closing.

This ensures these round projections coming out accurate.

With regard to Fig. 11, the sand used for the jacket core is a coarse-graded silica. Certain parts have to be made in somewhat finer sand, and in the thick parts very much coarser material is used, almost the size of small pebbles. It is bonded by molasses, and thoroughly mixed in a mechanical mixer of the barrel type, and it can be used almost immediately, but is better for standing a short time. The prepared sand should be stored in a well-ventilated room, and in winter must be kept free from frost or trouble will ensue. Further, it is essential that molasses of the highest purity be used, and definitely free from any alkali. The question whether molasses is preferable to oil or other patent binders has been solved by testing many of these, and while many of them have proved satisfactory in use, the cost has been found to be much higher.

The cores are baked at a temperature of 300 deg. C. for 20 mins., and are then passed to stores for inspection and gauging. The barrel coreboxes are also made in cast iron. These have runners recessed in them, so that each cylinder has the same amount of runner, and always in the same position. This core is made in ordinary sand, and has projections so that it is well supported when the mould is turned up for casting. The induction corebox was at first made in wood, which was rather fortunate, as it was subsequently altered several times.

Fig. 16.—The Mould ready for Casting.

The exhaust corebox is made in cast iron, and has a collar larger than the actual hole required, which provides a good firm bearing. Figs. 12 to 16 show the process of making the moulds. Fig. 12 shows the cylinder mould on the machine, Fig. 13 the gauging of the jacket core, Fig. 14 the gauging of the barrel core, Fig. 15 the mould assembled ready for closing, and Fig. 16 the mould ready for casting.

Practically all the Daimler castings are machine moulded, by means of a pneumatic jarring-machine which was originally designed and made in the works. Pneumatic machines require, of course, the installation of a compressor plant, and air at a pressure of 80 lbs. per sq. in. is used. The author advocates having the air pipes overhead. Originally they were placed in the floor, where leakages are not easily discovered, and it is more difficult to get rid of any condensed moisture; in fact, even with an overhead system condensed water is rather a bugbear.

The cylinder is moulded on its side, and boxes are designed and made in the foundry. The question of box plant is not a part of the equipment that can be scamped. The boxes should be accurately and well made, machined on the flanges, and the pin holes kept accurate. In this case the boxes are designed for a dried mould, and therefore the minimum amount of sand space is allowed. In America the casting of cylinders in green sand

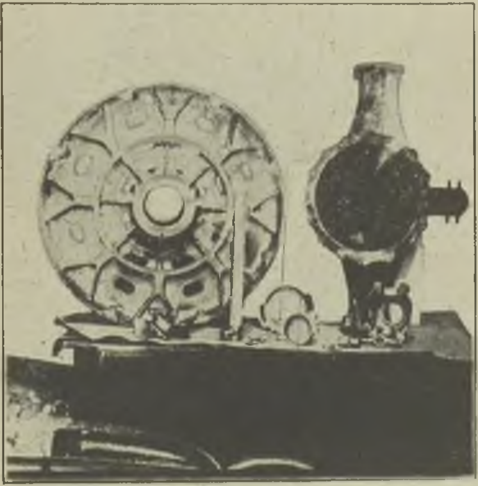


Fig. 17.—A Rear Wheel and Back Axle Casing.

has made considerable progress, and British foundrymen will have to give more serious attention to this matter. The intricacies of British design may account to some extent for the lack of progress in this direction, but there is no doubt that many of our difficulties could be overcome by improving the quality of our sand mixtures. Recent experiments have shown that the strength of green sand can be enormously improved by specialised methods of preparation.

Fig. 18.—A Wheel Pattern Mounted on a Moulding Machine.

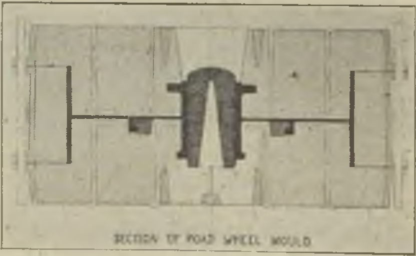


Fig. 19.

All the cylinder moulds are blacked by means of a pneumatic sprayer which does the job very quickly and effectively.

Production of a Cast Steel Road Wheel.

Fig. 17 shows a rear wheel with back axle casing, Fig 18 the pattern on the machine, and Fig. 19 a section of a road wheel mould.

DISCUSSION.

The discussion was opened by Mr. Bradley, who confirmed the author's views on the relative values of the electric and converter steel making plants. He had experienced no difficulty from the electric furnace in general, but in this connection one had to consider the capacity of the furnace in relationship to the number of moulds to be cast. He found that running from a 40-cwt. converter was equivalent to casting from a 30-cwt. electric furnace.

Electric Steel Castings Criticised.

Mr. Hyde said he thought the lecturer's remarks were very interesting in regard to converter and electric steel. They had used an electric furnace for three or four years and put in considerable time and experiment in order to get reasonably good results from it, and succeeded. Owing to prices they had introduced a converter, and had no further use for the electric furnace to-day. In regard to melting in the electric furnace, they melted the steel and tapped it dead. In the converter they tapped an oxidised bath, and while the silicon was acting there was more fluidity. He was not surprised at hematite being favoured for cylinder barrels, for it had been found it gave just as good wearing properties as the harder iron. It should be remembered there was 4 per cent. of graphite present, which was a good lubricant.

Mr. Darley, referring to the relative merits of the converter and the electric furnace plants, said his firm had installed both, but they had scrapped the Stock converter. During the time the Stock furnace was running, they could make castings as thin as from ⅛-in. section. They now used the electric, but they occasionally met with serious trouble with gas holes on the bottom side of the mould, due to the sluggishness of the metal. He had found that in the electric furnace, when the impurities were largely reduced, that there was no "life" in it, and that the metal would not run very far. Further, in his opinion, one of the chief causes was on account of the low phosphorus. They had increased the phosphorus by adding phosphorus, and they had obtained a very much better casting. He gave the example of marine pistons. Towards the outer edge the casting invariably showed gas holes which became more oval in form towards the extreme edge. Their research department had taken up the matter, and it had come to the conclusion that on account of the steel not being sufficiently fluid, gas became trapped, and there was not sufficient fluid to drive it out. Speaking with reference to the road wheel, which the lecturer had shown, he asked whether one had ever been cut up from the boss? He thought it would be found that when they chilled a casting on the outside it invariably pulled the joints of the chill. In conclusion, he would like to know where the lecturer could obtain the sand so near to Sheffield.

Pouring Conditions.

Mr. Rhydderch said that the lecturer had not dealt with the method of pouring steel castings. Opinions were sharply divided on the relative merits of bottom pouring and shanking. It would be interesting to learn the speaker's experience on this point. Personally, he favoured shanking for the production of light steel castings for soundness and solidity, and lip pouring for the very large castings, leaving bottom pouring to the medium-sized castings.

Another point was the shrinkage of steel. Had the lecturer noticed any difference in the behaviour of the shrinkage of electric and converter steel, especially with a widely varying phosphorus content? A friend of his had emphatically stated that shrinkholes were very much more pronounced with a phosphorus content of over 0.08 per cent., than if below this limit. Of course, this refers to mild carbon steel castings. Personally he had no experience in this matter on which to have an opinion.

It is a well known fact that slightly oxidised steel does not shrink nearly as much as dead melted steel, and over-oxidised steel " rises."

Fluidity of Steel.

The point has been raised by the lecturer and other speakers of the fluidity of electric steel. Judging from one example of carbon, less than 0.1 per cent., and a very low manganese and silicon, it would be difficult to get high fluidity. Generally speaking, increased fluidity with medium C steels can be obtained by using much higher manganese—say 1.2-1.4 per cent., and higher silicons—say up to 0.8 per cent. Further, a theory has been put forward that tapping on a slightly oxidised slag also gives greater " life " or fluidity to electric steel. There is nothing against this theory because there is a similar instance in the behaviour of electrolytes on colloids.

Skin on Castings.

The question of a skin on castings had also been raised. This generally happens with naturally bonded sands, in which the bonds are generally of a very low fusion point, and easily form slags as a result, but it is not considered to be useful for the larger castings. In fact, large castings that strip well often show unsoundness on machining, probably due to the excessive formation of this viscous layer. If this factor is investigated in detail, and reacting elements put under careful control, it might be possible with the heavier castings.

Dealing with the accuracy in the size of castings, cored faces, etc., it would be interesting to know to what limits the lecturer could work on routine steel castings for motor car work.

Mr. Edginton said before he contributed anything to the discussion, he would like to ask how to get pure hematite iron. Speaking of the trouble with machine shop castings, he was inclined to agree that if they were more particular there, the foundry would be saved much trouble, and there would be a saving in many ways. The machine shop did not give enough thought to the " set up." He would like to mention that he had put an electric furnace down and he had had to win his knowledge by experience. When first they started making steel castings the manganese content was about 0.4 per cent., with the result that they got pin holes on the bottom of castings. But when they raised the manganese content to about 0.9 per cent., they eliminated a great deal of that trouble.

Mr. Robinson referred to the amount of phosphorus in cylinder irons, and the regulations fixed by the Ministry during the war that 0.8 per cent. of phosphorus was the more satisfactory amount for such a casting. It would seem, he said, that below 0.3 per cent. of phosphorus and above 0.8 per cent. one stood a better chance of getting a sound casting than between those limits. At a lecture given by Mr. Cook, at Birmingham, the same opinion was expressed, and it was stated that cylinders cracked on the piston valves with a low percentage of phosphorus. By increasing the phosphorus this was eliminated. That was somewhat opposed to what they generally understood. At the same time, it was believed one could get a sounder casting by doing it. Speaking of the tensile and transverse tests, he believed a good test was the shock test. During the time they were making experiments on material for a certain type of steel shell, they instituted a shock test which proved very helpful. As to using softer material for cylinders, they found that softer material gave a longer life. He did not think it was due to the lubricant of the graphite and when using high-carbon iron a certain amount of the free graphite worked up on to the face and caused it to harden on the carbon face. In machining the casting, all their pistons, either large or small, directly they went from the foundry to the machine shop they were roughly machined and then annealed. In regard to aluminium, he always had better results from chills than from feeders.

Mr. Green said the higher the total carbon the greater the fluidity. That, apart from the property of withstanding wear produced by the lubricating action of the graphite, there seemed to be a structure on the micro-section shown, in which the pearlite predominated, and this, no doubt, helped in that direction.

To obtain this structure, it is necessary to obtain a proper combination of elements and also the correct rate of cooling.

Value of Pearlitic Structure.

Mr. J. Shaw (Chairman) said during his term of office he did not generally take part in the discussions, but he could not let pass the statement made by Mr. Harley with reference to high total carbon. Whilst for the thin work on which Mr. Harley was engaged it might even be beneficial; he had no hesitation in stating that in heavier sections it was harmful. He also agreed with Mr. Green that a true pearlitic structure was the one to be aimed for, both from the strength and machining point of view. The great difficulty was, under cupola practice, to hit the right composition. The speaker had once cast a tyre-roll that gave such remarkable life and lack of wear that a thorough investigation was made. This roll gave 2,227 tyres without redressing; the ordinary life being about 300. Nothing was found in the mixture but what had often been used before, but in this case the pearlitic structure had been developed by some means difficult to trace.

The Author's Reply.

The Lecturer, in reply, said he had realised that a very much different set of conditions existed in Sheffield as compared with his own. The heaviest steel casting he made weighed three cwts., and when examples were given about big moulds—he believed 20 ft. had been mentioned—he was afraid he did not know very much about it. With regard to the quality of Stock converter steel and electric steel, he would like to make it clear that at the back of his mind he felt that if he paid enough attention to electric steel he could get steel as good, if not better, than Stock converter steel. From the same moulds, prepared in the same way, he could make sound castings with converter steel, and he obtained more often porosity in electric steel. If he could overcome the trouble of fluidity, he could look after the other difficulties quite easily. But one of the principal reasons for not using the electric furnace was the fact that the cost of current was so high and was a handicap in competition. If it was reduced he would use the electric furnace. From what he had learned, he believed that the steel absorbed some of the aluminium and there was reaction with some of the gases coming from the mould. There was something mysterious in the action of electric steel. Road wheel castings were never annealed. He believed in annealing as a general principle, but in road wheels they had not found it necessary, as they had never had one returned. The steel, as cast, was perhaps more rigid than annealed steel, and the action of the road wheel was such that it supported it better. With regard to the accuracy of the casting, he thought a good section was not indicative of a good casting, but at the same time that should not prevent them from getting a good section as well as a sound casting. Accuracy of the casting depended on what the casting was, but he thought they could make cylinders starting from any point. because they knew where they were starting from. On work of urgency they could work to ¼ mm.

He was not claiming any advantage for high total-carbon iron. In making a casting they had to consider more closely the service that casting had to stand, the machine shop and the cost of machining, but what he did claim was that in auto-cylinders he did not need to reduce the total carbon. He knew it was only 10 tons tensile, but it was sufficiently strong. He had made more castings to withstand piston wear than anyone in England. He had listened to the suggestions on pearlitic structure, and he believed they would have to have metals of special composition where the range of fluidity was lessened. He advocated more purity in cast iron. If he had to use phosphorus, he would prefer it to be slightly above one per cent. Why it was he did not really know, but he had noticed that it was particularly persistent in quantities between 0.8 and 0.3 per cent., and the reverse up to one per cent. In regard to tests, he did not consider the tensile and transverse tests were sufficient. They required another test which would register the difference between various grades of cast irons.

Coventry Branch.

PHYSICAL TESTS FOR CAST IRON.

By John Shaw (Sheffield), Member.

Original Tests on Cast Iron.

Before an engineer can start work on the design of any piece of work he must have some idea of the strength and properties of the materials he proposes to use. For cast iron, various formulæ are given in text-books on the subject. These formulæ have been developed chiefly from data based on the loads obtained in the breaking of test-bars and castings. So far as this country is concerned, there is little doubt that the results of the experiments carried out by Sir Wm. Fairbairn and Hodgkinson from 1827 to 1837 form the basis of present-day formulæ for the strength of cast iron. It was about this time cast iron came into more general use in structural and engineering work. How little was known of its strength and properties was evidenced by the collapse of numerous mills and bridges. Fairbairn, amongst other data, suggested that 1-6th of the breaking load should be considered as the safe load for this material. As nine tons was the tensile asked for, a figure of 1½ tons per sq. in. was concluded to be the safe tensile strength of cast iron, a figure in fairly general use to-day. The designer having based his work on the above rule, naturally wishes to be assured that the material supplied complies with his estimated calculation; hence he imposes certain tests that he thinks will give the required information. How often these defeat the very object he strives for will be dealt with later.

That some test is necessary may be granted at once. Foundrymen all know of bars breaking at 7 tons, and where unsuitable metal is often used. Recently the author cast two 3-in. sq. bars, which were tested transversely at 3-ft. centres. One was cast from a No. 3 hematite, and the other from a close number of the same brand of iron. With each bar there was also cast three others, whose diameters conform to the sizes given in the I.B.F. draft specification. The results obtained by breaking these smaller bars will be dealt with later. The 3-in. sq. bar from the No. 3 hematite broke at 8.4 tons. The second, from the harder iron, broke at 9.5 tons. Yet the first iron was the dearer and under certain conditions the stronger, but for this thickness of casting would have been rejected as poor iron by many inspectors.

At this juncture attention should be called to a statement often made by some foundrymen. Why worry with tests? If there is any doubt about the strength of a casting, thicken it up; it is only so much bare iron that is being given away. These people forget that heavy sections, large fillets and strengthening ribs not only increase the cost of production and reduce the chance of making sound castings, but also weaken the structure as a whole. Increased weight means increased cost of foundations and other considerations. Increased weight in motor castings, for instance, is a vital point. The problem of design in such structures as the Forth Bridge resolves itself into one of carrying its own dead weight equally as much as allowance for wind pressure and the moving load—a point brought forcibly home by the collapse of the Quebec Bridge on two occasions before completion. Two points have now been established in the consideration of the subject:—(1) That before a machine can be designed there must be some strength data of the material to be used. Such data or formulæ have been built up from experimental work. (2) That the engineer requires some test applied to the material he uses so as to ensure it conforms to the standard mentioned in his formulæ. Coming now to the actual tests, everybody is agreed the best method would be to test the casting itself. That is not often possible, and where it is, often permanent set and deformation is set up, due to testing to twice or even three times the working load. Thus sometimes the casting is left in a weaker state than before testing. The testing to destruction of one casting out of a batch cast from the same ladle or metal only gives information about that one casting, and does not account for the hidden defects in any of the remainder due to causes other than metal. In short, it only proves that the particular casting was or was not sound, and that the metal was or was not suitable; the latter fact could just as well be found by a suitably designed test-bar.

While Fairbairn and Hodgkinson tested certain castings to destruction, it was more to arrive at the correct design than the mere strength of the material used. For this latter purpose, test-bars 1 in. sq. tested at 4 ft. 6 in. centres were used. While every credit must be given to the engineers of that and more recent times, there is no doubt their knowledge of cooling and mass action effect was very meagre, and it would appear from the tests for cast iron put forward that it is very little understood by their successors to-day. One has only to glance through the table of 51 British pig-irons, that took Fairbairn many years to compile, to realise this. He states:—"In the following abstract the transverse strength, which may be taken as *a criterion of the value of each iron, etc.*" Yet this value was obtained from irons where some were "hard," "soft," "soft and fluid," "rather hard," etc. No true comparison can be drawn from irons with such a variable structure. Three examples will explain this in Table I:—

Table I.—*An Abstract from the Work of Fairburn and Hodkinson*

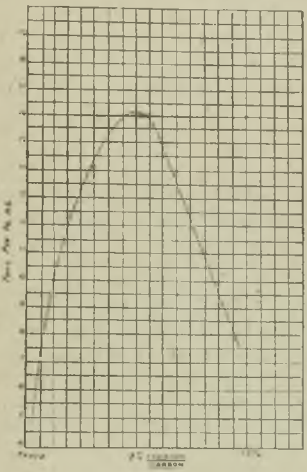
Brand	Breaking load 1 in. bar, 54 in. centres.	Deflection in inches.	Colour.	Quality.
Ponkey ..	567	1.75	Whitish grey	Hard
Butterley ..	489	1.01	Dark grey	Soft
Eglington ..	472	1.87	Dull grey	Rather Hard

The engineer has this consolation, that, judging from many of the weird proposals for mixing iron contained in the foundry literature of Fairbairn's time, the foundryman knew even less of metallurgy as we understand it to-day. How was it then that the foundryman complied with the tests specified. The chief reason was the fact that the blast furnaces were on cold blast, small, worked from picked local ores, with slow working. By these means a more regular and stronger product was made. It is common knowledge that to-day the cold blast irons of South Staffordshire commands just double the price of ordinary irons. For the above reasons the moderate tests asked for were obtained with a wide-difference in composition. With the advent of hot blast iron, with its faster driving and much more variable fracture and composition, also the fact that tests were more frequently asked for, trouble began, and there is little doubt many test-bars were made from iron that never went into the castings. The engineer, to protect himself, then insisted on the test-bar being attached to the casting. This led to the length of the bar being shortened. The whole question, so far as the foundryman was concerned, was so to place the bar as to obtain the strongest structure. If the casting was a thin one, he knew the most suitable metal for this was too open for an 1½-in. dia. bar, so he placed the bar as near the box edge and as far from the casting as possible, so as to obtain the chilling effect of the cool box.

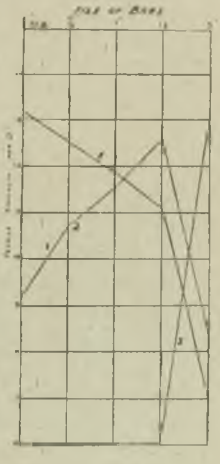
If the casting was a very thick one, the reverse procedure obtained, and the bar would be placed as near the heavy casting as possible to obtain the full annealing effect on the structure of the bar. The worst feature from the engineers' standpoint is the fact that the mixture is often hardened or softened, as the case may be, to get a compromise between the casting and the bar. By this means—the specifying of a size of bar utterly unsuited for the thickness of the casting—it is obvious that the engineer is directly responsible for many poor strength castings. Where the bar and casting are about the same section, there is little trouble in obtaining present-day tests.

The question of design in relation to this problem of tests and strength of castings is as vital as any, and calls for that consultation between the foundryman and engineer so often advocated. Given a casting of fairly uniform section, it would be possible to reckon on a safe load of 2.5 tons per sq. in. That would mean scantlings could be reduced by 50 per cent., even if one retained any thinner sections in the same casting, so as to give a more even thickness throughout and therefore a more even cooling and a stronger casting, using the correct type of metal.

Mention has been made of the casting of two 3-in. sq. bars from metals of good variation, and gave the test results. It was also stated that the author cast three bars from each metal which conformed to the sizes given in the I.B.F. specification. The results of the tensile tests on these bars were as follows. From the hard metal the $\frac{7}{8}$-in. bar was quite white. The 1.2-in. bar was badly mottled. The 2.2-in. dia. bar was grey, and when turned to 1.785 in. dia. in the centre, broke at 12.3 tons. The three bars from the soft metal yielded the following results. The $\frac{7}{8}$-in. dia. bar turned down to 0.564 in. dia. in the centre, broke at 13.04 tons per sq. in. The 1.2-in. dia. bar, reduced to 0.798 in. in the centre, yielded 12.04 tons per sq. in. The 2.2-in. dia. bar, turned down to 1.785 in. dia., broke at 9.6 tons per sq. in.



Graph I.



Graph II.

Graph I outlines the results of work done by Prof. Turner, Cook and others, showing that the greatest strength of any given iron is obtained with the C.C. from 0.7 to 0.9 per cent. Mr. Gresty, of the North-Eastern Marine Engineering

Company, recently informed the author that their results were round about 1 per cent. C.C. The publications and patents concerning the manufacture of "Pearlitic cast iron" is another confirmation of the above statement.

Graph II gives the results of a series of experiments made on various sizes of bars, each set cast from a metal suited to various work. The bars were $\frac{5}{8}$ in., 13-16 in., 1 in., $1\frac{1}{2}$ in. and 3 in. dia. Each set of five bars was cast in one box from the same ladle. No. 1 iron was used for thin strong castings. The $\frac{5}{8}$-in. bar yielded 13.25 tons per sq. in., and then, as the sizes of the bar increased, thus giving a more open structure, the tensile strength dropped till only 7 tons was registered on the 3-in. bar. Iron No. 2 was used in steam cylinders 1.5 in. thick. This iron was too hard for the $\frac{5}{8}$-in. dia. bar, and only 9.5 tons per sq. in. was registered. There was a gradual rise till, at $1\frac{1}{2}$-in. dia. bar, 12.5 tons was obtained, with a drop to about 8.25 tons per sq. in. on the 3-in. dia. bar It should be noted that both these irons would have met the ordinary test of 9 tons tensile. The last iron was used in some hydraulic cylinders. Every bar up to the $1\frac{1}{2}$-in. dia. was white, and therefore no tensile could be taken. The 3-in. bar was grey, and registered over 13 tons per sq. in. at the Sheffield Testing Works. It should be particularly noted, in view of the results shown in Graph 1, that the total carbon in this third iron was 3.2 per cent. The C.C. in the 1-in. dia. bar was 3 per cent., while in the 3-in. dia. bar it was only 0.9 per cent. This is clear evidence that the bar must bear some relation in size to the thickness of casting it is supposed to represent.

Where the thickness of metal varies to a great extent in the same casting—a ship's propeller is a type—no test-bar will represent all parts of this casting, just as no metal will give maximum strength in all parts. The best must be a compromise in both cases. The foundry manager has to make up his mind before charging for this casting what type of metal he will aim for, whether it shall be suitable for a casting 2 in. or 3 in. thick. Once this is done, he knows what diameter of test-bar to use, and the test result will give him some idea if he has attained his object.

Present Day Specifications.

Crown Agents.—Cast iron is to be made from best pig-iron, and must be close-grained, hard, tough and perfectly free from all defects or blemishes. The cast-iron test-pieces must be cast with the broader side of the bar uppermost. Bars for making these tests must be cast and tested before the commencement of the contract, and at such intervals subsequently as the Inspector shall direct. The cast iron to be of such a quality that a bar of the same, 1 in. broad and 2 in. deep, placed on edge on bearings 3 ft. apart, shall not break with a less load than 30 cwts. suspended in the centre, nor with a deflection of less than 0.3 in. Yet to this specification castings that do not exceed $\frac{3}{8}$ in. thick are asked for, and at the other extreme castings with no section less than $2\frac{1}{2}$ in. thick.

Admiralty.—The Admiralty specification presents the same anomaly. It reads that test-pieces are to be taken from such castings as may be considered necessary by the Inspector. A bar 1 in. sq., tested on supports 12 in. apart, shall bear a load of 21 cwts. without breaking. The minimum tensile shall be 11 tons per sq. in. taken on a length of not less than 2 in. The general practice for the latter is to cast a bar $1\frac{1}{4}$ in. dia. and to turn this down to 0.798 in. for 2 in. in the centre. Here, again, this specification has been used for small cylinders $\frac{3}{8}$ in. thick, and at the other extreme fly-wheels with a rim thickness of 12 in. Some little time ago the author was asked to make some chilled rolls for the Admiralty. The chill asked for was 1 in. deep. Now it is quite impossible to cast any bars below 3 in. dia with the composition needed to obtain 1 in. chill without the bars being white. Mr. Buckland, the Inspector, proved this for himself, and the down runner from the roll was broken off, turned down to 1.785 in. in the centre, and broke at over 13 tons per sq. in.

Many engineers seem to think that cast iron is a homogeneous material, and that a specification issued by the B.E.S.A. covers every casting on earth. Recently there was an inquiry for some compressor heads with a minimum thickness of

$5\frac{1}{2}$ in. The iron was to comply with the B.E.S.A. tests for pipes.

New Railway Specification.

In October last the L. & N.E. Railway issued a specification for iron castings. They specify a bar 2.25 in. × 1.25 in. × 28 in. long, to be cast near the top of the cylinder attached to the flange. The transverse tensile and compression test-pieces are to be cut from this bar. No serious objection can be taken to this bar so far as the cylinders are concerned; the two sections bear some relation to each other. A round bar would have been preferable. Also, care will have to be taken in centring for the tensile; otherwise the structure will vary greatly and there will be a weak side. Even if the bar is centred truly, it will be necessary to remove approximately $\frac{3}{4}$ in. aside from the 2.25 in. wide bars, while 0.25 in. will be all that requires turning off a 1.2 in. draw-bar to arrive at a diameter of 0.798 in. in the centre. When this bar is specified for general castings, grave objection will be taken to its application to thin or thick castings. If axle boxes now average about $\frac{3}{8}$ in. thick, then to get the best test on the size bar asked for will render the pin lugs on the grease box commercially undrillable.

Paris Conclusions.

At the International Foundrymen's Convention, held in Paris last September, there was a fairly general agreement that some modification of the present-day methods for testing cast iron was long overdue, both in the interests of the engineer and foundryman. When it is remembered that 14 nations were represented and over 1,000 delegates were present, the movement cannot be over-estimated.

M. Portevin suggested that the Fremont and Portevin methods of testing small pieces cut from the castings themselves offered a solution. While the method appears ideal, one can only say that for 14 years little or no progress has been made, the charts and figures put forward by M. Ronceray at Birmingham in 1922 being those to a great extent published by M. Fremont in 1912. However, as the American Committee are purchasing a machine, independent evidence may soon be expected.

American Conditions.

The A.F.A. adopted a standard arbitration bar in 1904. This, for several reasons, has not met with much support on the other side, and a combined Committee of the A.F.A. and the A.S.T.M. are revising the whole specification.

At a meeting of the General Council of the I.B.F., held in Coventry in 1918, it was resolved that instead of simply criticising specifications put forward by certain authorities, it would be better to embody the foundrymen's views in a tentative specification, this to be submitted to the leading engineering societies for acceptance or amendment before sending on for the approval of the B.E.S.A. This Committee of the I.B.F. started active work over two years ago. They realised from the first that if the specification was not to be a dead letter, it must carry the consent and approval of the engineers. They therefore had two objects in view. First, so to modify the size of the test-bar that it bore some relation to the section of the casting it represented, and so would have to a limited extent a similar structure. Secondly, to convince the engineer that these modifications would yield tests as high as any he had asked for before. Once this specification had been tried out by both the engineer and foundryman, a combined effort could be made to increase the test loads and help cast iron to take a better place.

This specification varies in a few vital points from the standard specifications mentioned earlier in the Paper. Clause 4, for instance, divides the castings into two grades, viz., Grade A is to include all important castings that often now call for higher tests. Grade B includes all other castings that require to conform to mechanical standards. Again, for Clause 6, the average sectional thickness of any casting shall determine the size of the test-bar to be used. Thus, for all castings where no main cross-section of the metal exceeds ¾ in. thick, a bar 0.875 in. dia. cast 15 in. long shall be used. For all castings where no main cross-section exceeds 2 in. thick, or is less than ¾ in. thick, a bar 1.2 in. dia. cast 21 in. long shall be used. For all castings where no main cross-section is less than 2 in. thick, a bar 2.2 in. dia. cast 21 in. long shall be used.

Clause 7 points out that the test-pieces for Grade A shall be cast on the casting wherever possible. When practical considerations do not permit of this, or when the consent of the engineer is obtained, the procedure outlined for Grade B shall be followed. Test-pieces for Grade B may be cast separately at the option of the supplier, and shall preferably be cast in duplicate sets of two bars, each of the dimensions specified in Clause 6. The test-bars shall be made in green sand or dry sand, according as to whether the casting is made in green sand or dry sand.

The test-pieces shall be cast from the same ladle as the castings, and as nearly as possible at the same pouring temperature. The test-pieces shall possess the same thermal history as the casting it represents. (This is to provide for the growing practice of heat-treating certain work.) The test-pieces shall be tested transversely as cast, or skin machined at the option of the engineer. The transverse tests are given in Table I.

TABLE I.—*Institute of British Foundrymen draft Specification Requirements.*

Transverse		Grade A		Grade B	
Diameter of bar in inches	Distance between supports in inches	Minimum load in lbs.	Minimum deflection in inches	Minimum load in lbs.	Minimum deflection in inches
0.875	12	11.85	0.12	10.50	0.10
1.200	18	19.50	0.15	17.15	0.12
2.200	18	10.000	0.12	90.00	0.10

Tensile (Piece prepared from one portion of the transverse test)

		Grade A	Grade B.
Diameter of bar in inches	Diameters after turning in ins.	Minimum maximum stress tons per sq. inch	Minimum maximum stress tons per sq. in.
0.875	0.564	12.0	10.0
1.200	0.798	11.0	9.0
2.200	1.705	10.0	9.0

Chemical Analysis.—Where physical tests are specified, the maximum percentage of P only shall be specified.

The Committee fully realised from the beginning that the test-bar only represented the quality of the metal going into the casting, and not necessarily the strength of the casting itself. They also realised that a separately cast test-bar is not an ideal method, but they felt that, in the absence of any satisfactory method of testing the casting itself, without injuring it, their first duty was to modify the present-day tests, so that they would be more satisfactory to the engineer and foundryman and lead to a better product.

Comments on Tensile Testing.

Dealing with the methods of testing, the author does not believe the tensile test is a suitable one for cast iron. This opinion is endorsed by foundrymen in most other countries. America and Germany both cut it out of their specifications. M. Portevin, in his address before the French Conference held at Nancy in 1922—an address which should be read by every foundryman and engineer—stated the four factors obtained by a complete tensile test are:—Elastic limit, ultimate tensile stress or breaking load, elongation, and reduction of area. Of these, the only two which really indicate the suitability of the material for a given purpose are the elastic limit, or the stress from which perfect recovery is possible, and the reduction of area, which is a characteristic of the ductility. Yet it is precisely the other two, that is, the breaking load and the elongation, which are frequently selected as the deciding factors. Briefly, the ordinary tensile test, owing to its long history and its apparent simplicity, has become established in an exaggerated position. As a matter of fact, the ordinary tensile test is incapable of indicating the elasticity of cast iron, for which purpose it is necessary to resort to the deflection test. It is often stated that few, if any, machines give a direct pull. The author recently examined figures relating to an interesting experiment on this point. A test-bar was cast with two 3-in. flanges about 4 in. apart cast on. The bar was machined up with the grip ends and also the faces of the flanges machined. The portion of the bar between the flanges was turned to 0.798 in. with good fillets connecting to the flanges. A gauge was fitted between the flanges, and then the bar was fixed into the tensile testing machine. Three points at an angle of 120 deg. were fixed and marked A, B and C on the edge of one flange. As soon as 2.9 tons per sq. in. was registered, it was found the gauge was very tight at A, that it would not go in at B, and that an 8/1,000 feeler went in at C. Increasing the load to 4.5 tons per sq. in., it took a 2/1,000 feeler besides the gauge at A. The gauge would not go in at B, while it took a 12/1,000 feeler to fill the gap between the gauge and flange at S. After this the load was taken off and the bar was re-measured, when the original data was obtained. The bar was again fixed in the machine, but the positions twisted 120 deg., so that the point C took B's original place, B where A was, while A took C's position. When the load was again taken up to 4.5 tons per sq. in., it was found that A (*c*) needed a 4/1,000 feeler, B (*a*) a 7/1,000 feeler, and C (*b*) a 3/1,000 feeler to fill the space. This test afforded good evidence that this particular machine did not give a straight pull. Another grave objection to the tensile test is the fact that it is more a test of the structure of the iron rather than its quality. The author emphatically states that he can obtain 11 tons per sq. in. tensile on almost any class of iron if the C.C. is round about 1 per cent., but that the corresponding deflection and transverse tests need quality as well. The hundreds of tests made by Fremont confirm this. Field unwittingly also added evidence when he stated he could obtain 15 tons per sq. in. tensile on a high-phosphorus semi-steel cast iron, but could not get the transverse with the same material.

Chemical Analysis.

Having regard to the very limited knowledge of the effect of composition, cooling effects, etc., it is not thought wise to embody complete chemical composition in any specification which calls at the same time for physical tests. The author is not aware of a single instance where a complete chemical analysis is included in a specification, where the allowable variation is not wide enough to obtain either good or bad castings at will. It stops research and suggests that the knowledge of metallurgy is complete. If this is so, why do we read such divergent views from foundrymen in the front rank? Why is it suggested in Coventry that phosphorus is detrimental between 0.4 and 0.8 per cent., while other eminent men say it is not harmful if below 1.0 per cent.? Why did Cook and Hailstone obtain an average of 15 tons tensile for sixty days using three irons, and only an average of 10 tons when a single iron was charged although the ordinary ultimate analysis was the same? Why did they obtain a net-work structure with one iron and not with the other series, although all conditions were the same as far as shop conditions will allow? Why is a cold blast iron stronger than a hot blast of the same composition? Why is good semi-steel so much finer in its graphitic carbon than an ordinary iron of the same composition? Why does Young advocate a high sulphur if the manganese is in balance for certain classes of work, while others advocate a low sulphur for the same work? Why does Smalley remelt his iron and run into chills if the iron recovers its structure fully on remelting? Why is it that an "over-grey" pig-iron that carries a No. 1 analysis has a No. 4 structure and retains

TABLE III.—*Relative Constitution of Cold-Blast and Hot-Blast Pig-Iron.*

	Cold Blast.	Hot Blast.
Specific gravity	7.194	7.047
Tensile strength	26.859	18.993
Com. carbon	0.0836	0.0687
Graphite	0.0476	0.0600
Silicon	0.0386	0.0593
Slag	0.0189	0.0375
Phosphorus	0.0228	0.0185
Sulphur	0.0014	0.0010
Undetermined	0.1141	0.0960
Earths	0.0117	0.0146
Silicon and carbon	0.1219	0.1281
Silicon and slag	0.0665	0.0975
Gr, slag and Si	0.1051	0.1568
Gr, slag, Si and P	0.1280	0.1753
T.C.	0.1312	0.1287
Gr, slag, P, S and earths	0.1411	0.1909

it on remelting, as mentioned by Pilkinton, Houghton and others? One could continue asking these questions, showing what divergent views are held. Till our knowledge on this side is more complete, it is not wise to dogmatise about definite chemical specifications. If a further warning is needed, let them examine the following analysis, and remember that in another 20 years the statements and figures they give now with such confidence may look just as ridiculous as those below. Yet it was upon this evidence that the trained chemical staff of the Pikeville Arsenal stated that hot blast iron was inferior to cold blast.

Table III shows the corresponding figures of cold blast and hot blast pig-iron.

Conclusion.

The following is thought to have been established:—(1) That tests are necessary to establish the data needed to enable work to be designed; (2) that tests are needed on the actual material to prove they comply with the compiled data; (3) that one size of test bar does not give even a correct idea of the structure of the metal entering into the casting; and (4) that full chemical specifications, together with physical tests, are not satisfactory in the face of our thorough lack of knowledge on the effect of composition and mass action.

DISCUSSION.

The Chairman (Mr. A. Harley), in inviting discussion, said the Paper was an exceedingly interesting one on a subject which vitally concerned every foundryman and engineer.

Test Bar Preferred.

Mr. Roxburgh, of Rugby, speaking with reference to the recommendation of that Committee that round test bars be used for transverse tests, said he was of opinion that the square or rectangular bar would give a better indication of the stress that castings would stand than the round bar. If the castings made in this or any other country are considered, he would say that the structure of a square or rectangular test bar would be more in line with the structure of the metal in 99 per cent. of these castings than that of a round bar. A round bar gives higher transverse test than a square bar of the same sectional area. and he would therefore like Mr. Shaw to say why the round bar was recommended for this test

He drew Mr. Shaw's attention to a rather peculiar test result he recently encountered. As the lecturer was aware, the foundry with which the speaker was connected is called upon to meet fairly high physical tests. The foundry was running a mixture with the Si content approximating 1.3 per cent. to cast two jobs with test bars attached. The moulding box for one of these jobs was rather tight, and the moulder was therefore obliged to put the test bars very close to the castings, and, owing to the slow rate of cooling, the management naturally expected somewhat low tests.

The tensile bar was cast at 1⅝ in. dia., and the transverse bar at 1¼ in. sq. In the case of the other casting identical test bars were cast-on, but they were in a position well removed from the casting. When the bars were broken it was found that the tensile bar which was cast close to the casting only gave 9.87 tons per sq. in., whereas the transverse bar, which was also cast close to the casting, gave 3,300 lbs. per sq. in. The test bars of the second casting both gave fairly good results, namely, tensile bar 13.7 tons per sq. in., transverse bar 3,420 lbs. per sq. in. It seemed rather peculiar that the transverse bar should give such a good result, in view of the big drop on the tensile bar, and both cast under similar conditions. Had Mr. Shaw encountered anything like this in his experience, and could he give some idea as to the cause? All the test bars were sound.

Reasons for Round Bars Explained.

Mr. Shaw replied that in regard to a round bar the matter turned entirely on the point as to whether the bar represented the casting or the metal. If it represented the metal, then they wanted to arrive at something which would give them the least variables. It would be well to remember that in all patterns, if at all possible, sharp corners and angles were eliminated. That a square test bar showed diagonal lines of crystallisation, and a tendency for small cracks along the sharp edges. With a round bar both these drawbacks were minimised. The matter was, of course, open to discussion, but both the I.B.F. and the American Committees, after going thoroughly into the matter, supported the round bar. In any case it was necessary to have a square transverse bar so as to give a similar crystalline effect as the flanges of the casting it represented. For the same reason the tensile should be cast square and turned round. The question of the strength of the bars mentioned by Mr. Roxburgh depended on the composition of the metal, and the cooling effect on the mass. As shown in Graph II it was quite possible to have any of the three-sized bars in the I.B.F. the strongest, according to the composition. As stated there, if the C.C. was round about 0.9 per cent., that of the three-sized bars was the strongest. It was also shown that from the same metal poured into bars at the same time, it was possible to have 3 per cent. C.C. in the ⅞ in. dia. bar while there was only 0.9 per cent. in the 3 in. dia. bar due to cooling effects only.

Mr. Roxburgh: The 0.9 carbon was in the same ladle and cast in another casting.

Mr. Shaw added that much would depend on the size of the bar, for he could get 3 per cent. in one bar and 0.9 per cent. in another.

An Engineer's Views.

A Visitor said that engineers had not really a satisfactory figure on which to design. Suppose they had three transverse test bars, and one was to correspond to a certain casting with a breaking point of not less than 3,000 lb., another of 3,300 lb., and the third 4,200 lb. Now the engineer did not build his machines on round test bars of the same size, and consequently those figures meant nothing to him unless he knew the stress to which he could subject the various classes of machines. He would then have to turn to the tensile test, which was not much use for cast iron, especially if in testing these results afforded them no absolute units. Of course, there might be a bigger variation in big test bars. Taking, however, the test result of 25 lbs. per sq. in. in conjunction with the modulus of rupture, they did get at the amount of stress a casting should sustain, and they could use it as an absolute figure in calculation. If transverse tests were given from the metallurgical laboratories instead of tensile tests they would certainly know more about the compression and tensile qualities of the material, and they would also have something more definite to work upon than in the tensile test, as in machining and gauge length operations the chilled portion was torn off. For this reason engineers preferred one size of bar, for if they knew it was broken at 2,000 lb., it suggested something definite to them, whereas if another size bar were used which was figured to break at 3,000 lb. they would naturally decline it because of the absence of reliable comparisons. He was in agreement with Mr. Roxburgh in his remarks as to the use of the square test bar, because castings were normally rectangular, and not round. Moreover, in a round bar the stress was concentrated at a certain point, but in the case of the square test bar it was uniform and all over the surface, which the speaker illustrated by a rough diagram. Urging the dependability or advisability of the modulus of rupture, the speaker mentioned that he had, for a period of twelve months, made a series of tests with an inch square bar, one of 12 in., and another of 22 in. length. These two figures were in the ratio of 54.5 per cent., according to the recognised formula. Now the average figure on the 12 in. test was something like 53.9, so far as he could recollect.

Bases for Designers.

MR. SHAW thought the last speaker had missed the whole point. The specification gave definite figures for the various thicknesses of castings, and so the engineers had something to start from for their designs. They reckoned on—(AN INTERRUPTER: 1½ tons per sq. in., but what did that mean?) That meant tension. (THE INTERRUPTER: But if the foundryman gave the engineer a figure to design on it would be better.) Before that could be done much would depend on the design. What the speaker insisted upon was that sufficient care was not expended on the design from the foundry standpoint. As far as possible uniform thickness should be incorporated. Then, if the casting was about an average of 1 in. thick, present day tests asked for 21 cwt. on an in. sq. bar at 12 in. centres. If the casting averaged

2 in. thick, and a 2 in. sq. bar was used, tested at 12 in. centres, they would expect to get approximately 168 cwts. (THE INTERRUPTER: I do not quite agree, because they are not in direct ratio. If you have a bar 1 in. sq. and another 2 in. sq., the one would not have a breaking load of four times.) Theoretically it ought to have eight times, but due to size would have a more open centre, and the breaking load might fall a little. (THE INTERRUPTER: Oh, no; there is the moment of inertia.) After further passages, Mr. Shaw laid down that the bar should bear some relation to the thickness of the casting; that was the whole point of the controversy at present. With regard to the square or round bar for the transverse test, it was not a question of the load. (THE INTERRUPTER: Quite.) The round bar might give a wrong deflection, due to sinking in of the top and bottom steel bearings. (THE INTERRUPTER: It would affect stress, because stress is distributed all over the piece.) To this Mr. Shaw answered that he had not considered that point, but even if it was so, as they proposed to use all-round bars, the stress would be comparable. With regard to the deflection, this gain due to sinking in of the steel bearings on the large bars could be met by special bearings, or there was a machine that automatically deducted the amount of sinking in.

Automobile Castings.

MR. G. H. JUDD said he might point out, because he did not know whether Mr. Shaw was aware of it, that in Coventry, where the majority of the foundries were engaged in motor cylinder work, the average thickness of cylinders was ½ in. to ¾ in. He believed that at last the automobile section of the B.E.S.A. had tackled the question for the district, and had now allowed them to use a ½ in. sq. transverse bar which called for 400 lb. It was quite a small bar, but for cast iron it was certainly more representative of the casting and comparable with it than the 1 in. sq. bar originally called for. They also tackled the question from the flywheel point of view for motor cylinders, although the majority were made in steel pressings, but where it did apply to cast iron a 1 in. sq. bar was allowed, equal to 2,000 lb transverse and 11 tons tensile. So that in their district they were trying to approach the question and make test bars comparable with the castings. (Mr. Shaw: Thank you.)

Mr. H. Beeny, referring to the remarks of a previous speaker, said that he had been making test bars, cast in sizes ranging from 3-16 in. to $1\frac{1}{4}$ in., in order to demonstrate the influence of the rate of cooling upon different grades of cast iron. When the first set was broken—the bars were cast in duplicate—and he had calculated the results to the square inch, on the assumption that the cross-sectional area and the breaking stresses were proportional, he found that instead of getting a maximum transverse result at a certain critical rate of cooling, the figures rose steadily upwards, so that on the $1\frac{1}{4}$-in. bar, with a very grey iron, he obtained the highest transverse value. Now that was not what was expected, as he anticipated that the maximum transverse test for each grade of pig-iron would occur on some intermediate section. The second batch of bars were turned to exactly $\frac{1}{2}$ in. dia., and when broken on the transverse machine the maximum was obtained. When he examined the other figures obtained with the first bars he found that, if he assumed that the transverse test was proportional to the cube of the diameter of the bar, then the figures obtained from the bars broken at various sizes agreed quite well with those obtained from bars broken after being turned down to 0.5 in. dia. Could Mr. Shaw quote them the formula used in calculating the figures given in the tentative specification?

Mr. Shaw replied that he could not at that moment, but he could send it on. The figures were published, and were obtained for them by the Professor of Engineering at Birmingham University.

Mr. Beeny added that assuming the transverse was proportional to the cube of the diameter of the bar, the figures came out very well, there being approximately 1 cwt. per sq. in. difference between the two sets of values.

Mr. Shaw observed that of course a great deal would depend on the quality of the iron as to whether they obtained the maximum strength on the small or the big bar.

Mr. Shaw commented on the importance of the combined carbon constituent, saying that it might be 0.8 or 0.9, or even 0.71, which Professor Turner had reduced it to, and was for that particular iron the highest test; while Cook found it one point higher. What they wanted to know was the suitability of iron for the size of bar. If the iron was too hard for a small bar they would expect a drop.

Test Bars Useless for Automobile Cylinder.

Mr. F. H. Hurren remarked that while he was in practical agreement with what Mr. Shaw had said about the value of test bars, he should like to qualify that agreement by stating that test bars were exceedingly useful on cast iron which was used on structural or constructional work generally. But as Mr. Shaw had expressed a wish to "have the gloves on," he would like to oblige him by saying so far as automobile work was concerned, he really could not see the practical utility of a test bar in connection with motor car cylinders. These cylinders were required to perform certain functions, and the chief factors required of them were effective long life, freedom from abrasions, general resistance to porosity, and standing up to the work of what was very often a high revolution engine. The question as to whether the material in automobile cylinders would give 11 tons tensile or 21 cwt. transverse tests did not to his mind matter twopence. The main thing was that the material must stand up to its work day in and day out, often under bad conditions, with bad driving and lack of lubrication. And the matter of tensile or transverse tests had no relation whatever to the necessity which was all important in a cylinder —its long life under varying conditions. Mr. Shaw had also mentioned that, so far as chemical composition was concerned—and it had also been stated in Coventry—a phosphorous content of between 0.4 and 0.8 was harmful. He thought this point required some elaboration. From practical experience he had found that an iron which which was suitable for automobile cylinders, taking into consideration the total carbon and silicon content. if it had a phosphorous content of that range, was always liable to segregation. The chief and most desirable factor in automobile cylinders was a very short cooling range, and this could only be obtained by what little they knew of the balance of chemical constituents. A cast iron with less than 0.2 or over 0.8 per cent. phosphorus, assuming there was a silicon content of approximately 1.5 per cent., would give far better results day in and day out than a similar iron with a phosphorous content of 0.2 up to 0.8 per cent. The only explanation he could offer for this experience was the dimension of the cooling range. Mr. Oliver Smalley, when lecturing there recently, showed some bars with a cooling range in one case of only 80 deg., while in the other instance it was somewhere about 250 deg. To his mind an iron for an automobile cylinder which had the latter cooling range was liable to all sorts of trouble, local segregation and local porosity, however good or bad the iron might be. In such a case they might still be getting a good test bar, but he would rather obtain a good casting with a bad test bar than a bad casting with a good test bar. However, he could not suggest any alternative test, but he would like to add his opinion that test bars for automobile cylinder work were a waste of time.

Mr. Shaw, in reply, agreed with Mr. Hurren entirely on this particular point, because cylinders were small castings, and they also had the Brinell test instead. Moreover, they could easily test the casting by water pressure, before machining, and under these conditions he did not think a test bar was necessary for automobile cylinders. He might explain that he simply mentioned the phosphorus question because he had heard it whispered twice, and had only referred to it as a tool to prove that their chemical knowledge was not complete.

Stress Estimation not Practised.

Mr. R. N. Aveline thought the last gentleman put the case for the engineer in a nutshell. So far as engineers in that district were concerned, what they required was a uniform standard of quality in the castings supplied, and this under very different conditions from those of the ordinary tensile test. He suggested that very few engineers ever worked out stress figures for cast-iron parts. In the case of automobile cylinders, previous designs were generally followed, and the selection of the metal to be employed was not usually a result of stress estimation. But he could see Mr. Shaw's point when he said the quality of the metal going into the casting was the factor for the foundryman to keep a check on; because it was surely unfair to expect the foundryman to produce cylinders giving engineers the desired results unless he was perfectly sure each day that he was putting into the mould metal of a certain composition. The first cylinder of the batch might be perfectly satisfactory, but Mr. Shaw had shown them that although the chemical composition of the iron might be more or less the same, the physical results of the metal might be very different, if the mix were slightly altered. He would like to ask if Mr. Shaw's Committee had experienced any difficulty in trying to compromise between engineers' views in cases of responsibility for the design of such parts as were of a widely differing nature. Of course, the strength of a structure such as a bridge was actually calculated, whereas that of many automobile parts was not. With regard to the size of test bars, there was just one difficulty, and he was not quite clear how Mr. Shaw proposed to overcome it. This was that if they were having a multiplicity of sizes of test bars, was it not going to complicate their testing equipment? Granted a transverse test on most machines could be fairly wide, and most of the machines could accommodate a varying span and varying thickness of the bar; in a tensile test it must be a question of some difficulty. For example, if many test pieces of the section which Mr. Shaw had shown—a round section about 3 in. in diameter—had to be tested along with the ordinary standard small one, certain additional labour in the testing department would be involved in changing chucks and jaws continuously. Concluding, Mr. Aveline inquired had anything further been done regarding the impact test for cast iron. One had read of further experiments being carried out, and that would certainly be a direction in which more research was necessary. So many automobile castings were subjest to shock, and probably on that basis the engineer would find the most beneficial results from any standardised form of test.

Mr. Shaw, commenting on these remarks, said the speaker was relying on somebody else's work.

The first cylinder must have been designed. Were they to place more value on the testing machine than on the strength of the casting, they must make a testing machine do the job. As regards big bars, it was only a question of taking the grips out, and they had to do that to make a test at all. But he was sure that so far as Coventry was concerned this question was not a serious one. Suppose they had a big casting, was it to be marked out and machined before they had any idea of its capabilities? Or if they had a £1,000 casting must they wait till they put the test on the casting before they could tell whether the metal was even suitable? They, as foundrymen, did not mind what test was employed so long as it was one which foundrymen could make under proper conditions and the engineer would accept. That was what they were out for. As to the impact test, he used nothing else, but whether it was a good one or not he was still open to doubt. He used a French one, with a direct drop of ½-in. at a time, but was not at all sure that on some metals he obtained relative results. On some semi-steels they had consecutively good results, but on hard metals he was not so satisfied. They had not found any definite data yet.

Mr. Beeny's Contribution.

Since the meeting the following data has been supplied by Mr. Beeny to Mr. Shaw:—

The test-bars mentioned which were round were cast vertically in green sand in sizes varying from 0.5 in. up to 1¼ in. dia., two bars being cast off each size. One set was broken in transverse between 12 in. centres with the skin on, and gave

(D_2) diam. in ins. of bar at fracture.	(W_2) Transverse cwts. on selection.	(W_1) Transverse calculated to 1 sq. in.
0.510	2.261	24.65
0.630	4.500	25.81
0.755	8.125	27.09
0.897	12.50	24.84
1.021	18.38	24.77
1.148	26.50	25.13
1.284	34.00	23.03

the following results for a grade of iron containing T.C. 3.56 per cent., and Si 1.39 per cent.

Certain of the remaining set of bars were machined down to 0.5 dia., and broken in transverse under the same conditions as before.

(d_1) Dia. in ins. of bar before machining.	(d_2) Dia. in ins. of bar after machining.	(W_2) Transverse cwts. on section.	(W_1) Transverse calculated to 1 sq. in.
0.505	(not machd.)	2.250	25.05
0.633	0.50	2.391	27.43
0.760	0.50	2.578	29.57
0.895	0.50	2.375	27.24
1.020	0.50	2.250	25.87
1.285	0.50	2.125	24.31

It will be seen that a very fair comparison is obtained between the bars broken in the various sizes as cast, and the corresponding bars broken after machining to 0.5 in. dia.

The question raised concerned the method of calculating the values obtained on bars of various sizes to one standard area of cross-section. The writer has used the following formula:—

$$W_1 = \frac{d_1^3}{d_2^3} . W_2$$

Where W_1 = Transverse value in cwts on round bar having an area of 1 sq. in. and dia. d_1 in. (= 1.128 in.).

W_2 = Transverse value in cwts. obtained on bar having dia. of d_2 in.

The contributor would be obliged if the author could tell him whether this conforms with that used in drawing up the specification for the testing of cast iron.

These bars were actually cast in various grades of foundry iron in order to study the effect of different rates of cooling upon the microstructure and physical properties.

THE AUTHOR'S REPLY.

Mr. Shaw sent the following answer:—

The formula used is quite correct for a comparison of different diameter bars tested at the same centres. The test figures forwarded are very interesting, but lose some of their value because the variation in diameter of the bars is not sufficient to have a great effect on structure. If the bars had ranged from 0.5 to 3 in. dia. his results would have been quite different. It is also evident from the results that the metal was suitable for the medium size bar, and so one would not expect much cooling effect with the 5-16 in. increase of the diameters either way. The experiments are worth repeating, using bars varying from 0.5 in. to 3 in. dia., with metals suitable for each size. Then he would find a vast difference in the results when compared with the formula.

Birmingham Branch.

A PATTERN SHOP TALK.

By G. E. Dicks.

In speaking of the pattern shop it is almost necessary to refer to the drawing office and foundry also. These three departments, where patterns are concerned, should be closely allied, and work together to find the best way to increase output and produce the best castings.

The designer of any particular machine, after preparing his rough outline and details, should confer with the heads of the foundry and pattern shop before finishing the drawing. Their advice at times eliminates much unnecessary patternmaking and simplifies the work in the foundry, the moulder and patternmaker can work out their own salvation; this, as a rule, is an easy matter. From personal experience the foundry will always co-operate to attain the best possible productive results.

The draughtsman is not in so close touch with the foundry as the patternmaker, and however good he might be in his own line, it is the moulder who has to produce the castings required. Numerous difficulties can be overcome without any loss of dignity on either side by consultation.

All patternmakers should have a technical knowledge of machine drawing and construction, together with some practical training in foundry work. If their ideas of the future do not carry them beyond being a patternmaker all their lives, they should at least have self-respect enough to try to be a first-class patternmaker. It is hoped the present time apathy is only a passing phase, that the younger men will value the many advantages gained by knowledge, and make every possible sacrifice to collect it. They will find later that in one thing alone they will be amply repaid, and that is in having the pleasure and satisfaction of being "on the top of their job."

The foreman and employer have, of course, their responsibilities also towards these young men, the foreman in not only explaining how to do the work, but also giving a reason why it should be done in any particular way. A pattern shop foreman always has plenty to do, and his main job is to get out the work; but still, he should remember that a little extra time spent on his younger hands will be well repaid later, both to himself and his employer.

In one recent case a youth was given a job, which, under ordinary circumstances, a man would have done; with a little supervision it was completed to everyone's satisfaction.

All patternmakers should not only be able to read blue prints quickly, but should have a clear vision of the finished job before starting on the work; a few hours spent in thoroughly grasping all details will save much later worry and anxiety This, of course, refers to larger work that may take three to four weeks to complete.

Selection of Timber.

A judicious selection of timber for various kinds of jobs is necessary; quite common pine, or even spruce, is good enough for many jobs, but in every case it should be well seasoned. Usually for large and medium size patterns pine is used; if the timber is properly seasoned it is the best and safest wood for pattern work. For small standard patterns mahogany has long held first place; it is light, easily worked and gives a good, smooth surface when finished. Unfortunately its use is somewhat restricted by its cost, but it is the ideal wood for patterns that require skilful handiwork. Quite a number of the harder woods from time to time have been tried, such as apple, cherry, whitewood, and birch, but in each case there is a tendency to warp, although a good finish can be obtained. The nearest approach to mahogany is cedar, which is easily worked, but of a much softer nature than mahogany.

Built-up Jobs.

In built-up jobs more consideration should be given by the men themselves to the thickness of the wood, and to the number of battens necessary, as it will often be found that internal strengthening ribs are twice the thickness required, making the job much more expensive and heavier to handle. Glue should be used sparingly in the pattern shop and with discretion. For segment work it is essential, but where there is a possibility of any alteration in the future to a pattern it should be avoided. A thin coating of shellac varnish will make a good joint, with the advantage that on parting the joints will not tear the wood very much. This allows for any alteration that may be required to the pattern. Too many nails are often used, making any future alteration somewhat expensive. It is far better to use screws wherever possible. Screws, though less economical than nails, make a much sounder job, and can easily be removed when alterations have to be made.

It would seem unnecessary to refer to the filleting of corners; patternmakers are so much aware of the necessity of this, but do they put their knowledge to actual use? In many cases the fillets are left out no doubt for the moulder to pare, and for him to make them any size he cares to. Reference is not made only to simple fillets in corners, but also to special pipes, tee pieces. etc. The corners may be filleted upon the pattern, but the cores, being struck upon a plate, are butted together and the corners left sharp. Fig. 1 shows a tee piece, angle and fillet-rubber treated in this manner.

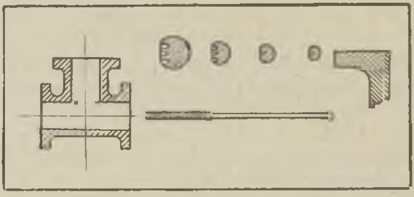


FIG. 1 SHOWS A TEE-PIECE, ANGLE AND FILLET RUBBER.

Even with the ordinary fillets at a corner placed there by a patternmaker, they are often either too small or flat. A fillet should in most cases incline more to the thinner section, as is shown in Fig. 1. A very useful fillet rubber is also shown; it has a handle screwed at the bottom to take various cups, to suit different radii; this is for leather fillets from $\frac{1}{8}$ to $\frac{3}{4}$ in.

Taper.

Taper is often a sore subject between pattern shop and foundry, and on this one point alone, both with patterns and core prints, a good patternmaker with judgment is an asset, and he may be expected to give a correct angle between the 45 deg. the foundry asks for and the 90 deg. usually given.

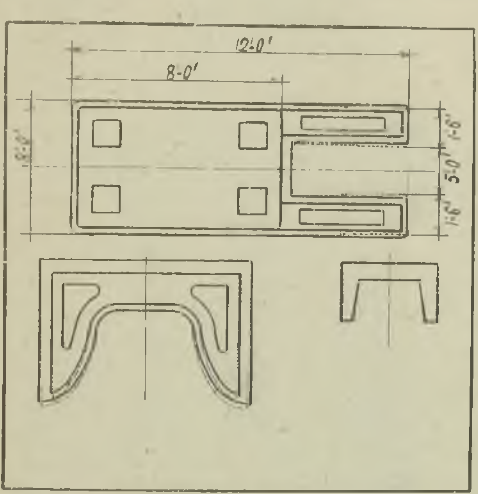


Fig. 2 shows a Bedplate, Bracket and Channel.

Splitting Patterns.

The splitting of patterns is another debatable point. The ideal pattern is, of course, the one that is split right along the parting line, no matter how irregular that may be. This is seldom possible, but a patternmaker should remember that this is the ideal, and it is something between that and the solid pattern which is correct, taking into consideration the design, number off, etc.

Fig. 3.—Showing some of the Castings Used in Lighthouse Construction.

Contraction.

Contraction is another subject when the patternmaker of judgment comes into his own. How often do we hear, " But I worked to the contraction rule," in a tone that implies it is the beginning and end of all things. Even a plain plate, say 1 in. thick, where everyone would agree (if discussed at all) that the thickness would gain, is made to the contraction rule, when the pattern should be at least 1-32 in. undersize.

When castings are made from pattern plates and these have in turn been made from iron-masters, the necessity of judgment is even more essential; and for many castings, such as stove, grate and electrical work, say 3-16 in. thick, the masters, if made from rolled plate metal, should be 1-32 in. less to allow for the gain that takes place.

In dealing with larger castings the size and shape must be considered in making contraction allowances, and the following illustrations will, no doubt, be interesting.

The top diagram of Fig. 2 shows a large bed plate, approximately 12 ft. long, the main square portion being 8 ft. × 8 ft., with long projecting arms on each side extending out 4 ft., these arms being 1 ft. 6 in. wide. Patternmakers would allow the ordinary contraction, say, 1-10 in. per ft. on the main portion, 8 ft. square, but between the arms at the extreme end there is 5 ft. of sand. This dimension should be made to the standard rule, and gradually die back into the main body of the pattern. At these points there is no metal to contract, and in the cooling of the casting the tendency is to force the arms outwards.

In the case of a large double bracket, where the irregular internal rib and beading are of a similar section to the sides, one would expect the full contraction to take place along the straight portion at the top of the bracket, but where the ribs join the sides at the bottom the irregular shape causes partial contraction, and it will be found advisable to allow only half the usual contraction on this dimension.

With the channel shown in Fig. 2 a similar action takes place, and should the flanges be very deep there would probably be no contraction at all. In fact, the cooling of the metal in this case might have a tendency for the flanges to incline outwards.

For some years the author was engaged with a well-known firm of lighthouse engineers, the only firm that manufacture the complete structure from the base to the weathervane, with the exception of any masonry work; this, of course, being a separate branch of engineering. The towers of lighthouses are constructed principally of cast iron. From a patternmaking point of view, this kind of work is very interesting. It is proposed to illustrate some methods of the construction and marking out some of the principal patterns, such as the diamond frame, top carriage, and the peculiar shape racks.

The diamond frame shown in Fig. 3 forms the outside framework of the lantern, and is fitted with plain glass. This acts as a protection chamber for the optical apparatus.

The helical framework (Fig. 4) is constructed in sections, the number varying according to the diameter of the lantern. It is, of course, only necessary to make one section for the pattern. This is built up on a ramming board A. The outside diameter of the frame radius B is struck to standard rule. The outline of the pattern is then marked

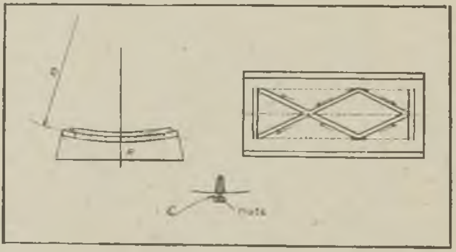


FIG. 4.—HELICAL FRAMEWORK FOR LIGHTHOUSE CONSTRUCTION.

out on the board, also to standard rule, along the strips in the directions shown by the arrow marks, the contraction being added. The outline is again marked to the new points found, this gives the shape and correct length for the pattern.

The pattern being in strips and fragile is made of mahogany in short lengths, dovetailed in one another, each part being dowelled in position on the block before cutting to shape; this portion of the pattern is finished, and forms the part that is in the drag.

The strips C, which run the whole length of the pattern, are also made loose and in short lengths, fitted with sockets that match the corresponding dowels in the frame. The strips C are placed in position on the pattern after the drag is rammed and the block removed. The section of the frame follows the radius, and, looking along the strips has an elongated screw formation; this is the reason the frame is made in parts, so that each can be drawn separately from the mould. As the full contraction only takes place along the length of the strips, the horizontal one forming the top rim has to be set slightly inwards, as the frame is only connected in the centre.

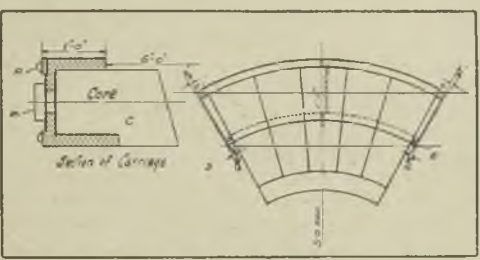


FIG. 5.—TOP CARRIAGE PATTERN.

A recent invention consists of an arrangement called the light valve for unattended lights. This has recently been patented by Messrs. Chance Brothers & Company, Limited. It is affected by the daylight, and at present used for acetylene lights. It operates a valve which shuts off the gas in daytime, and allows the gas to pass freely at night, a small bypass, of course, continually burning. This action is caused by two small glass bulbs connected, each being half-filled with ether; one of the bulbs has a coat of black, the other clear. The light's rays on the black bulb causes heat, which raises the ether, forcing it into the clear bulb. This overbalances the lever, so shutting off the gas, and at night the reverse action takes place, and allows the gas to pass free to be again ignited by the small bypass flame.

Top Carriage.

With the top carriages (Fig. 5) these are made up of four, six or eight segment castings, according to the diameter of light required. This pattern is built up with two rows of segments, one at the front and one to form the taper of the print. The top and bottom plates are let in, these being sectional pieces of wood radiating to the centre, thus adding to the rigidity and preventing any warping likely to take place. The beading A is made loose in two or three parts, to be drawn in after the main body pattern is removed from the mould. The cores B are for inspection holes; these holes have a small beading round. These cores are placed in position before the main core C. If the carriage is of a light type design and not very deep the whole front panel of the pattern, in two or more parts, is made loose and drawn afterwards.

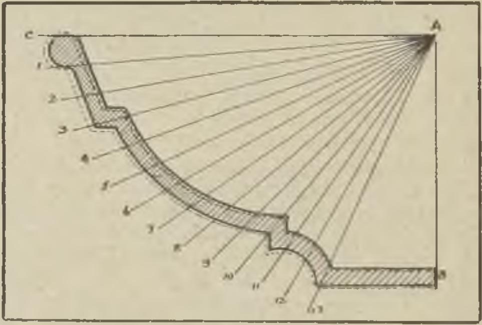


FIG. 6.—CORNICE AND GUTTER.

In this case the cores B will not be required. In setting out after the segment is built up in its rough state and planed to the proper depth, taking the example cited, the outside diameter being 8 ft. and the inside 6 ft., the 3-ft. radius of the inner circle is struck to standard rule, the width of the segment, 1 ft., is marked off by contraction rule, setting the trammels and maintaining the same centre the curve is drawn, then on the inner circle to the standard rule points D and E are found, equally on each side of the centre line. From these points radiating lines are drawn, cutting the outer circle at F and G. Next a cord line is drawn through points D and E. And the contraction is added on this cord on each side, and parallel lines are drawn to the radiating lines. This gives the contraction on the length of the pattern. From personal experience of patterns of this or similar designs, very little perceivable alteration of the curves takes place; if anything, the outer diameter of the segment has a tendency at the extreme points to open out, and this method of setting out gave the best result.

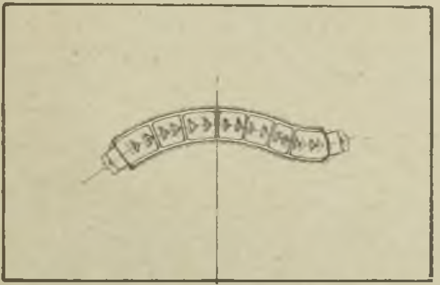


FIG. 7.—THE RACK PATTERN.

Cornice and Gutter.

With the cornices and gutters of the lantern there is a very irregular section to deal with, being in most cases of an ornamental design. The pattern is made in hardwood on a ramming block. The reason for this is that lighthouses are of various designs, and very seldom can the pattern be utilised again. If required for repetition work, of course, the pattern would be made of iron. Work similar to this requires care in adding the necessary contraction. Fig. 6 shows an ornamental gutter. This was set out from the drawing exactly full size to the standard rule, the vertical line A, B is drawn, and the line A C at right angles to it. A series of points, 1, 2, 3, 4, etc., are marked on the main features of the section, and lines are drawn radiating to the point A. These lines are measured with the standard rule and the contraction added. It will be noticed the dotted line gives the exact outline for the pattern. If this method be adopted for adding contraction to irregular work of this description many anxieties will be overcome in the pattern shop.

First order quadruple flashing, light flash equal to 400,000 candles, gives four flashes in quick succession every 15 seconds.

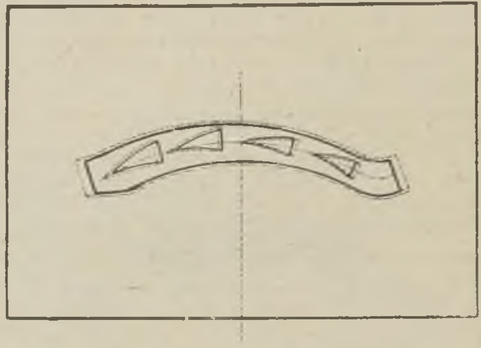


FIG. 8.—DETAIL OF THE RACK PATTERN.

The weight of the lenses, with table, etc., revolving in the bath of mercury is 4 tons.

Racks.

The gunmetal racks of the flashing apparatus carry and support the refractor and reflecting prisms, some of which run vertically through the light, and others at different angles; the latter are termed projection racks. In many cases there are twenty prism-shape holes. The patternmaker works from a tracing, which gives the outline and position of the holes when cast (Fig. 7), an allowance of 2mm. all round for fixing the glass prisms in plaster is given. Some racks are solid, and others are lightened out. Dealing with the latter, these are generally right- and left-handed, so they can be made in pairs. The backs are approximately 3-32 in. thick, strengthened up to $\frac{3}{8}$ in. by means of ribs around the rim and bars between alternative holes. The contraction of these racks has given considerable trouble on occasion, but it was successfully overcome by the following method of setting out.

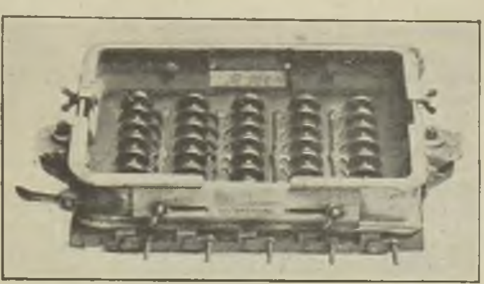


FIG. 9.—PULLEY PLATE PATTERN.

With a pair of racks the backs are planed to the 3-32 in. thick, and tacked together by small panel pins. The tracing is placed on top; the outline is pricked through. On removing the tracing the outline is drawn with pencil, and through the centre of the rack a line is drawn, striking each centre point of the holes. This is the construction line, on which is added the contraction, working from the centre of the rack, first to the right and then to the left. The points now found give the position to mark the holes on the pattern. These holes are cut square through, taper being cut after

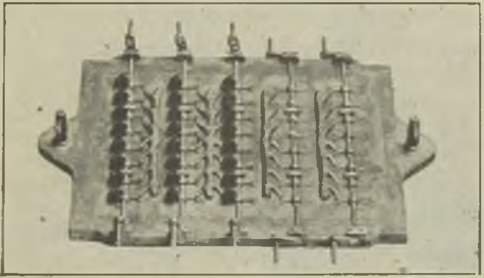


FIG. 10 SHOWS THE STRIPPING ACTION OF THE PULLEY PATTERN.

separation. The strengthening ribs around the rim and bars are added on reverse sides of the plates, thus making them right- and left-handed (Fig. 8).

Speaking on contraction, it is to be clearly understood that it is not the author's intention to enunciate any fixed methods of setting out work. Many points must be taken into consideration by the patternmaker.

Fig. 11.—Wood Pulley Plate Pattern.

Metal Patternmaking.

Metal patternmaking is not a distinct trade—practically the same knowledge is required as in wood patternmaking. Pattern plates have been in existence for a long time, but have increased during recent years owing to the demand for castings of a repetition character. Many advantages are gained by metal over wood; the metal does not warp, neither are the dimensions seriously affected by the atmospheric conditions, and with care, endless number of castings can be made from plates. With pattern-plates, the joints and runners are already formed, thus saving the operation in the foundry. If it is decided to have a pattern plate it is essential that the workmanship should be of the best. The design governs the class of plate to construct, either an all-cast, reversible, plain, turnover, or stripping plate. Where a plate is used on a moulding machine it is advisable to be at least ⅝ in. thick, and if a wood plate is used, which is sometimes the case, the plate should be 1¼ in. thick; this should be the minimum to prevent springing when being rammed. All plates need attention after using, and should be thoroughly cleaned and dried before placing in the stores. Some standard should be observed between pattern plates and moulding boxes to suit the general requirements of the particular foundry, but this should not interfere if output is to be maintained. Although pattern plates are not by any means a new method for production, there is certainly great room for extension in this country if we are to meet the foreign competition. Money spent on the installation of plant, such as moulding machines, pattern plates and suitable boxes, will not be regretted, if the ultimate result is the regaining of a large proportion of the world's trade.

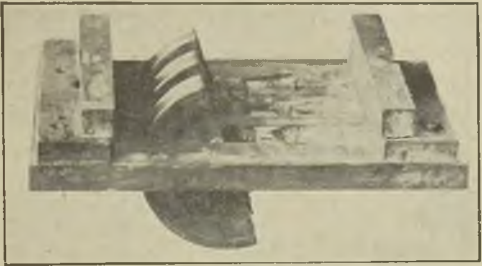


FIG. 11A.—THE STRIPPING ACTION OF FIG. 11.

Pulley Plate.

Two pattern plates recently completed by the author's firm no doubt will be interesting, although nothing is claimed as novel in their construction; both are pulley pattern plates. The first (Fig. 9) is a small sash pulley, $1\frac{3}{4}$ in. dia. by $\frac{1}{4}$ in. wide, and on this plate are 40 half-patterns. The plate can be termed a combined stripping and pattern plate. Each row of the gun-metal patterns revolves on a spindle running the width of the plate in a half-round groove. On each end there is a lever to revolve the patterns out of the mould after ramming. The spindles act as coreprints, being the diameter of the holes required; around each half-pattern the usual white-metal joint is run, holes being cast with a dovetailed slot in the plates. This holds the metal securely in position. Tops and drags are rammed from the same plate, reversing the top when closing on. Fig. 10 shows the stripping action.

Wood Pulley Plate.

Fig. 11 shows an 8-in. pulley plate. It is made on similar lines to the smaller pulley, but in this case both patterns and plate are of wood, the plate being 1¼ in. thick, which should be the minimum. The same method of moulding is adopted, both top and drags being rammed off the same side of the plate. The only difference is that instead of levers to draw the patterns a steel handle is attached to the centre half-pattern at the back. By this handle the moulder slightly revolves the patterns, then completing the draw by handling the patterns. The spindle is the size of the cores and form the core prints. The number of boxes laid down per day of the small pulleys average 60 and of the larger pulley 30. A snap flask is used for the 1⅝ in., and an iron moulding-box for the 8-in. dia. Fig. 11A shows the method of stripping.

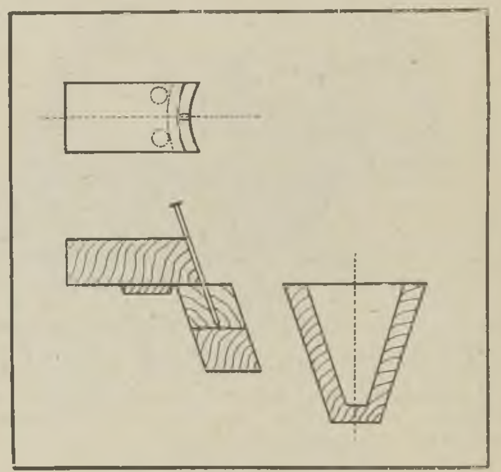


FIG. 12.—SEGMENT JIG.

A useful pattern-shop idea is a jig used in the rapid construction and building-up of tapered patterns, such as bell valves, etc. (Fig. 12). This jig is made of hardwood, cut to the angle of the pattern. Two small bosses at the back form the guide, the front edge being to the centre of the segment. A small groove is cut the same diameter or shape of the nail in the plate. The nail is inserted and driven in half way. The jig is removed, and the nail finally driven home. Where there is a number of rows of segments to be built up the jig gives the correct angle for nailing, and the patternmaker need not fear when turning his job of running into nails.

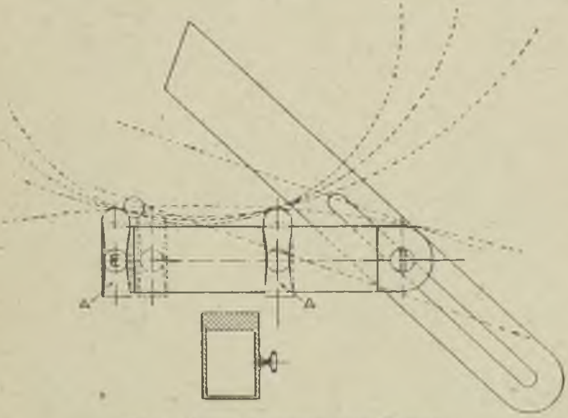


FIG. 13.—ADDITION FOR BEVEL.

A Bevel Arrangement.

Another useful arrangement is an addition to a bevel. When the two clips A, shown in Fig. 13, are added to an ordinary bevel, a simple yet effective arrangement is obtained for getting angles on circular work from a small circle to the straight line. The illustration shows a few circles drawn, a clip being detailed in section. It has been found beneficial on all kinds of circular work, such as tanks, towers, etc. It will also be noticed that the clips can be used on internal work. They work on the shank of the bevel; slides, like a pair of trammels, being fixed in any position by the small screws E.

Spring Compasses.

Another serviceable tool is the single shaft spring compasses; most patternmakers, no doubt on several occasions, have had to strike circles or semi-circles in acute angles or on work where it has been impossible to use an ordinary pair of spring dividers or compasses. With the instrument shown in Figs. 14 to 17 one is enabled to get circles on square work or circular work. The plan (Fig. 16) shows that the small shaft can be placed in any position on the main shaft by adjusting screw A. The spring on the cutter gives a marking pressure. It may be fixed by screw B, and by the same screw the strength of the spring pressure can be regulated. Figs. 14 and 15 give acute angles, and the sections may represent a straight or circular plan. The two views show the spring, which is attached at C (Fig. 16), extended and contracted. The screw D sets the diameter of the circle required. In Fig. 17 is shown the operation of striking a circle inside a core box on a semi-circular surface. The small block X is to hold the centre point.

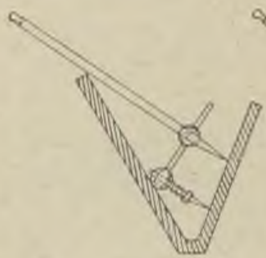


FIG. 14.

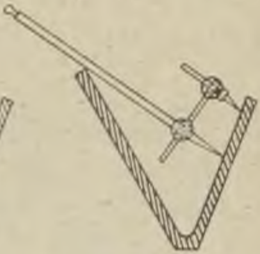


FIG. 15.

Band Saw Guides.

Fig. 18 shows a guide for a band saw. In most pattern shops the breaking of saws causes delay and annoyance; two or three sometimes break in a day. In most band saws that have come under the author's notice the guide of the saw has been provided with wood blocks, either all wood or wood blocks fixed in metal guides to steady the saw when running. At the slightest wrench the teeth catch the wood, straining the saw and wearing the blocks. In the guide illustrated the saw, whether for wood or metal, runs between four small pulleys in separate plates A and B, with springs attached when operating the saw. At the slightest twist the springs give, both right and left, thus preventing at least half the breaking—a great consideration in the cost of brazing and renewals of bandsaws, as well as the time spent in refitting wood blocks into guides. In this case the guide is all metal. The back of the saw runs on hardened steel ball-bearing roller C. The cap is screwed to $\frac{3}{4}$ in. in gas thread to clear the ball bearing, the diameter of which is 22 m/m., and the shaft 8 m/m. The front and side elevations show the guide without the face plate D, which is screwed on last when plates A and B are in position. A detail shows the clearance for the back roller in plates A and B.

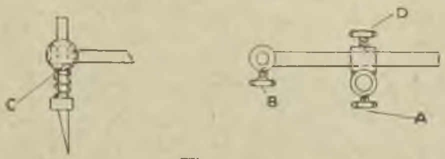


FIG. 16.

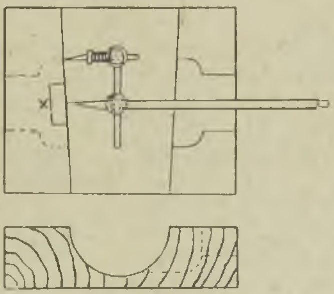


FIG. 17.

The shank E must be made to suit the existing slide of band saw. The plan shows the plates in position and guide complete.

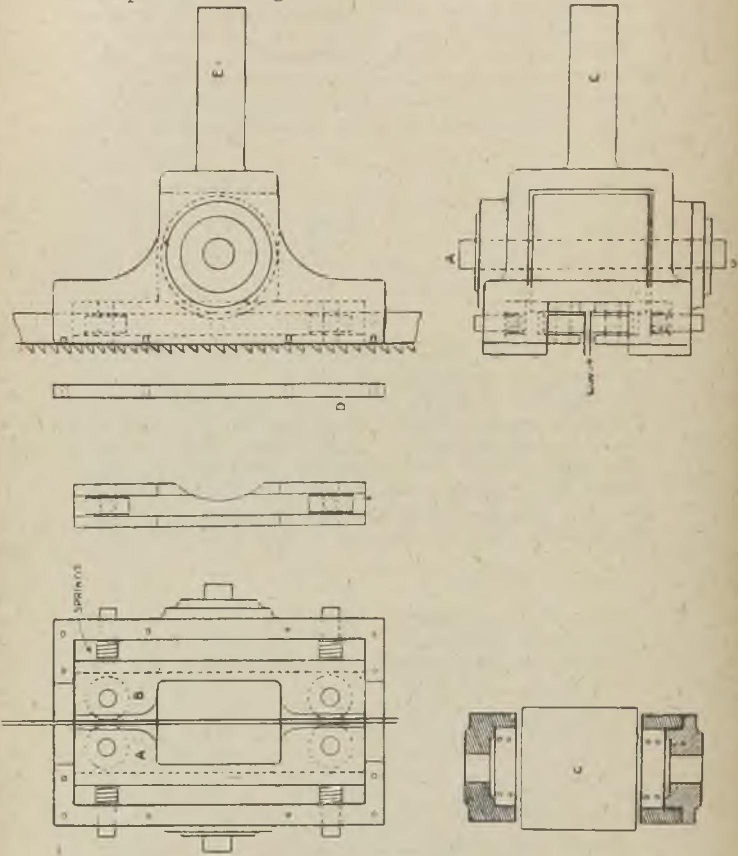


FIG. 18.—SPRING GUIDE FOR BAND SAWS.

In conclusion, the author would like to express his thanks to Messrs. Chance Brothers, Smethwick, Birmingham, and to the Editor of the "American Machinist" for courtesies extended to him in the preparation of this Paper.

Lancashire Branch.

JOLT-RAMMING MOULDING PRACTICE.

By A. L. Key, Member.

The purpose of presenting this Paper is primarily to present the author's practice with jolt-ramming machines. It is not intended in any way to assume that the practical application is intended to represent the last word on jolt-ramming, in so far that this system is still full of possibilities. For progress for the foundryman there is great scope, provided that he is prepared to undertake a fair amount of extra work, for personal attention is *sine quâ non* until each individual job is established.

Any scheme for increasing production should be considered, first from the aspect of its effect upon the workman, for if speeding up of production has to be done, it should not be considered if it is going to inflict unnatural conditions on those who have to provide the physical power. From this point of view alone the jolt-rammer highly commends itself, inasmuch that the saving in direct energy is remarkable. The increase in production and quality is governed by the general lay-out of the job, a small amount of common sense, and local conditions. Local conditions are mentioned, mainly for the reason that physical energy and adaptability varies in different areas, so that in changing over from one system to another, results must be compared locally.

Any of the castings which will be illustrated in this paper are not ordered in large quantities at one time, therefore the tackle has to be curtailed to accommodate those conditions; but, on the other hand, if large quantities could be ordered at one time, additional tackle and apparatus could be set up, which would further minimise the human fatigue and also increase the saving in cost, with a relative increase in production. Even with the above limited quantities, the net cost of production of the above subjects will compare very favourably with the net cost of production of other countries where quantity production prevails.

Principles of Jolt-Ramming.

How far back the system of jolt-ramming moulds can be traced is somewhat obscure. Possibly the idea may have emanated from a grocer's shop, for the principle is quite similar to packing sugar in a bag by simply dropping a bag full of loose sugar on the counter a number of times until the sugar becomes closely packed. The resultant action may be defined as "an arrest of the force of gravity." This is exactly what happens when sand is being rammed or packed by means of jolt-ramming. Perhaps "sand-packing" would be the more correct designation, for what is actually produced by the jolting action is a mould of closely-packed sand.

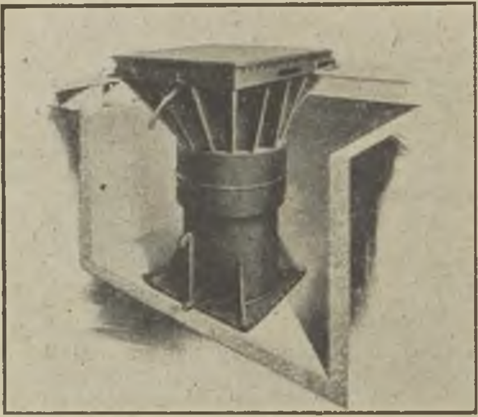


Fig. 1.—The Plain Jolt Machine.

Any mould can be produced by this method with more or less advantage where the pattern is of such a shape as to allow the sand an uninterrupted flow downwards. In quite a number of instances patterns which have overhanging projections can be dealt with without the necessity of printing or blocking by the aid of a certain amount of pre- or post-tucking or ramming underneath such projections.

It is essential that there should be an absence of vibration when jolt-ramming, otherwise the sand, instead of being packed evenly, will be in laminations, and is liable to flake off—more especially where flat surfaces are concerned—either in the bottom part or the top part of the mould. This can be avoided to a great extent by having good rigid patterns and pattern plates or boards. Wherever it is possible, the pattern should be fastened to the pattern plate or board. The moulding box should be securely fastened to the pattern plate, taking great care that the moulding box fits flat on the pattern plate without rocking.

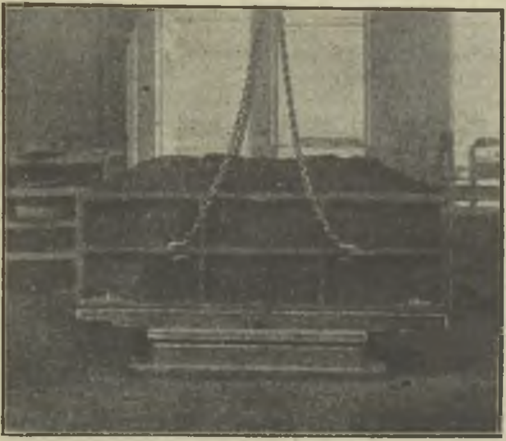


Fig. 2.—Box on Machine showing Overhang.

Briefly, rigidity and stability are absolutely necessary to obtain the best results from jolt-ramming.

Advantages of Jolt-Ramming.

There are quite a number of advantages in favour of jolt-ramming. A mould or core can be produced of fairly even density, for the sand is packed evenly all about the pattern or core box, being tight on the face of the pattern or core box, and gradually becoming less dense the further the sand is away from the pattern or surfaces of the core box. This should commend itself, for it is too well known how disastrous is the result of uneven hand ramming, with its evils of hard and soft spots near to the face of the mould or core. It interferes with the natural escape of the gas which is set up during the filling of the mould. Additionally, it causes scabs of various sorts, and sometimes local strains. Jolt-rammed moulds are naturally self-venting, and further, it is not necessary (provided that the sand is of the correct temper) to use a vent wire, as is so often the case with hand-rammed moulds, for the regular packing of the sand makes it self-venting. As a proof of this, a large mould, especially a dried mould, is a mass of blue flame all over the box after being cast, although a vent wire has not been used; this shows that the pore spaces must be in quite natural positions.

Castings produced by jolting are of a more uniform size and considerably better in appearance. As many castings previously made by hand moulding would need priming before painting, so as to give a nice enamelled appearance, now similar castings produced on the jolt machine do not need priming, for, speaking generally, they have good level surfaces. In fact, as the surface and the appearance of the pattern, so can this be reproduced in the casting.

Again, from the humane point of view, the saving in that most fatiguing work of hand ramming is nearly 100 per cent. When one considers that for every blow given whilst peg ramming there is used a force equal to 5 ft.-lbs. of energy, and at the same time a dead weight of 6 lbs. has to be lifted. It is interesting to note that it is sometimes necessary to lift a rammer several thousands of times to complete the ramming of some moulds. The jolt machine almost eliminates this fatiguing work, for, with the exception of butting off or flat ramming, the machine will accomplish in a far more satisfactory manner in one minute or less what otherwise might take a man several hours to accomplish by ordinary hand ramming. The larger the box the more this fact is brought in evidence. No mould that is rammed entirely by the jolting method should take longer than 60 seconds to ram the mould, whether for iron, brass, aluminium, or even steel.

Another great advantage of jolt ramming is that castings are less liable to develop blowholes. This comparison is taken assuming that both the hand-rammed mould and the jolt-rammed mould are prepared with sand of the same moisture content, and that the temperature of the molten metal in both cases is similar. Any number of castings can be produced similarly alike in weight or quality, once the necessary number of jolts has been determined so as to give the necessary density to the mould. This density can generally be predetermined after a very short acquaintance with the jolting method.

A great point in favour of the jolt machine has reference to moulding boxes, whereby quite a large range of sizes of boxes can be accommodated on one size of machine, varying from boxes any size less than the size of the machine table, to boxes 50 per cent. larger, or even more than this, above the size of the table, thereby making it possible for several gangs of men on different sizes of boxes to make full use of the one machine without

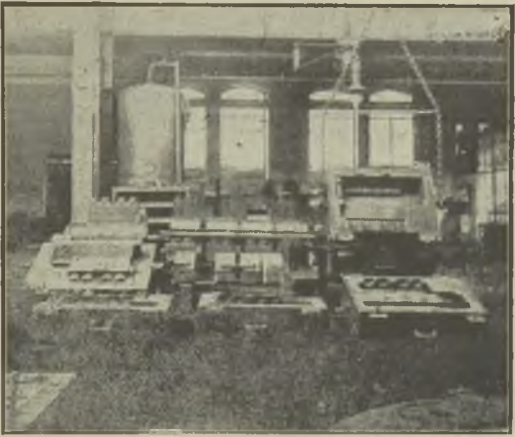


FIG. 3.—WALLIS TRACTOR MOULDS.

By using the jolter for this job 60 per cent. in cost and 150 for gains in production were shown. Three moulds are made in 8 hours.

having to use any adaptors or other contrivances which are necessary on some other types of machines when changing the sizes of boxes.

Types of Machines and Installation.

There are several types of jolt machines in use, the simplest and most versatile being the plain jolt machine such as is shown in Fig. 1. This machine takes a 30-h.p. motor and a compressor developing 300 cub. ft. of air per min. The machine consumes 213 cub. ft. of air per jolt. The diameter of the cylinder is 20 in., the stroke 2¼ in., and the size of the table 6 ft. by 5 ft. It is capable of lifting 10 tons at 100 lbs. per sq. in. pressure.

There are also several machines which have pattern-drawing arrangements, and also arrangements for turning or rolling the mould over after it has been rammed.

In considering the installation of a jolt-ramming plant, there are many factors which control the selection of the most suitable type of machine or machines. One can sometimes see lying derelict large machines of an elaborate type, owing to the wrong type of machine having been installed. Possibly the machine was thought suitable for a special job, but was unable to be kept fully occupied owing to insufficient quantities being required. Here a machine of another type would have embraced a sufficient variety of work to keep it fully occupied. The class of labour that is intended to operate the machine is an important factor, for, although the writer's work is all produced by skilled labour, with the most satisfactory results, work can be produced quite satisfactorily with semi-skilled labour, provided that the class of work and other conditions are made suitable. It does not necessarily follow that semi-skilled labour will always prove the most economical, for several instances are in evidence where it has proved considerably more economical to employ the best of skilled labour.

Perhaps the primary factor in considering jolt-ramming is the stability of the foundry buildings. for the earthquake which is set up when a fair-sized plain jolt-rammer is working is very considerable, and sometimes travels much farther than the foundry. Several instances of this have occurred, and the effects have caused a considerable amount of expense to remedy.

The cost of installing a jolt-ramming plant will compare very favourably with other types of power press and squeeze machines, with the advantage of versatility in favour of the jolt machine.

The position of the machine or machines in the building is also of great importance, for in the case of the plain jolt machine, which is simply a ramming apparatus, much valuable time can be wasted by the unnecessary conveyance of moulds and materials.

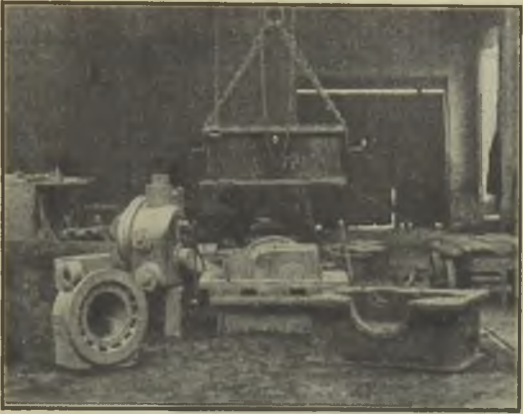


FIG. 4.

Cylinder end casting. This casting requires 60 jolts for making. The method shows 50 per cent. and 100 per cent. gains on cost and production respectively.

Lay-Out and Tackle.

Lay-out and tackle should be very carefully studied, as on these items the success of the plant largely depends. Sand-preparing, conveying and lifting facilities, proximity to drying stoves and cupolas and moulds bedded in the floor, pattern and moulding-box accommodation, convenience for the safe-keeping and easy access of all small tools and tackle, pattern and pattern-plate lifting apparatus, loose pieces, etc., require careful consideration.

Moulding boxes should be of definitely rigid construction, not necessarily of heavy section, but designed specially with a view of obtaining a combination of the maximum of rigidity with a minimum of weight. This is very important, for vibration must be minimised to the utmost degree, for here is quite a common cause of many failures, more especially where the design of the pattern is inclined to have flat surfaces.

Fig. 5

Small flywheel castings. With 5-h.p. jolting machines 59 per cent. cost and 145 per cent. production gains were registered. Transferring to 9-h.p. machines, the figures were lowered to 67.5 and 136 per cent. respectively.

Vibration has been mentioned previously, but has been purposely mentioned again for the purpose of emphasising this point. Wherever possible, cast the moulding boxes in one piece, although quite successful results can be obtained with boxes built of loose plates, provided that after bolting the box sides and ends together, holes are drilled and fixed dowels inserted in those flanges where the box sides and ends have been joined. Wherever possible, it is advisable to plane or mill the joints of moulding boxes where the joints have to rest on the pattern-plate or board. This outlay will be amply repaid. Projections on the inside of boxes, such as bolt heads or nuts, such as are encountered when fastening loose bars, are not desirable, for the projecting nuts interfere with the flow of the sand and cause weak places, which are liable to cause the sand to fall out of the box, as in the case of a top part which has to be turned over.

Built boxes are not recommended for top part boxes, but should this be necessary, then the better alternative to bolting in loose bars is to cast a series of lugs along the box side and arrange for a slot, cast vertically in each lug, as this then makes it possible to have flat plates for the box bars, which can then be fastened into position by means of iron wedges.

Fig. 6.

Group of G.R. bed tackle. The bottom half is given 45 jolts to the top 60. The box is 8 ft. x 3 ft. 6 in. x 2 ft. 10 in. A production gain of 88 per cent. is shown.

Loose, steady or registering pins can be used, but where fine limits are concerned, such as with very thin sections of metal and perfectly accurate joints, fixed pins are more satisfactory. In any case, fixed pins should be used for registering the moulding box on the pattern plate.

The standard limits of clearance between pin and pin hole is 0.015 in. for the 1¼-in. pin and 0.005 for the ¾-in. pin. These two sizes of pins have proved quite equal to accommodating quite satisfactorily the smallest size of box as well as the largest.

Any less clearance than that mentioned for the 1¼-in. dia. pin has been found to give trouble in assembling the top and bottom boxes, especially in the case of stove-dried moulds, as the difference in size and weights of the top and bottom box affects the expansion and contraction sufficiently to cover up the small amount of clearance in the box pins. Cotters have proved both very effective and expeditious as a means to fasten the moulding box to the pattern plate or board.

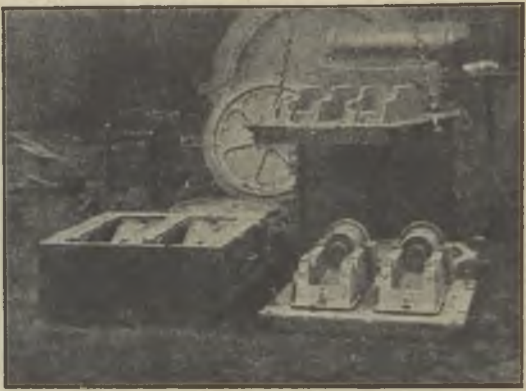


FIG. 7.—TWIN BED CASTING.

By jolt ramming 66 per cent. cost gain and 200 per cent. production gain were shown.

For mounting patterns, either plates or boards can be used, the choice of which can be readily determined after a short acquaintance with the jolt-ramming process. Boards are to be preferred, wherever possible, mainly on account of their portability, while, on the other hand, C.I. plates for the heavier boxes are advisable. The difference in the initial cost is not great, while the difference in durability is considerably in favour of the C.I. plate. Flat plates or boards are not ideal, as any sand which may cling to the underside of the plate, or which may have gathered unnoticed on the jolt table, will prevent the plate from resting flat on the table, such conditions are liable to cause vibration. A lighter and much more rigid plate can be made by means of webbing the plate on the underside. This is an advantage in cases where the pattern plate overhangs the table, as shown in Fig. 2.

FIG. 8.—CORES AND A CORE JOLTING MACHINE.

Patterns which are to be moulded by jolt-ramming should be strongly constructed, for the duty of the pattern is very trying. Blocking-up or printing-up overhung parts on patterns should be avoided as much as possible. This can be overcome by a very small amount of extra hand-ramming, which results in an improved appearance on the casting than otherwise would have been had core prints been resorted to. It is generally known how unsightly core-marks show up on the face of a casting unless the joints of the core and the mould are very carefully stopped in.

The condition and temper of the moulding sand plays a very important part in the success of jolt-ramming. Sands of a sharp nature flow easier than sands which are of a woolly or tough nature. These differences can be more or less regulated by judicious tempering; therefore, this is a very important factor to control, for in all cases the drier the sand used, the nearer natural flow is realised.

In conclusion, the author wishes to thank his firm for courtesies extended and to Mr. Brierley for help in the preparation of the illustrations.

West Riding of Yorkshire Branch.

SHOULD PIG-IRON BE BOUGHT BY FRACTURE OR ANALYSIS?

By Robert Buchanan (Past President).

Recently there has been an awakened interest in this question, partly due to the advocacy of some American friends; but really the question has always been with us to a more or less degree. More than 20 years ago the author came out boldly for analysis alone, and said that if he obtained a certain required analysis he did not care under what conditions the pig-iron was made, or what fracture the iron showed. Since then, with a wider experience, he has had to modify his views, and is not so certain of this opinion as he was then.

The subject is such a large one, and the effects on the ironfounding industry are so important, that it is very necessary for full consideration to be given to the question.

Sale and Use of Pig-Iron by Fracture.

This is the traditional British method, which has been in use since the rise of the iron trade in this country, and is much prized by many foundrymen to-day. Others use a combination of fracture and analysis. The latter is a growing practice, and has much to commend it. Of what is the particular fracture a product? This is due to the influence of a great many contributory causes. Fracture is affected by the kind of ores used—by the temperature and quantity of the blast used, the regularity of the descent of the furnace charges, the temperature at which the ores are reduced from oxide to iron, and the rate of cooling of the iron on the pig bed. These are only some of the physical causes affecting the kind of fracture.

What of the chemical causes? There is not one constituent but affects the fracture in more or less degree. Silicon, for instance, in moderate amounts, say, from 1 to 2 per cent., has the tendency to open the grade, other things being equal. When the silicon approaches 4 per cent. it closes the grade again as its usual effect. In fact, some high-silicon iron is as close as some low-silicon iron, and unless one analyses it is only a practised eye which can tell whether the closeness is due to low-silicon or to high. The author's method of deciding whether the closeness is due to low- or high-silicon when viewing the pig-iron, is that in the case of the high-silicon it has a brighter sheen on the surface, as if there were many small diamonds present. A similar closeness of fracture is duller when the silicon is low.

Definition of "Closeness" or "Openness."

Either term is really an attempt to indicate the size of the crystals of iron in the mass, as also the size of the graphite plates. On the authority of Professor Turton, F.R.S., a noted crystallographer, it can be stated that these crystals are not pure iron, and they usually have some manganese as a constituent. Another very powerful chemical influence on "closeness" or "openness" is sulphur, though the author is not in agreement with the opinion that sulphur in all its degrees is harmful. On the contrary, it is very useful in many cases. He agrees with Thomas D. West, who said there was no good iron and no bad iron; it all depended on the use to which it was to be put.

The carbon also has a marked effect on the fracture, not only from the quantity of carbon present, but also in what condition it is in, whether in the combined form or in the free or graphitic form. And, again, on whether the graphite carbon is massive or finely divided. The latter, however, is more due to the furnace conditions than to any other cause.

One could follow this reasoning as regards the manganese darkening the fracture, and phosphorus lightening it, but enough has been said on the chemical aspect so far as it affects the fractured appearance. Speaking generally, open-grained iron is weak; close-grained irons are strong. To the latter statement there are well-known exceptions even in grey varieties of pig-iron. White and mottled irons are always weaker than similar make of iron which is grey and close-grained.

Effect of Blast Conditions on Pig-Iron.

The effect, on fracture, of whether the iron is being produced in a blast furnace using cold blast, semi-cold blast (400 deg. C.) or hot blast, can be stated from experience to be that cold-blast and semi-cold blast iron generally have a closer grained fracture for a given analysis than hot blast iron. This is due to the finer divided graphite in the last two. Hot-blast iron of a given analysis has the graphite more massive than the other two irons, and thus shows more open fracture. But high-blast temperatures and rapid production have effects not discoverable by fracture or analysis. Physical tests, cleanness of melting and the finished casting provide the means known at present by which these differences can be ascertained.

Fracture, or grain structure, and analysis of two irons may agree, and yet the physical results be widely apart. This was shown years ago at Swedish blast furnaces, and they came to the conclusion that gases dissolved in the iron were the cause of the iron made at the higher temperature being weaker than that made at the lower.

To judge iron by fracture alone may be deceptive, in so far as the cooling conditions on the pig bed are unknown to the user. The hot pig-iron may, and often is, quickly cooled by a hose-pipe for quickness of handling. The result is a closing of the grain. If the blast furnaceman wanted a specially open grain, he could cover the hot pigs with a thick coating of sand, but exigencies of output will not allow that even if he wanted to. And so in the case of very large pigs which show large crystals, these, and the two cases mentioned, when melted in the cupola, will revert to their original real quality, irrespective of their original condition as pigs.

In judging pig-iron by fracture, there is plenty of room for error, but experience in mixing irons by fracture, coupled with a knowledge of the blast-furnace conditions under which the iron is produced, will help to obtain the best results within limits.

Analysis.

When analysis of pig-irons became fairly common many thought that they had come pretty well to finality as regards the quality of pig-iron and their knowledge of it. Then they supplemented analysis by using the microscope. Then they supplemented the microscope by tensile and transverse tests. Now it is proposed to supplement these aids to knowledge by using shock tests. The fact is, those interested are looking each time at a different facet of a diamond, but still the same diamond, and as yet it is not quite known what the diamond really is. Analysis is one facet of the diamond, and an important one, but it is not the whole diamond; neither is fracture. Physical tests are more important than either. For physical tests, grain structure is more important than chemical purity.

As regards analyses of pig-irons, some foundrymen have a rather pathetic faith in analysts. In the foundryman's view, or in the view of many, analysts never make mistakes. If they do not, they are unlike the rest of humanity. One could readily give instances of discrepancies between the findings of different analysts on similar samples, but not so much as one would find between different foundrymen melting similar irons.

Analysts, though not more perfect than foundrymen, yet fill a most important place in the foundry world as an aid to the knowledge of foundry materials. They are a help before the foundryman begins his work, and a corrective if he fails to do it right. In Keighley, foundrymen are fortunate in having a public laboratory under able management, and it says much for the enlightened view of local employers as to its usefulness to the foundry industry.

The analyst can indicate very closely the constituents of the various irons to be used, but unless the foundryman knows also the changes which will take place during the course of melting these irons, the results need not necessarily be all that is required by both maker or buyer.

Two distinguished American foundrymen, Dr. Moldenke and Mr. Walter Wood, who recently visited the country, advocated the standardisation of silicons and sulphurs principally, and in some degree the fixing of minimum total carbons. The difficulty in heavy engineering is to keep the total carbons down. The silicons our friends showed, with their related sulphurs, were wrong in the author's view. These showed the lowest sulphurs along with a related low silicon, and the highest silicon with the highest sulphur. In British blast-furnace and foundry experience, it is generally the reverse. Here high silicons connote low sulphur, and low silicon usually has higher sulphur.

Buying to Fracture and Analysis.

It is often complained of how variable in their working blast furnaces are, and undoubtedly they are very delicate giants which sometimes behave like children. They are even affected by the weather, but their variability, like a certain section of the community, is one of their charms.

What would foundrymen do if every furnace never took the " pot " and refused to change from one grade of iron? Where would the ironfounder be who had a different job to cast and had only one source of supply and one grade? It is the " infinite variety " of the blast furnace which makes the blast furnaceman tired, and conduces so much to the comfort and happiness of the foundryman.

Were buying to fracture and analysis universal, the blast-furnace people would be in for a bad time. The iron, as it comes from the furnace, may have three grades of fracture and three differing analyses from one cast. Picture the half of a pig bed being carried on a travelling crane to the pig-breaker. Where should a drilling be taken for analysis? From the pig nearest the furnace, or from the pig farthest away? Or from a mixture of these two pigs? Would either or both represent the pigs as a whole? They would not be definitely accurate.

Obviously, there has to be compromise on a general average of analyses. Thus, if one took drillings for analysis of the iron in a ship's propeller, would one take it from the boss or from the blade? Either would not represent the other. The same could be said of samples from boss and blade for miscroscopic examination. The same may be said about test-bars out from the boss and blade. The ship's propellor is given as an extreme example of what, to more or less degree, obtains in most castings for engineering purposes.

Mr. Wood's Views.

Through the kindness of Mr. J. Wood, of Wakefield, who has had a very large experience in melting irons and seeing the products tested, the author is able to put the gentleman's views on record, which are:—

> During our conversation recently on chemical analyses of pig-iron and its effect on castings, I understood that you wished to convey, that unless one knows the chemical composition of the iron one uses, and mixes it accordingly, it is next to an impossibility to get sound castings and uniform results. In other words, that judging by fracture is a sort of happy-go-lucky method.
>
> This may have been true in the old days, but since the advent of the chemist in the foundry it has been proved beyond doubt that neither the chemical composition of iron nor merely judging by the appearance of the fracture are very reliable. What is really necessary is a common-sense application of both. To judge by either chemical composition or fracture without taking the physical properties of the iron into account is wrong, and not conducive to sound castings and uniform results
>
> ### Danger of Relying Solely on Analysis.
>
> As you are aware, we are large consumers of pig-iron, and during the time I have worked here, some twenty-five years or so, I have had the opportunity of seeing and using nearly all the important brands of pig-iron made in the kingdom, and I have made a study of the various characteristics of the different irons that have passed through my hands. To enter into details of all this at the present time would take too long, therefore I will just point out two or three cases where, if the iron had been mixed to analysis alone, serious results would have happened.
>
> Some time ago we accepted a large quantity of iron (some 700 or 800 tons). On analysing this

(several samples were taken from each consignment) the following results were obtained :—Gr. 2.25; C.C., 0.86; Si., 0.94; S., 0.048; Mn., 0.65; and P., 0.31 per cent. This iron, although of such a low silicon content, was of a very open fracture, very soft, and rather weak.

The works chemist suggested that the iron on re-melting in the cupola would come out very hard, owing to its low silicon content, and advised using it sparingly. I did not agree with him, and obtained the manager's permission to melt 10 cwts. of this iron by itself in the cupola after the day's blow. This was done. Some of it was poured into an open sand casting, a plate $\frac{1}{8}$ in. thick, 3 ft. by 4 ft. The remainder was poured into castings that had to be machined and put under 400 lbs. per sq. in. hydraulic pressure. Now, had this iron acted according to its analysis, the open sand plate would have undoubtedly split whilst undergoing contraction. But the reverse happened. The plate was perfectly sound, and on being broken up for examination, showed an open-grained fracture and machined easily. The other castings also machined easily, but on being put under pressure leaked at the top part of the casting, being porous from one end to the other. This shows that the low silicon content of the iron has not the effect it is supposed to have, as the iron was neither hardened nor the grain closed to any appreciable extent.

A Second Example.

Another example which shows that it is not wise to rely too much on analysis is shown by the following :—

A consignment of pig-iron was received and several samples analysed, with the following results :—Gr., 2.75; C.C., 0.66; Si., 2.26; Mn., 0.051; and P., 1.03 per cent. This iron gave a very close, dense fracture, and taken on its fracture alone, likely to give a hard casting. But judging it from its chemical composition it should give a soft casting, with good machinability. To test the physical properties of this iron, a quantity was melted and run into test bars, moulded in green sand. The first mould was stripped soon after it was cast and the bars allowed to cool in the atmosphere. The second mould was not disturbed until the bars were quite cold. The first bars were not machinable; the second lot were machined with difficulty. This again shows that too much reliance cannot be placed on the chemical composition of the iron. The above examples are by no means isolated. Almost every week we receive consignments of pig iron the fracture of which is not in accordance with its chemical composition and vice versa, and it would be an impossibility to obtain regular results did we rely on analysis alone.

On the other hand, it is not always advisable to rely upon the appearance of the fracture. It often happens that a close-grained iron (chemical analysis and fracture of which are in accordance), when cast, will have a more open grain than it had in the pig, and under hydraulic test, leak, thus showing its porosity. This class of iron can only be detected after careful examination, a casual glance at the fracture and one might conclude that it was an ordinary close No. 4, and would probably use it as such. But after careful scrutiny one sees the graphite flakes are extremely small, giving the fracture an appearance similar to that of a lump of fine sugar. An expert blast furnaceman explained that this is caused by the iron being rapidly cooled, which, if with a normal rate of cooling, would have an open grain. This is probably the explanation, because when re-melted and cast into a test bar or a casting of medium thickness, the grain is more open than in the original pig.

A High Strength Pig-Iron.

Another class of iron which gives remarkable physical properties, although the analysis does not warrant such, is shown by the following :—T.C., 3.25; Gr., 2.64; C.C., 0.61; Si., 1.34; Mn., 0.86; and S., 0.127 per cent. On the surface of this fracture is a fine network structure, a thin white network, the interstices of which are dark grey. This is generally found in an iron containing a fairly high percentage of sulphur. I have not been able to satisfy myself about the cause of this particular structure, but when examined microscopically and a sulphur print taken, one might suggest a theory as to the formation of the structure. The graphitic carbon is finely divided, possibly due to rapid cooling of the metal after melting in the blast furnace. This forms the grey background, while the white portion, *i.e.*, the network appears to be high in combined carbon. and from the sulphur print it is seen to be high in sulphur, and these conditions increase the strength considerably. One can only theorise as to how this structure is formed. However, there is no doubt about its physical properties. The test bar 36 in. by 2 in. by 1 in. cast from the above iron gave a transverse load of 50 cwts. The deflection at 40 cwts. was 0.40 in. The machine on which it was first tested only registered up to 40 cwts. It was then transferred to a larger machine, which is not provided with a means of measuring deflection. Another bar with practically the same analysis: T.C., 3.25; Gr., 2.52; C.C., 0.73; Si, 1.23; Mn, 0.99; S, 0.122; and P, 1.02 per cent. cast with pig-iron, but without the network structure, the pig-iron gave a transverse load on 36 in. by 2 in. by 1 in. of 35 cwts. with a deflection of 0.39 in. So that, although there is very little difference in the chemical composition of these irons, there is a great difference in the physical properties.

The last figure quoted, may be considered exceptionally good by the majority of foundrymen, but they are assured that they are the rule rather than the exception at the contributor's firm. This is only brought about by a very careful selection and mixing of the brands of iron without giving too much consideration to the chemical composition.

Major Miles's Contribution.

Major Miles, of Thorncliffe Iron Works, sent the following contribution, which the lecturer read.

It is brought home to me, more than ever, that only the bold or the very ignorant would nowadays affirm a belief in purely chemical or purely physical information. The reasons for saying so are as follows:—

(1) Modern scientific research has broken down completely the barrier that existed between purely chemical and purely physical effect. One has only to bear in mind, for instance, the recent researches in molecular structure and into the activity of protons, ions, etc. Another example is the behaviour of colloids. A further example which may be of interest to foundrymen is that Professor Wheeler has shown that neither CO nor CO_2 alone is formed where blast is applied to hot carbon, but an intricate "complex" of CO and CO_2 depending on the temperature and pressure. If purely chemical or purely physical effects cannot even be defined to the exclusion of the other, one obviously cannot base the results of tests of one to the exclusion of the other, for practical working and pretend to have full information.

(2) The foundryman's work is not only scientific —it is an art also. However much we reduce the

skill of the foundryman to applications of general rules and figures, there will still be a wide margin for the expression of the foundryman's experience and what I might call his personality. For all we know of the chemical and physical nature of pig-iron, it cannot be denied that a number of leading foundrymen, under certain conditions, use a judgment that is gained from their previous general experience, and not based solely on an array of figures, though these are used to supplement his experience.

(3) The question of cost must be considered. As is well known, the economic use of pig-iron does not depend on the least possible sum for which a given quantity of proportion of Fe, Si, Mn, etc., can be obtained; or the least possible sum the largest number of cwts. transverse; or tons tensile; can be obtained; though they are very helpful guides. It depends on the least possible sum for which the satisfactory casting can be completed.

From the point of view of a maker of pig-iron, the question of providing iron to analysis presents no difficulty, but if the iron required falls outside the practical limits of consistent manufacture, the extra handling must be paid for.

The "normal limits of consistent manufacture" can be described as, say, 0.25 either way in the silicon; 0.10 above the maximum for sulphur; 0.20 either way for manganese, and 0.10 either way for phosphorus, though as one constituent affects the other the number of permutations and combinations of the quantities of the elements in pig-iron is enormous, and consequently the chances of one or other of the above elements coming outside the specification are very great. Hence the limits of "off grade" iron are vastly increased. It must be borne in mind I speak from our experience at Thorncliffe, where we maintain a most rigid chemical control of our raw materials, and I doubt whether the makers of large quantities of common iron would agree to the limits I have mentioned.

But if strict limits of the analysis are insisted upon by the buyer of pig-iron, he must not grumble if the fracture is not quite to his liking, because other factors operate, as you have explained, and no blast furnace operator can control all the factors, all the time.

Who is to Analyse?

A practical difficulty would arise in analysing. This would have to be done at the makers' works, or else the price would have to be enhanced to allow for the freight on possible rejections. As it is essential that analysis be obtained within a few hours of the cast, it would require a neutral analyst to be in residence at the blast furnaces, and this, again, would increase the cost.

Adjudication of Value.

To sum up, my personal opinion may be stated as follows regarding the quality of pig-iron I would purchase, after ascertaining precisely the type of pig-iron I required for a certain job.

Out of a hundred marks for the perfect iron in all respects, I would allot :—

50	for analysis.
15	for physical tests (under the same conditions as the finished casting).
10	for cleanness in melting.
5	for appearance of the fracture.
20	for my personal prejudice.
100	

The views of foundrymen on this allotment would be of value for the various pig-iron makers of the country.

Conclusion.

The various aspects of the subject are not so simple as they appear at first to be.

If the ultimate decision should be for analysis, and analysis only, the position is a comparatively simple one, especially for the blast-furnaceman. The question of supplying to fracture only has been omitted, as this is a declining aspect, and will fade away in not many years from now.

If the ultimate decision is for fracture and analysis, then the blast-furnaceman has to meet a very large problem and solve it as best he may. No doubt it can be done, but it will involve added costs for handling and checking. It will mean for him the holding of a great many parcels of iron, each of an agreed grade of fracture and its complementary analysis. With the necessary trouble taken it can be done, but it will cost money to do it well.

A discussion followed, in which the Chairman (Mr. W. Haggas), Mr. Wood, Mr. J. Robinson, Mr. J. Haigh and others took part, and the meeting closed by votes of thanks being accorded to the lecturer, Mr. Wood, and Major Miles.

London Branch.

MALLEABLE IRON CHAIN.

By J. W. Gardom, Member.

The subject of this Paper was selected because it was thought that the manufacture of a product which lends itself—and is—manufactured on repetition lines would be of interest to foundrymen at the present time. Further, a description of manufacturing methods of a particular article enables more constructive criticism being offered than when general principles are involved.

The iron used in making this chain is the European or white-heart malleable, as this, when correctly made, is more suitable for chain than the black-heart iron.

Various types of malleable chain are produced, such as Ewarts, Pintle and Grays type. Each style has a large number of sizes, and each size a larger number of different attachment links. This involves a great number of costly patterns.

It is intended to deal more particularly with Ewart's or detachable-type chain, although the manufacturing principle is similar for the various classes.

When making forged chain and cast-steel chain, the links are joined together in the process of manufacture, whilst in some cases individual links are made, then spaced a link apart in a long mould, and the intermediate links cast through them. In all such cases the complete chain is the problem of manufacture.

In detachable chain the production of accurate individual links is the problem. The moulder may never see the completed chain.

The preparation of the patterns is specialised work, while particular care is necessary in running and feeding the links to ensure perfect soundness, and to counteract the high contraction in malleable of ¼ in. to the foot.

The patterns (Fig. 1) are made up in sprays of from two to sixty links, dependent upon size, with an odd side of plaster, traverse or metal. So far, it has not been possible to use match-plate patterns for this work.

Foundry.

For moulding, a hand-squeezer portable machine is used, as is shown in Fig. 3.

The operation of making a mould on this machine is as follows: First, the odd side with pattern and bottom box is placed in the centre of the table, and is riddled on and the box is shovel-filled with sand. Using the shovel handle, the mould rams round the sides of the box. The mould is struck off level and the bottom board is placed in position. The presser top is pulled forward with the left hand, and with the right hand the lever on the right of the machine is pressed on. The box is rolled over and the odd side is replaced by the top box, and the above operations are repeated, but the presser board is used, which has knobs fastened to it to mark the position of feeders and pouring gates instead of the bottom board. The presser top is pushed back, the gate and feeders cut through, and the pattern tapped *across* the links, so that no alteration of the length takes place, which would destroy the pitch.

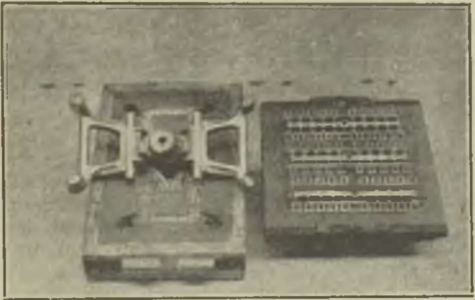


Fig. 1.—Patterns for Malleable Chain are Made Up in Sprays from Two to Sixty Links.

The mould is then opened, the pattern is withdrawn, and the cores placed in position. The top is replaced, the snap box opened and put on one side, and the mould placed on the floor in a position for casting.

The moulding operations have been given in detail because it is proposed to outline some figures of the output obtained. These figures represent work repeated daily, and are given by a user to help foundry managers in selecting a moulding machine for their requirements. It must be remembered that different jobs require different moulding machines, a point often forgotten, it being quite usual, when a change is made from floor to machine moulding, to expect the one type of machine bought to do all the various work of a jobbing foundry.

The usual method of giving the number of moulds turned out by a machine per day is not satisfactory, because no comparison can be made of the labour cost of working the machine. It is proposed, therefore, to give the output as moulds per man per hour. This has been obtained by dividing the number of moulds put down from 50 machines by the number of men employed to turn out the castings from these, and includes the labour engaged in sand preparation, moulding, casting, cupola operation, and the necessary general labour, cleaning up, etc. If this method

FIG. 2.—ILLUSTRATING THE METHOD OF RUNNING LINKS.

was always used, a more correct figure for comparing one type of machine with another would be obtained.

The figures given in Table I are a daily average.

TABLE I.—*Output from Machine Mould Chains.*

Size of box.	Chain.	Cores per box	Moulds per hr. per man
14 × 14 × 3 × 3 in.	1-in. pitch	60	7
18 × 10 × 3 × 3 in.	1½-in. pitch	24	8

When it is remembered that in some cases a man is laying as many as 4,000 cores a day, it is thought that the Bagshawe concern can feel proud of this output. To obtain this it is essential that every help, such as perfect patterns and boxes and easily-riddled sand, must be given to the moulder, and everything possible standardised.

To give a general comparison in this foundry when this type of machine is used, an output of 120 moulds per machine is obtained in eight hours for a 14 × 14 × 3 × 3-in. mould with no cores.

To relieve monotony, each moulder "turns over" his own sand, brings the necessary facing sand from the mill, brings his cores from the core room, casts and knocks out his own work.

By this method a greater output per man is obtained than if monotony is allowed to affect the work by keeping a man at one particular job.

The cores used are made up from half red moulding sand and half burnt sand, to which is added various small proportions of resin. These are made up in banging boxes, one girl turning out 4,000 cores for 1-in. pitch chain per day.

All the work is cast from hand ladles, which are filled direct from the cupola. It is usual to obtain the stream of iron from the cupola at such a speed that no "botting in" is necessary during the whole of the cast.

As soon as the castings are set, they are "knocked out" of the moulds. At the end of the cast the feeders and runners are "knocked off" and the links passed to the cleaning department.

After cleaning, each link is subjected to a double inspection, where all defective moulding or links likely to give trouble in too-tight or too-loose fitting are rejected.

Annealing.

After inspection, the work is passed to the annealing department. The links are placed in iron boxes 2 ft. 6 in. × 2 ft. × 1 ft., and surrounded by ore. This packing must be carefully carried out, so that distortion of the links is avoided during the heat treatment. Six boxes are placed one upon the other to form a tier, which is then conveyed into the annealing oven; when the ovens are full, the doors are closed, luted up and firing commenced. After about 48 hours' firing, full heat temperature of about 900 deg. C. is reached. The oven is then held at this temperature for a definite period, then closed down, and the temperature allowed to fall to 750 deg. C. in a given time. The furnace is then again taken up to full heat, and the process of holding at heat and closing down is repeated. The number of hours the furnace is held at full heat in each high-temperature period, and the number of times the temperature is allowed to fall, is dependent upon the chemical composition of the iron, the ore strength, and the thickness of the work to be annealed. After the necessary annealing time the furnace is allowed to fall to below 600 deg. C., when the tiers of pans are withdrawn and the castings dumped on to grids. After being rumbled

FIG. 3.—HAND SQUEEZER PORTABLE MOULDING MACHINES ARE USED.

they are subjected to a second inspection and passed into the grinding department, where the runners are ground off. Most of the links being run on the hook, it is necessary to use great care in grinding, so that the correct form of the hook is not destroyed, this coming into mesh with the teeth of the sprocket wheel when the chain is in use (Fig. 6).

Assembling the chain is perhaps the most interesting part of the manufacture, and the cost of the operation is not high, owing to the ease with which the links can be put together. Care, however, must be taken that the fit is not so loose that the links will come apart in handling. A "nip" is placed in the side arms close to the tail bar. This allows one link to slip into another when the links are held at an angle of 60 to 70 degrees one with the other. Each link is taken from a stock pile placed at the proper angle, with respect to the last link, pressed into position, and then straightened (Fig. 7).

The links are made up into 10-ft. coils, each coil being tested against a standard to check the pitch.

The allowable variation of a 10-ft. coil being plus or minus $\frac{1}{8}$ in., each coil is now subject on a special test machine to a combined tensile and shock test of double the working strain. The coils are again checked for pitch against a standard and, if correct, are passed into stores.

Metallurgy of Chain Making.

Turning now to the metallurgical side of the production of malleable iron chain, it is intended to go through each stage of the production, pointing out the theoretical side of the process, but more particularly to lay stress upon the application of the theory to the practice. The iron, as cast, has a chemical composition of approximately:—T.C., 3.2; Si, 0.6; S., 0.25; P., 0.1; and Mn, 0.13 per cent. Each constituent must be kept within very close limits of these figures, and such an iron, when broken, must give a white fracture, and when examined microscopically, must show pearlite, as a dark constituent, and white cementite. To produce such an iron in the cupola is difficult. It must be remembered that the work to be cast is very small, so that a very hot iron is required. The usual method obtaining hot iron is to increase the coke to iron melting ratio, but this would mean increased carbon absorption by the molten metal, and as any increase in T.C. is a disadvantage, very close watch must be kept upon the coke charges and the air supply. The desired result is best obtained by using a very soft blast and melting somewhat on the slow side this method of melting also helping to reduce the possibility of over-oxidation of the metal, which with such a low silicon content is liable. It has been stated by Mons. T. Levoz, "Fonderie Moderne," June, 1922, that oxidation of the iron during melting is the cause of most failures in malleable iron production.

FIG. 4.—THE ANNEALING OVENS.

Further, it is necessary that the composition of the iron should not vary at any part of the cast. To obtain this result, various methods have been tried, such as a receiver in front of the cupola, a double tap-hole, one above the other, so that a quantity of iron is held in the crucible of the cupola. Both these methods tend to cool the iron, so that to work them successfully a high melting temperature must be used, with its consequent detrimental increase in carbon absorption. They have therefore been discarded, and advantage is taken of the practically demonstrated fact that the charges in the cupola cannot be definitely separated. It is well known that the increase in sulphur and loss of silicon is greater at the beginning of a cast than at the end. The charges are therefore made up accordingly, *i.e.*, with a decreasing silicon content from the first to the last charge, and an increasing sulphur content.

As more than one charge is in the melting zone at a time, a practically constant chemical composition is obtained. This is checked by having an analysis from a test-bar cast every 1 ton of metal melted. The moulds are knocked out as soon as the castings are solid; this is an aid to the retarding of graphite formation, as it is well established that slow-cooling of iron produces large graphite flakes. Any particles of graphite present in the " as cast " material limit the possibility of obtaining good bending properties after annealing.

Annealing.

While it is perfectly true to state that, unless the castings received from the foundry are of the correct chemical and microscopical composition, no amount of annealing will produce malleable iron, 90 per cent. of the defective malleable produced is due to incorrect annealing.

Pyrometers.

Pyrometers are used to control the heat treatment. It is certainly surprising to hear men in charge of heat-treatment work say that pyrometers are useless, particularly when in some cases these men have actually worked with pyrometers. No heat treatment can be constantly repeated successfully without the use of some mechanical check upon the temperatures. The present-day pyrometer is quite a robust instrument, and with ordinary care and a little understanding will give years of service.

In using a pyrometer, the main point to be remembered is that the temperature reading shown upon the indicator is only the temperature of the furnace at the particular point where the couple is inserted. In a large room it is obvious that a thermometer placed in the draft from a window or doorway could not give the correct temperature of the room, yet that is so often exactly what a pyrometer is expected to do. Couples are often seen so placed in a furnace that the flame from the heating source plays around them. The correct position of a pyrometer is for the hot junction of the couple to be in contact with the work. That is, for the present conditions, it should be buried into the centre of a row. This is not practical, because of the excessive length of couple that would be required, and also the number of breakages due to the rows settling down during the heat treatment.

To overcome this difficulty it was necessary so to place the pyrometer that its reading would give a similar figure to that obtaining if the couple had been placed in the centre of the row. This condition was obtained by placing one couple in contact with the work and another couple through the furnace wall with firebrick insulation around the hot junction. The thickness of this insulation was varied until a definite ratio was obtained between the thickness of firebrick and depth of ore and work, to give a similar heat penetration.

FIG. 5.—SHOWING THE PACKING OF THE BOXES.

Ore.

The work is packed in hematite ore, a proportion of new ore being used with a proportion of old ore. The physical advantage of this packing is to prevent undue distortion of the castings during the annealing process. Its chemical action is that the ferric oxide of the ore splits up when heated, giving off oxygen gas, which directly or indirectly combines with the carbon of the casting. There can be no doubt that the ferric oxide present in the ore is the essential constituent governing the annealing process, although it has been shown that such impurities as oxides of calcium and manganese must be kept within certain limits. As, however, different brands of annealing ore vary in their ferric oxide content from as low as 75 per cent. to as high as 97 per cent., it is surprising that the strength of annealing ore to be used is spoken of as one of new to six of old, or as adding sufficient new ore to replace that lost in use. The author has advanced a stage further in his work to the following figures:—For work of less than ¼-in. dia., the ore mixture contains 4 per cent. of ferric oxide; from ¼-in. to ½-in. dia., 7 per cent.; from ½-in. to 1-in. dia., 10 per cent.; and above 1-in. dia., 15 per cent.

Close watch is kept upon impurities and also upon the silica content, which is very important: It is to keep the silica content to the desired ratio that the ore is sieved after each heat treatment.

To confer upon the brittle "as cast" white iron, the desirable malleable quality chemical and microscopical changes must take place. Only one chemical constituent is appreciably altered; this is the carbon, which is greatly lowered, the amount depending upon the time of annealing and the percentage of the other constituents present. An annealed link under the conditions outlined would have about 1 per cent. T.C. Microscopically, the hard cementite, with the elimination of carbon, is broken down into pearlite, with more or less ferrite depending upon the extent of annealing.

The ease with which this breakdown of cementite and the elimination of carbon takes place is dependent upon the amounts of the other constituents present, particularly silicon and sulphur. Also the temperature of the anneal, the time at annealing temperature, and the strength of the ore. That carbon is burnt out during annealing there can be no doubt, as this is clearly shown by a simple chemical analysis, as well as by microscopic examination. The actual means, however, by which the oxygen and carbon combine have not yet been proved. The first action must necessarily be the breakdown of the cementite. This is followed by the elimination of carbon by oxidation. It is probable that this combination of carbon and oxygen is a secondary reaction. Does the active gas actually penetrate into the casting, combine with the carbon, and then pass out again into the atmosphere, or does this action only take place on the surface of the casting?

A study of Papers on "Malleable" before the Institute of British Foundrymen, and the discussions by members upon these Papers, seem to show that the penetration of the gas into the casting is generally accepted. With this theory, however, the author cannot agree. He believes that oxidation of the carbon by the active gas can, under normal conditions, only take place on the surface of the casting. This being the case, then the elimination of carbon from the centre of the casting can only take place by migration of carbon from the inside to the surface of the casting, where it will then come into contact with the active gas and be oxidised away. This can perhaps be better illustrated by Fig. 8.

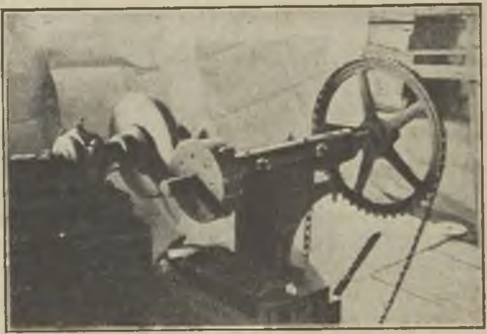


FIG. 6.—THE GRINDING OF THE LINKS.

Supposing this figure represents a section of a hard, white casting. The percentage of carbon present throughout the section will be constant if taken at varying depths represented by the lines A, B, C, D, E and F. Now surround this section by active gas at a suitable temperature, and the carbon at the surface will combine with the gas and be oxidised. Further oxidation cannot take place until the lowered carbon content at A has been restored by migration of carbon molecules from a point within the section, say B, which in turn receives carbon from points nearer the centre of the section until F is reached. If this theory is correct, then decarbonisation can only take place at a rate dependent upon the speed at which the carbon molecules will migrate to the surface.

Experimental Work.

During the past twelve months the Bagshawe Company has, in its laboratory, carried out numerous tests to prove this theory. The methods used have been partially to anneal test-bars obtaining an exterior low in carbon and the interior with a high-carbon content. These bars were then packed in inert material and heated to various temperatures for varying periods. The work is not yet complete, but the results tend to show that not only does this migration of carbon take place, but that varying percentages of chemical constituents present in malleable have an influence upon the migration speed of the carbon.

From research work and practical experience it is known that decarbonisation of the iron cannot take place until a temperature of about 900 deg. C. has been reached. It is, however, a well-established metallurgical fact that diffusion of carbon can take place well below this temperature, but more readily at any point above which the carbon exists as solid solution. Reference to the iron-carbon constitutional diagram will show that this point may be as low as 710 deg. C. It is seen, therefore, that there is a critical temperature below which decarbonisation cannot take place; this is in the neighbourhood of 900 deg. C., and a definite temperature above which diffusion of carbon can take place more or less rapidly; this for malleable iron is about 750 deg. C.

Suppose, then, the work packed in annealing ore is brought up to annealing temperature and held at that temperature for a definite period. The carbon of the surface will be oxidised away, and no further decarbonisation can take place until the deficit has been replaced by diffusion of carbon from the interior.

Diffusion.

As, however, this diffusion can take place rapidly below the decarbonisation temperature, it is perfectly reasonable to allow the furnace temperature to drop below the critical decarbonisation temperature, and as long as the drop is not below the point at which diffusion is rapidly retarded, then annealing (from the essential elimination of carbon point of view) is virtually still taking place. This is the explanation of the "close down" periods during the annealing cycle.

FIG. 7.—ASSEMBLING THE LINKS.

Defects due to incorrect annealing are many, but the greatest is that known as skinning. This is shown on bending the work by the outer skin of the casting separating from the core. In its worst form the centre of a bar can actually be withdrawn, leaving an exterior tube. The cause of this has, at different times, been put down to :—(1) Too rapid heating-up of the furnaces; (2) a too high sulphur content; (3) the use of a too high temperature; (4) a too high manganese content; and (5) too strong ore. These factors can all be brought under one definition if one says skinning takes place "when the rate of carbon diffusion from the interior to the surface is less than the rate of carbon elimination at the surface by oxidation." It has been stated that the periods at full heat vary according to the section of the work to be annealed—compare the ratio of the surface of a section to the sectional area of different diameter bars, and the explanation is seen (in Table II):—

TABLE II.—*Showing the Ratio of Circumference to Area.*

Dia. of Bar.	Circumference.	Area.	Ratio of circumference to Area.
¼ in.	0.785	0.0491	16 to 1
½ in.	1.507	0.1963	8 to 1
1 in.	3.141	0.7854	4 to 1

As the source of supply of carbon to that eliminated on the surface is so much greater in the 1-in. bar to the ¼-in. bar, it is possible to keep larger section work at the decarbonising temperature longer before the first close-down than light section work.

It must be remembered that diffusion of carbon takes place more rapidly the higher the temperature, and as it is necessary, for commercial reasons, to cut the length of time in the annealing ovens to the minimum, the longer the periods at the high temperature, the quicker the elimination of carbon, and consequently the annealing.

Each 10-ft. coil, when tested against a standard for pitch, is only allowed a variation of plus or minus ⅛ in. in 10 ft. After all the known mechanical errors had been eliminated, it was still found that the pitch of the chain varied from one batch to the next. Experimental work was started to find the cause of this. Keeps' 12-in. bars were used; these were measured after casting and after various heat treatments.

The bars were cast direct from the furnace on different days and at different times, and annealed in the usual way. In the first fifty bars examined the following variations during anneal are shown in Table III:—

TABLE III.—*Influence of Annealing on Length.*

Lab. No.	Length. as Cast.	Length. after Anneal.	Difference.	Bend.
306	11.866	11.808	— .058 in.	45°
492	11.865	11 858	— .007 in.	90°
507	11.868	11.868	+ .000 in.	70°
560	11.870	11.880	+ .010 in.	73°
570	11.875	11.950	+ .075 in.	45°

By a gradual elimination of varying factors it can now be definitely stated, from the study of some 600 tests in this series, that if all other conditions are identical, then a small variation of the silicon content is sufficient completely to alter the pitch of the chains. The deciding factor appears to depend upon how the iron carbide is split up in the first instance. If temper carbon is deposited a growth is obtained. If decarbonisation takes place at the moment of the cementite breakdown, then a contraction takes place. This is actually the difference between black-heart and white-heart malleable. Of the usual constituents present in malleable, the T.C., Si, S, and Mn can each influence the way in which the cementite is broken down, and so can alter the pitch of the chain.

FIG. 8

Test-bars were prepared with a standard analysis of T.C. 3.4, sulphur 0.28, phosphorus 0.06, and manganese 0.16 per cent., but with the silicon varying from 0.35 up to 0.80 per cent. When the silicon was 0.56 per cent., the length of the bar* did not vary during the time of an ordinary anneal. Below this figure contraction took place, and above 0.56 per cent. a growth.

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* Whilst the silicon varied, the rest of the analysis was constant at T.C., 3.4; S., 0.28; P., 0.06; and Mn., 0.16 per cent.

As was to be expected on repeated annealing, which means elimination of carbon, the bars contracted until a standard figure was reached. This is shown by Table IV, a study of which shows that the pitch of the links can be varied by slight difference in chemical composition, and also by different annealing times.

Table IV.—*Keeps' Bars Annealed in Light Ovens.*

Lab. No.	549/779		558/800		559/801	
Si. %	0.56		0.59		0.65	
Original length of bar	11.868 in.		11.865 in		11.873 in.	
	Length.	Difference.	Length.	Difference.	Length.	Difference.
1st Anneal.	11.868	.000 in.	11.869	.004	11.903	.030
2nd Anneal.	11.842	.026 in.	11.847	.018	11.893	.020
3rd Anneal.	11.848	.020 in.	11.845	.020	11.891	.018
4th Anneal.	11.843	.025 in.	11.842	.023	11.887	.014
5th Anneal.			11.842	.923	11.875	.002
Bend.	180 Unbroken.		180 Unbroken.		180 Unbroken.	

DISCUSSION.

The Branch-President (Mr. V. C. Faulkner) said that Mr. Gardom, probably rightly, had thrown over an established law of economics, which said that no work should be given to a skilled man when it could be done by a lower-priced man; the lecturer had his moulders running around fetching cores and sand. Mr. Gardom had given no information as to the life of the annealing boxes. If he (the Branch-President) remembered rightly, Mr. Poole, when speaking on this subject, had stated that they only lasted three or four heats. A business was being developed by at least three firms for making these packing boxes in a nickel-chrome alloy.

The Migration of Elements.

Mr. Gardom had brought out a very important point when he was dealing with the migration of carbon. He (the Branch-President) agreed, except on one point, namely, in regard to peeling. Mr. Gardom had pointed out that when the rate of gas penetration was not equal to the rate of migration then peeling took place, and further, that during that period the oxygen would attack the next most easily oxidisable element, which was the iron. He would refer Mr. Gardom to the working of a Siemens furnace or any other, where he would find that the next most easily oxidisable element in ferrous alloys was the silicon, and suggested that a fusible slag of ferrous silicate was formed between the peel and the core, and so effectually prevented any more migration of carbon. He (the Branch-President) was most interested to find that Mr. Gardom had put forward the migration theory, and it should have a considerable amount of modern thought devoted to it. He had been exceptionally interested in the metallurgical side of the Paper, because the author had dealt with it in a very rational way

Temperate Movements.

Mr. H. J. Maybrey said he did not quite understand the reason for dropping the temperature during the annealing process. There seemed to him to be some sort of balanced action. If there was migration of carbon going on in the casting, the carbon could only migrate so long as it could be eliminated to the surface, and if elimination were quick migration must be quick; if slow, then migration must be slow. Therefore, he could not quite see the point of dropping the temperature during the annealing process.

Cause of Scaling.

Mr. H. O. Slater complimented Mr. Gardom upon his very instructive lecture. It was a revelation to him to know that Mr. Gardom's firm could go through the whole process of malleable iron—which was just about double that of cast iron—and still turn out chains within an accuracy of plus or minus ⅛ in. in 10 ft. It was really exceptional, because he himself had lost ⅛ in. on one casting alone, let alone on 10 ft. of them. With regard to the lecturer's metallurgical explanation of scaling, Mr. Slater said it seemed extraordinary to him that the malleable iron industry, which was one of the oldest in the country, should have been carried on so well without a metallurgist.

It was carried on without the aid of the metallurgist by men with no knowledge whatever of chemistry; of course, he was not belittling the metallurgists, because he recognised that they benefited the industry very much. He himself had never looked at scaling from a metallurgical point of view, but in his practical way he overcame that trouble. He considered that scaling could be caused by (1) quick heating, (2) too-long annealing, or (3) using a wrong mixture of ore. Dirt in the ore would also cause scaling, which was very detrimental to the skin of the casting. With regard to the annealing of chain links, he had noticed that the links were packed in boxes in the ordinary way and the boxes piled one on top of the other. He would like to know whether there was anything used to protect the boxes at the bottom against the weight of the boxes at the top. He had never dealt with a specialised product in malleable iron, but he had been concerned with jobbing work, such as motor-chassis work and so on, where different thicknesses and different types of castings had to be annealed in the same oven. He had found very often, in annealing heavy with light castings—which he had been bound to do, for economic reasons, although it was not altogether a good policy—that it was beneficial, if he had a casting which was liable to crack, to insert a plate half-way up, so that that plate would take the weight of the top half, and the bottom half would stand its own weight. As to the pyrometer, he must confess that when he had first attended the meetings of the Institute nobody was more prejudiced against some of the scientific instruments than himself, but as his experience and knowledge had increased he had felt that, in the malleable trade, pyrometers and other scientific instruments were really necessary. With regard to the variations of temperature in different parts of the same oven, Mr. Gardom had given no idea as to how his ovens were built, the way his flues were constructed, or how he regulated the temperature in any particular part of the oven—whether by a series of dampers in the flues. As to annealing pots, he did not consider it would be a commercial proposition to make them of nickel-chrome steel.

Embrittlement of Malleable after Ageing.

The Branch-President said he had referred to annealing boxes of nickel-chrome alloy, not nickel-chrome steel. There was another question he would like to put to Mr. Gardom. It had been found that American black heart malleable iron was prone to suffer from embrittlement taking place a few months after manufacture, and the American Bureau of Mines had developed a heat treatment to overcome that.

Average Tests from Malleable.

Mr. H. O. Slater asked Mr. Gardom what were the highest tests he had applied to his bars—tensile, elongation and yield point—and what was his method of casting test bars. He would also like to know Mr. Gardom's ratio of coke to iron in every-day working. If he remembered rightly, Moldenke, in his book, advised a ratio of 1 to 4.

Blast Pressure.

Mr. E. H. Brown, referring to the attempt to standardise cupola working by varying the percentage of silicon in the mixtures, asked whether Mr. Gardom had tried to obtain the same result with a constant mixture and varying the blast pressure during the course of the run.

Mr. H. G. Sommerfield (Branch Hon. Secretary), dealing with the analysis of the metal used —3.2 carbon, 0.6 silicon, 0.25 sulphur, 0.1 phosphorus, and 0.13 per cent. manganese—asked whether that was the analysis of the metal as charged into the cupola, or of the actual casting before annealing.

Economic Employment of Skilled Labour.

Mr. G. C. Pierce said he had heard and read sufficient about malleable iron to make him say that he hoped he would never be in the position of having to deal with it. He had no burning desire to become a malleable-iron expert. But he was interested in one question raised by the lecturer, which was rather a psychological than a metallurgical one. It was true to say that Mr. Gardom had thrown over an elementary law of economics through reducing the monotony of the men's employment, but he himself was very pleased to know that there were some people in the founding industry who had some regard for the human as well as the economic side. One of the things they had to do as an Institute was to watch both sides, and not concentrate too much upon economics. Of course, they had to keep their eyes on the clock of progress, but at the same time he considered that very often too much consideration was given to the other side, and it was refreshing to find a lecturer standing his ground and saying he could defy an economic law and yet maintain the same output as he would have done if he had not defied that law.

Pattern Plates.

Mr. G. Hall, referring to the pattern plate used by Mr. Gardom, said it was certainly a very fine piece of work, but he would like to know why Mr. Gardom preferred that to an ordinary double-sided metal plate or the wooden pattern produced by the pattern maker. It had been said that it could not be produced on a match plate. He had seen wooden patterns and had used them in the foundry, and the joints had been as nearly perfect as possible. Mr. Gardom's pattern was a very elaborate piece of work, but he should have thought that it could have been produced so as to be much stronger, to last longer, and would be perhaps cheaper. He himself sometimes had a pattern such as that shown by Mr. Gardom made with a plaster of paris odd side, but not for the purpose of producing castings by the thousand. If he were producing thousands of castings, he had a metal pattern, either single- or double-sided, made to match the box on one side of the plate.

Hard Spots from Grinding.

Mr. Summers asked whether, in malleable iron, it was easy to create hard spots on the casting by grinding too much locally. For instance, if there were a big lump to be got off, and the casting were held too long on the emery wheel, would that result in the creation of hard spots?

THE AUTHOR'S REPLY.

Mr. Gardom then replied to the discussion. With regard to the Branch-President's question as to cleaning castings, he said they were tumbled, and dust extractors were used. That was the only method of cleaning used before passing them into the annealing department

Elimination of Monotony to Promote Production.

With regard to the question of the moulders getting their own cores and so on, the main point was output; he was not considering the moulder so much—though that would probably disappoint Mr. Pierce. He believed that he obtained a greater output by eliminating monotony. If the Branch-President wanted to use the argument he had done, why had he not asked how many more moulders would have been available if somebody else had brought their cores along for them? It must be remembered that there was only one man on each of the portable machines, and that man was doing all the work in connection with his machine. If he stopped, the machine stopped, but the fact that the moulders fetched their own cores did not upset the production to anything like the extent it would if automatic machines were used, where an automatic machine was turning out perhaps ten times the number of moulds that a hand machine would. He quite agreed that if an automatic machine were used—hydraulic or air—it was not advisable to stop the machine, but with the particular type of machine used in his foundry he could afford to do it simply because the output of the machine was not affected very much as the result of the machine being idle for a certain time. With regard to monotony, there were many people who were referring continually to apprenticeship in the foundry, but one must face the fact that the apprentice in the foundry was a thing of the past. It seemed to him that moulding as a skilled job was finished.

A Voice: Not yet.

Mr. Gardom said that, at any rate, it was on its last legs. For instance, in the production of his own particular product, his firm could train a boy or a man who had never seen a foundry before to do this work accurately in three weeks. The skill was needed in the preparation of the work. That was where the foundries had to look for the apprentice, and the man who prepared the patterns was the man who had to know his job. When such a pattern as he had shown that evening was put into the work it must be perfect; if it were not perfect, then back it would go to the pattern shop; if the moulder had to touch it up then output decreased. He was sorry for the apprentices, but we must face the fact that moulding—which he quite admitted was an artist's job--was dying out.

Cost of Nickel-Chrome Boxes.

Dealing with annealing boxes, he said that, for the particular oven he had mentioned, the cost of an oven load of pans was £300—and the firm made them themselves. The cost was about 3d. per lb. On the other hand, the lowest price at which he had had nickel-chrome offered to him—but not delivered—was 2s. 6d. per lb. He simply could not afford to use it, and did not know that anybody else could. Again, he had never yet found nickel-chrome to stand up to all the conditions which the makers claimed. He had used it for pyrometer sheaths, and had found it was quite usual for it to give only six months' service. That was nothing when one came to consider the extra cost involved. As to the life of the annealing boxes, he had carried out careful tests and could safely say that he got 10 heats out of them. The Branch-President had referred to some special boxes mentioned by Mr. Poole. He (Mr. Gardom) had tried them, and had got only four heats out of them.

Does Silica Formation Cause Peeling?

With regard to the migration of carbon and peeling, the point about it was that, working on the theory he had expounded, he had obtained results—and results which he could understand. Was silica formation responsible for peeling? The Branch-President had thought that one might have the silicon oxidising and preventing further migration of carbon. He would like the Branch-President to go further into the matter. One could get peeling by forcing this oxidation faster than the migration; it could be obtained by using too strong an ore, or on a sample which still showed white iron in the centre, *i.e.*, with a carbon content of about 2 per cent. Such a sample could be re-annealed and the carbon removed. That more or less broke down the theory that silica formation stopped migration. In his own experiments he had annealed a bar first in the ordinary way. Then the difficulty was to say how far the drillings were to be taken off. Some people took a drill and drilled through ⅛ in., then another, and then another. He himself put it in a lathe and turned off ⅛ in., and then another, and so on, and he certainly considered that, by taking the whole of the sample for the carbon estimation, he obtained better results than were obtained by drilling. He could check it better, and he did get every part of the particular ⅛-in. depth he sought. He had re-annealed the sample and had repeated the test, to see whether migration went on, and undoubtedly he could obtain a peeled casting with a hard iron in the centre. One could bring all the factors that caused skinning under one definition if it was said that "skinning takes place when the rate of carbon diffusion from the interior to the surface is less than the rate of carbon elimination at the surface by oxidation."

Dropping Temperature during Annealing.

It had been asked by Mr. Maybrey why the temperature was dropped during annealing. If the temperature was not dropped then de-carbonisation on the outside took place faster than the migration from the centre, and if that happened skinning would result. If one annealed at a temperature below the critical temperature of de-carbonisation, no more de-carbonisation would take place, but migration could still take place.

Contraction of Chain Castings.

In reply to Mr. Slater, with regard to the contraction of ⅛ in. in 10 ft. of chain, he would like to say that he did not for one moment claim that none of the links varied by more than the amount obtained by dividing the number of links in 10 ft. of chain into ⅛ in. One might be slightly over and another slightly below, and they equalised each other right through. He agreed with Mr. Slater that this malleable work was done before the advent of the metallurgist, but it was poor stuff. The point about it was that when a metallurgist left his firm another metallurgist could come in and carry on the job from his predecessor's notes. The practical foundryman could not say that. If a practical man had worked with him for ten years, that man might be able to take on the work and improve on it, but he did not leave anything behind him when he died which would help on the work.

Migration and Skinning.

He was in agreement with Mr. Slater that skinning could be caused by quick heating, too long annealing, too strong ore, and by dirt. With rapid heating there was rapid de-carbonisation without the correspondingly rapid migration. With too long annealing, also, de-carbonisation was bound to be faster than migration, and the same applied when too strong an ore was used. As to the prevention of distortion in annealing, usually between every two pans he placed a cap. At one time he used to cap up outside the pans, the cap extending right through the pans to the outside. At present, however, he put the cap just inside. Sometimes there was distortion at the top, due to bad packing. The practical man would not understand that in packing ore a far better packing was obtained with a poker than with a rammer. With a poker we were able to get in between, and the ore would sink much better.

Pyrometers.

With regard to pyrometers, he assured his hearers that since he had been with his present firm, the men employed in unloading castings, and who were paid by piece work, agreed with the use of pyrometers, because they could make larger quantities. When he went there at first they used sledge hammers to get out the castings.

Dampering Furnaces

With regard to dampering, that was another point on which he seemed to differ from most people. If the castings were not heated properly he should not say he could not do them in that particular oven, but should set about putting right the oven. That was what had been done in his foundry. They had fired from the outside of the oven, and the fire came in at the top of the oven. That was wrong according to all theories. There were dampers all along the bottom side, and pyrometers also. They worked by means of the dampers, and the heat was drawn to whatever part of the oven it was required. As soon as the temperature dropped at a particular spot the heat was increased there, and when the temperature was too high at any particular spot it could be let down.

Test Bars and the Importance of Yield Point.

Dealing with test bars, Mr. Gardom said that for his iron he obtained about 22 tons tensile, 5 per cent. elongation, and a yield point of 17 tons per sq. in. If he had said that in his Paper, those present would have said that the Americans could do better than that. He knew they could; so could he if he took it beyond the realms of commercialism, and annealed for a period about three times longer than he did actually. A test bar did not always give the actual results obtained with the product itself. He obtained 10 tons per sq. in. on nearly all types of chain produced. The reason he mentioned it was that when the Americans came out with their black-heart process and said that they got 10 per cent. elongation, the English people came along and tried to repeat it. There had been much discussion about semi-steel and what it was; that could easily apply to black-heart and white-heart malleable. Why should we try to make a metal appear to be something which it was not? They did not require the same tests from a 0.9 carbon steel as from a 0.2 per cent. carbon steel, but that was what the Americans were doing with malleable. The reason his iron was better for this work was that the yield point was about 17 tons per sq. in., whereas in the black heart it was only about 12 to 14 tons per sq. in. If the chain were used on a chain drive, and it reached a point which was beyond its yield point, i.e., when it was stretched, then it would get over the top of the sprockets and would break. It was not a question of maximum stress but of yield point, and that was the reason why Reaumur material was better for this particular job, as it possessed a higher yield point. The position was exactly the same with a ball bearing. A 1-in. ball would stand 40-tons pressure before it would break. But the yield point on a 1-in. ball, or the point of permanent deformation, was only 7 tons, and that was the point at which it failed, because the moment it was permanently deformed the point of contact was lost.

Varying Blast Pressure or Composition.

Replying to Mr. Brown as to the varying of blast pressure during the run in the cupola, Mr. Gardom said it seemed that the easiest thing to do was to vary the mixture. Certainly he could vary the silicon, but he would not vary the sulphur. He did not say that the variation of the blast could not be done, of course, but it was easier to vary the mixture. Actually the blast pressure was dropped during the run, because at the commencement the cupola was full, and more pressure was needed to get through the charge than when it had dropped down. Therefore it was necessary to lower the pressure as the iron dropped down.

In answer to Mr. Sommerfield, Mr. Gardom said the analysis he had given was the analysis of the iron as cast. He might, of course, change his mind with regard to the analysis at any minute. He simply used that analysis at the moment because he considered it most suitable for the job. With regard to the division of the carbon. At the commencement the total carbon was 3.2 per cent.; it was entirely in the combined state. At the finish there was somewhere about 1 per cent., but that varied slightly (after annealing) up to 1½ per cent. But he could say it was only 0.8 per cent.

Silicon and Growth.

A question had been asked about the action of the silicon with regard to growth. Of course, a high silicon content, say 2 per cent., did make the casting grow, but the point that had struck him particularly was the variation in pitch. With a silicon content of 0.57 per cent., with the particular analysis mentioned, there was no growth. If the silicon and the sulphur content were increased one obtained the same result, he believed—although he had not finished the test—because it seemed to be dependent on the way the carbon was precipitated. If precipitated as temper carbon a growth was obtained, so that if one used the black-heart process there was a growth of ⅛-in., and so resembled the single contraction conditions as in grey iron. But with the white-heart malleable there was a double contraction, as in the case of steel. If the total carbon were high, precipitation was more liable; if the silicon were higher, precipitation was assisted; sulphur retarded precipitation; manganese combined with the carbon and retarded precipitation; phosphorus had very little effect, except that if it were present in any quantity it formed the phosphide eutectic, and it was advisable to keep it away.

Hard Spots and Grinding.

With regard to the creation of hard spots in castings during grinding, it was easy, of course, in any type of malleable to do this. For instance, the white-heart malleable was practically pearlite, which when heated returned into solution, and if the temperature were raised to about 800 deg. the carbon also went into solution; if it was cooled quickly there was hardening. The same thing applied in the black-heart process, but there the temperature must be taken higher, because the carbon only came back into solution at 900 deg. or more. Hard spots were easily formed by grinding, and it could easily break castings, so that if there were much to grind off only a little should be removed at a time.

Coke Ratio.

As to the ratio of coke to iron, it worked out to a ratio of about 10 to 1. He believed, unlike Mr. Slater, that slow melting was beneficial because one had to consider the final result. If it produced high total carbon it had to be removed when annealing. The cost of annealing was very high, and if foundrymen could do anything to reduce the annealing time it would pay to do so.

Vote of Thanks.

Mr. G. C. Pierce, in proposing that a very hearty vote of thanks be accorded to Mr. Gardom for his splendid Paper, touched again on the question of foundry apprentices, and said he wanted to tell Mr. Gardom and anybody else interested in that question that perhaps they were wrong when they considered that skilled moulders would not be necessary in the future. As a basis for his argument, Mr. Pierce said that, 25 years ago, the scientific apparatus used in the foundry for production purposes was nil, whereas to-day its use was increasing very rapidly, and there was no comparison between the two conditions. There had been great strides in so far as methods of production were concerned, and yet there is nearly twice the number of skilled moulders to-day that there was 25 years ago. Therefore, the theory that skilled moulders were going out was erroneous. If he were correct—and he believed he was—then surely, if we progressed in the future to the same extent as we had in the past 25 years, he had as much justification for thinking we should want more skilled moulders as others had for thinking that we should want fewer. In fact, he had more justification for adopting his point of view.

The vote of thanks was accorded with acclamation.

Mr. Gardom, after expressing his thanks, asked Mr. Pierce whether, in referring to the extra number of moulders employed at the present time, he had taken into account the extra weight of iron turned out at present as compared with 25 years ago.

Scottish Branch.

SOME PROBLEMS IN LIGHT CASTINGS.

By J. C. Dorsie, Associate Member.

Dr. Percy Longmuir, in a recent lecture, described how the crystals in cooling arranged themselves at right-angles to the edges of the casting. Therefore, in a frame the weakest parts are at the corners where the crystals set at right-angles to each other. A further source of weakness is due to the fact that the diagonal, being longer, freezes more slowly.

With the definite object in view of making castings which would illustrate the weakness of square corners, four frames were cast as shown in Fig. 1. These are 24 in. × 24 in. outside. The flanges were 3 in. wide × $\frac{1}{4}$ in. thick. They were all run on the edge with the exception of frame B. It was only after considerable pressure that the moulder—an old stove-plate hand—was persuaded to run it as shown. He said he would need to lift it out in pieces, but it refused to oblige and broke in the mould through one of the sides, one of the edges of the break curling up over the other edge. In frame C, the centre of two opposite sides was thickened to 1 in. The casting was quite sound. The centre of the other two sides was then increased to 1 in. thick, and in this case it was removed from the mould in three pieces. It is hoped that some explanation will be given as to why the other corner remained whole.

Manhole Covers.

An interesting problem at present is the designing of covers for roadway manholes that will be capable of sustaining the ever-increasing loads that are imposed on them. The simplest method is, of course, to increase the thickness of the casting, but if this idea is carried much further the roadman will require some mechanical apparatus to lift the cover. Foundrymen must therefore devise some system of strengthening the cover

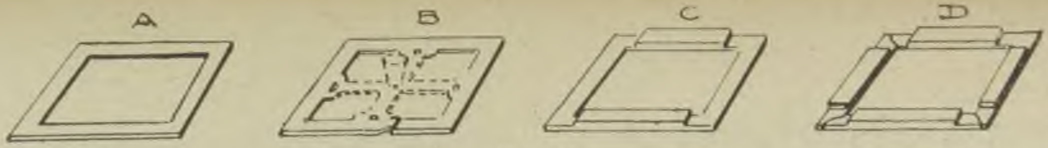

Fig. 1.

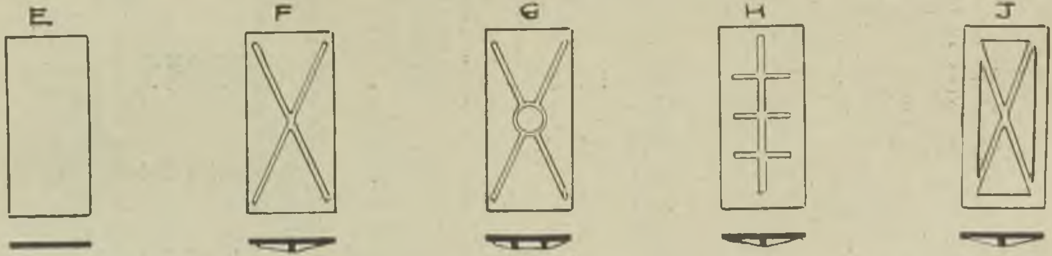

Fig. 2.

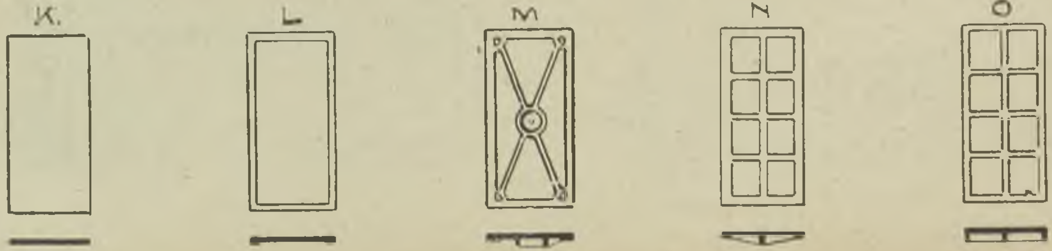

Fig. 3.

without unduly increasing the weight. Figs. 2 and 3 illustrate some scale models of plates which were cast with the view of comparing the efficiency of various forms of strengthening ribs. The size of the plates was determined by the capacity of the testing machine. The five types in each set were cast in one box. The tabulated results were the average of four boxes, but the records of each type were nearly identical. The types illustrated in Fig. 2 represent covers for trenches which are supported at the ends only. The experimental plates are 13 in. × 6 in. × $\frac{1}{4}$ in. thick. They were supported on end bearings at 12-in. centres, and the bolster used for transverse test was employed. This bolster is a cylinder 1 3-16 in. dia. × $3\frac{7}{8}$ in. long. The average results are shown in Table I :—

TABLE I.—*Strength of Model Manhole Covers.*

Type.	Transverse in cwts.	Deflection in ins.
E	8.5	0.325
F	6.5	0.120
G	9.5	0.155
H	5.7	0.080
J	9.6	0.110

It will be noted that in types F and H the supposed strengthening ribs are really sources of weakness, and the plain plate, with its capacity for greater deflection, compares favourably with types G and J. Table II shows a comparison of the plates in terms of the weight of plate to the transverse load.

TABLE II.—*Strength of Manhole Covers per Unit Weight.*

Type.	Sustained per lb. of Plate in cwts.
E	1.67
F	1.14
G	1.62
H	0.94
J	1.46

The plates illustrated in Fig. 3 are also 13 in. × 6 in. × $\frac{1}{4}$ in., but they were supported on the four sides. The usual compression bolster, 2 in. dia., was used, but a spherical seating was inserted between the bolster and plate to limit the area under pressure. The results are given in Table III.

TABLE III.—*Strength of Manhole Cover Models Supported on Four Sides.*

Type.	Crushing Strength in cwts.	Deflection in ins.
K	15.3	0.055
L	16.3	0.070
M	19.7	0.085
N	23.4	0.050
O	20.3	0.030

It is interesting to note that the system of dividing the surface into a number of small compartments by means of longitudinal and cross bracings—type N—seems to give better results than the usual design of diagonal bars connected to a central ring. Again, comparing the weight of plate to the load, the figures shown in Table IV were found.

TABLE IV.—*Strength of Model Manhole Covers Supported on Four Sides in Unit Weight.*

Type.	Sustained per lb. of Plate in cwt
K	3.33
L	2.93
M	3.28
N	3.78
O	3.06

Warping of Gutters.

A perennial subject of discussion in the light casting trade is the casting of a channel section or gutter with open ends, and the amount of curvature on the casting by "pounding" the ends the pattern to ensure that casting turning out straight. For economical reasons these gutters must be made in the narrowest possible box. The metal is run by flat gates direct on to the sole and flows down the sides. If the sole and sides are of equal thickness, the edges of the side will cool before the sole, and a warped casting results. This warping takes the form of a concave curvature along the sole. So decided is this warping on light gutters with shallow sides that allowance must be made on the pattern to counteract the camber. It is common knowledge among gutter moulders that this type of casting invariably rises at the ends, and if the pattern has not enough camber, a moulder can slightly reduce the curvature on the casting by " pounding " the ends of the mould. The question has been asked: " Does the casting only rise at the ends? Does it not also sink in the centre? "

Behaviour of Metal in Moulds.

For the purpose of testing the actual behaviour of the fluid metal in the mould, the apparatus shown in Fig. 4 was used. The arrangement in practice was found to be capable of improvement, but it was the simplest and cheapest that suggested itself. It consists of an ordinary gutter box with planed edges. The pattern is 6 in. × 4 in. × 7-32 in. thick × 6 ft. long. It has two plain ends instead of the usual spigot and faucet ends. The pattern was made in wood and rammed on a solid block. Three pins were rammed up with the top part and cast in the sole of the gutter. The height of each pin was measured, before pouring, on a

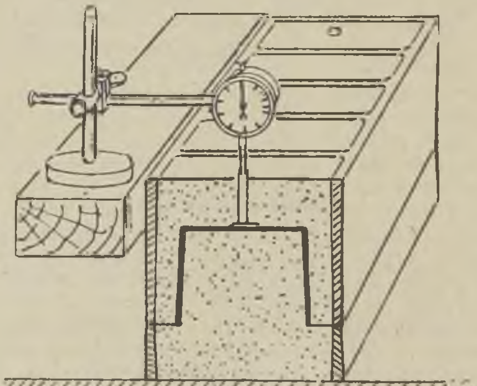

Fig. 4.

dial gauge which registers in thousand parts of an inch. The gauge was left in position on the centre pin during the duration of the experiment, and the variations in height of this pin were carefully noted. At the conclusion of the test the height of each of the end pins was taken before the box was unhooked. It is only proposed to give the summarised results of two of the latest tests in which an extended series of dial readings on the centre pin were recorded.

In the first half minute the dial registered a rise of 17/1,000; at 3½ minutes it dropped 1/1,000; at 5 minutes it again reached 17/1,000. From this point a gradual rise took place, until at 12½ minutes after pouring the highest point was touched, 27/1,000. This point was maintained until 21 minutes, when a gradual fall took place. At 30 minutes it was 21/1,000; at 45 minutes 12/1,000; and at 60 minutes it had returned to zero. A further fall of 1/1,000 was recorded at 68 minutes, and another 1/1,000 at 73 minutes, when the test had to be suspended for the night. The gauge was left in position, and next morning it registered 5/1,000 under zero. The difference between the highest and lowest readings was therefore 32/1,000, say 1/32. The end pins were then measured and recorded at a rise of 23/1,000 and 31/1,000 respectively. The camber on the casting as it lay in the box was therefore 32/1,000, say 1/32. The hooks were then loosened, and the immediate rise of the end pins was apparent. The casting when measured had a camber of 170/1,000, say 11/64, but it has to be remembered that this casting lay in the box the whole night. Probably this accounts for the small camber. It is certainly less than the amount usually allowed for.

In two gutters with 1½ in. sides, the camber on the castings was 29/64 and 26/64 respectively, but these two gutters were knocked out of the box shortly after casting. That was before the author had appreciated the curious behaviour of the centre pin. A 6 in. × 1½ in. gutter with a round bead ½ in. deep × ⅜ in. projection on each edge was then cast, and the behaviour of the centre pin was again very carefully noted. In the first minute it jumped 25/1,000, in the next minute it gained 1/1,000, but during the next three minutes it lost 5/1,000. It then gradually rose again until the highest point, 35/1,000, was recorded 13 minutes after pouring. It remained stationary for 18 minutes, when a very gradual fall took place, until 1 hour 20 minutes after casting it indicated 29/1,000 above zero, when it had to be left for the night. In the morning it registered 22/1,000 *above* zero. The end pins were 6/1,000 and 8/1,000 *below* zero. As it lay in the box the casting therefore had a convex curvature of 29/1,000, say 1/32, but when it was measured on the surface table a concave camber of 45/1,000, say 3/64, was noted.

Lancashire Branch.

(BURNLEY SECTION.)

DRY SAND AND LOAM MOULDING.

By A. Sutcliffe, Member.

Introduction.

It is acknowledged that art is the result of work, and depends upon the skill and mental capacity of man, without the aid of formulæ. Ironmoulding, perhaps, cannot be classed amongst the fine arts, but it certainly is not crude. It is an industrial art. Considering the problems that remain unsolved in the foundry, and the difficulties which are added each day through the rapid advance of the engineering industry, it is no exaggeration to say that the work of the foundryman calls for more self-reliance, keen foresight, skill and concentration of thought than those industries which are assumed to be of more importance.

The moulder has no definite method of counteracting the erratic behaviour of the metal with which he deals; it is only by practical experience and the judicious use of the materials at hand that he obtains the satisfactory results that are witnessed to-day. It would be impossible, at least from a commercial point of view, to make flasks or casings to accommodate the number of patterns which differ in their thickness, size and contour, so that when a moulder has given due regard to the appliances at hand and finds he is short to deliver a certain job his mental faculty is called upon to supply some method that will sustain the mould and metal whilst casting.

Doubtless a knowledge of the nature and properties of sand adds to the interest in foundry work. But though various facts have been deduced in the laboratory, the moulder is again without a positive formula to guide him in practical work; he is still left to his resources. He judges the qualities of the sand by his sense of touch, and adds certain materials and energy to get a desired effect. In consolidating the sand around and in a pattern he is called upon to give due regard to its fragility, firmness of the sand to resist heat and liquid pressure, without impairing the porosity that allows the gases to strike back to the vents.

It is proposed to outline a number of typical jobs recently made, which might have been produced by either the dry sand or loam method. This matter is treated from a jobbing-foundry point of view, and it is not claimed that these methods are in any way superior or even as good as might be possible is made in a foundry specially equipped for one class of work.

Green Sand Moulds.

As is well known, moulds that are made in various kinds of sand and retain their own moisture until poured or cast, are termed green sand moulds. This method is, without doubt, the best for making the majority of castings in ordinary foundries doing work in connection with modern engineering.

When moulding in green sand, sands that are charged with moisture above a certain limit should not be used, as any attempt to pour hot metal into a wet mould will immediately generate dangerously-large quantities of steam and gas, and the molten metal will not lie on the bottom or face of the mould, as these gases and steam, causing it to be blown or forced back through the runners and risers just after casting. A mould of this kind is useless, but it serves to show the danger of an excess of moisture in green sand.

No additional venting will ensure a sound casting in such circumstances, and even did the casting appear to be a success there would be trouble with machining and fitting, and the casting would not stand the strain sometimes demanded, being too hard and brittle. On the other hand, sand rather too dry will not bind, but will fall and crumble away; or if it did stand in the mould it would very likely be washed away from its position by the force of the metal passing from runner into the mould. It is evident, then, that combined sound judgment and experience are required to determine the amount of moisture to be used in the making of clean green-sand moulds, which will readily discharge the air and gases, and cause no trouble to the moulder or anyone concerned.

Skin-dried Sand Moulds.

Skin-dried moulds are those which are rammed up in green sand, and then dried skin deep, after being cleaned up and washed with wet blacking. It will be seen that by skin-drying a mould the moisture on the surface or face of the mould is reduced to some extent. Skin-dried moulds often give sounder and much cleaner castings than do green sand moulds, and when cast do not generate as much steam and gas, and are therefore less liable to give blown or scabbed and dirty castings. There are moulds which it is necessary to skin-dry owing to their intricate and delicate construction. Such moulds are better able to withstand the flow and force of the molten metal in passing down the runner and then over the face of the mould at the time of casting.

Reducing the moisture on the face and walls of a mould also stiffens the green-sand cores, and there is not the same likelihood of particles being washed up from the face and walls of the mould as with green-sand moulds.

Dry Sand Moulds.

Dry-sand moulds are those which are rammed up in the same way as the ordinary green-sand mould, but are subsequently dried. These moulds should be vented to a certain extent in exactly the same way as green sand moulds, for although there is no moisture to expel or force through the walls of the mould, there is always a certain amount of gas generated in the sand at the time of casting, which will pass and escape through the vents without any marked effect. When not vented, sometimes these moulds explode or their gases ignite before the pouring or casting is finished, and the shock causes the face or top of the mould to suffer by small pieces being shaken off, the result being a dirty and unsatisfactory casting, only fit, perhaps, for the scrap heap.

Loam Moulding.

There is little in common between sand and loam moulding, except that each method forms a mould that will hold molten iron and turn out a satisfactory casting.

A loam moulder's daily routine is concerned with spindle plates, bricks, straight-edges and square, strickling boards, strickles, etc., whilst the sand moulder is concerned with various kinds of patterns.

When making a casting in loam, whether large or small, plain or difficult, the preparation of the tackle is most important, and if the casting is a difficult or intricate one there is more reason for forethought by draughtsman, pattern maker and moulder at this point.

The work is laid out full size, as far as is necessary in the pattern shop, and the moulder, with the aid of the pattern maker, procures the dimensions for his tackle from it. The important points for the moulder to watch in this matter, apart from the correctness of size, is, first, that the tackle is sufficiently strong; second, that provision is made for runners and risers, bolting up, and escape of air; third, provision for easing or liberating after pouring, and for the contraction of the casting. It is far preferable for a moulder to err, within reason, on the heavy rather than on the light side when making his tackle, because the breaking or snapping of a plate, binder, staple or bolt often means commencing afresh, besides the possibility of injuries to those near the work.

Efficiency in Handling Bricks and Mud.

In arranging the work, the most efficient manner of bringing both bricks and mud to the wall will depend upon the size of the job, thickness of the wall, and whether the wall is being run up in a pit or above the floor level.

At some shops, skips or buckets handled by the crane are used to deliver the bricks to the moulder. Where this is the case, the bricks should be carefully arranged in the skip in order and not thrown in haphazard. When the bricks are piled in the skip neatly the moulder makes the same motions in removing each succeeding brick, and does not

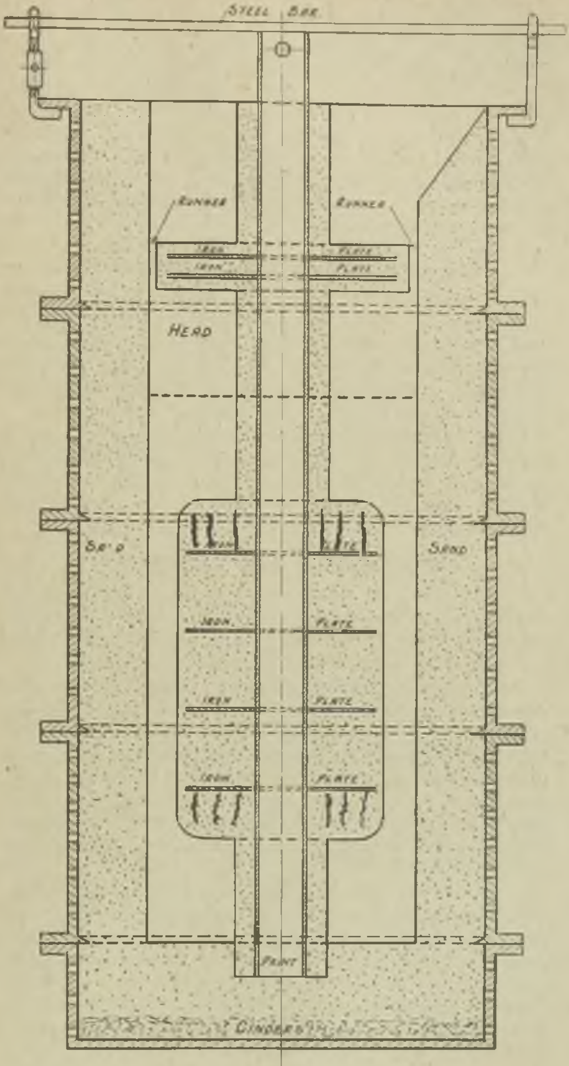

FIG. 1.—MOULD FOR RAM CASTING.

have to twist his arm back and forth to grab bricks lying at various angles.

As the wall rises both the bricks and the mud should be delivered as nearly on the level of the wall as possible. In some cases the moulder's helper piles the bricks on to short "board packs" and places these on a box or pair of "horses" beside the moulder. The bucket of mud should also be set on a box or "horses" as near the level of the wall as possible.

Increased Efficiency and Lessened Effort.

By carefully considering these items, and eliminating, so far as practicable, unnecessary and fatiguing work on the part of the moulder, the number of bricks he can lay in a day will be materially increased without adding to the physical effort he must put forth.

Good moulders intuitively recognise the advantage of proper handling of bricks and mud, and it is the thoughtful observance of these minor savings that differentiates between the high-grade loam moulder and the indifferent workman.

MOULDING A RAM CASTING.

The making of this casting in loam will first be dealt with. The author has seen similar castings made in many foundries in Lancashire and Yorkshire in both loam and dry sand.

For the loam method plates of different sizes are required: a bottom plate, cope-ring, two building rings, and, if the casting is over 6 ft. long, it will require splitting to enable the moulder to get it into the stove. This, of course, will cause more work, and will require another cope-ring and two extra building-rings, a top-plate with holes for risers and core, and two staples cast in for holding down the barrel core.

A start can now be made on the bottom plate with an inch seating, or a four-inch seating, for it is then merely a straight build all the way up, but two bricks must be left out at the bottom so that the moulder can remove the dropping loam from the strickle. An inch seating will be sufficient for the covering plate, as this will set the centre core.

If the coping has to be split in the centre it can be done on the building, or a dummy seating can be set up. If the mould is put together in the pit it will require ramming up.

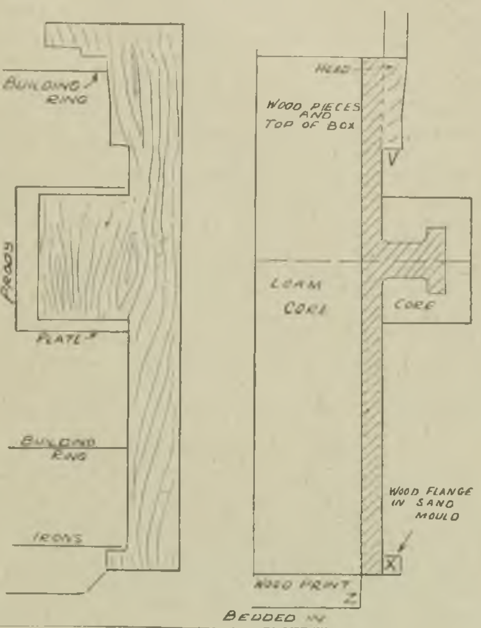

Fig. 2.—Cylinder for Crank Lathe.

It is assumed that all cores are made on a barrel, as shown in Fig. 1, but should they be made in the mould by the loam-moulder extra work is entailed, and the job will cost much more per cwt.

Another method of making a ram casting is by using half-boxes. It involves fixing the board fast to a horizontal spindle, revolving in a socket at each end of the box. This should be cored with a barrel core, put together and turned up on its end to cast in a pit. Rams are also made in half-boxes in dry sand from a pipe pattern, cored and turned on end the same way as described above.

This casting can also be made in boxes of two sizes—8 ft. inside, and 3 ft. 6 in. inside—with 18 in. deep middles and an 8-in. bottom, with shell patterns to form the outside part of the mould, as shown in Fig. 1. It will be seen that the bottom box is a full part, having no bars. It has only two 3-in. holes in the bottom, and is perforated on the sides.

The method adopted by the author is to put some cinders in the bottom box, and ram up with sand to the joint. At this point the shell pattern is placed in position, putting eight sprigs on the outside of pattern, so that the moulder can get the centre for the print. Then each middle is rammed up, making a joint at each box, or every two. The middle boxes have a flange all round on the bottom inside to prevent them from dropping out after being in the stove for the night.

After having rammed up to the height required sufficient space is allowed for the runner, as shown in Fig. 1, scraped down at one side about a foot. The outside of the mould must be made higher, for, as will be seen, the core forms the casting.

How the Core is Made.

The core is made on a perforated iron tube or core barrel in the ordinary way, only a stop-piece 4 in. wide is incorporated to form the gate, and this forms the end of the casting. This part of the core is ⅛th in. less than the body of the mould, and this will run a job weighing 5 tons.

A print is bedded in the bottom box. After the job has been in the stove over-night it is put together in the pit with three bricks on the bottom joint, so that when the core is lowered down the mould the moulder will be able to guide it into the print.

The bricks must be taken out after this has been done, and the middle boxes lowered into the bottom. After this the proceeding is to cotter up the whole and put three thin wedges between the core and the mould. The core will be in the centre of the mould; it is then bolted down as shown in Fig. 1, and is then ready for the metal.

After the cast, loosen the screw bolt which is holding down the core a little at a time, or the barrel will sag in the middle. It will be seen therefore that the dry sand method of making this casting is much quicker and cheaper than the loam method.

Cylinders for Crank Lathes.

The conditions appertaining to these were that an order was placed for six castings, which were made in loam, and a further order came in twelve months later for two similar castings. This time, as there were only two required, and all the loam plates had been broken up, to save expense it was decided to make them in the boxes used for the ram casting and in dry sand, especially as there was a shell pattern handy to form the outside of the casting.

So all that was required now was a flange for the bottom (X, Fig. 2) and a wood strickle for setting the cores in the centre, using the same core box as in loam. Then there must be provided some wood strips to form the top flange and head of the casting, also a blank flange from stock to set the core in the bottom.

It will be seen that this casting cannot be run the same way as a ram, as the metal would drop on the shoulder V, which would be wrong, so a covering plate was made with holes for the core to come through, and gits. This plate is held down with three clamps under the flange on the box, the barrel core being held in the same way as in the ram mould. After making up the git bush on the plate, it is ready for casting.

This mould being put together in the pit, it is better to cast with the ladle. The time for making this job in loam was 40 hours, whereas making the same casting in dry sand was 16 hours, including both moulding and core-making. The sand used for both this job and the ram was made up with 12 parts of red sand, 5 parts of black sand, 2 parts of sea sand, 3 parts of manure, and $\frac{3}{4}$ of a part of coal dust. It was milled for a quarter of an hour when all in the mill. The metal used was made up of 10 cwts. of steel, 20 cwts. of hematite, 20 cwts. of Scotch, 10 cwts. of Sheepbridge, and 40 cwts. of scrap. The casting analysed out at C, 3.0; Si, 1.3; Mn, 0.6; P, 0.4; and S., 0.1 per cent.

MAKING A CONDENSER CASTING IN LOAM.

The making of this casting in loam will first be dealt with. As this was an outside job for an engineering firm, they supplied boards, loose branch and four feet.

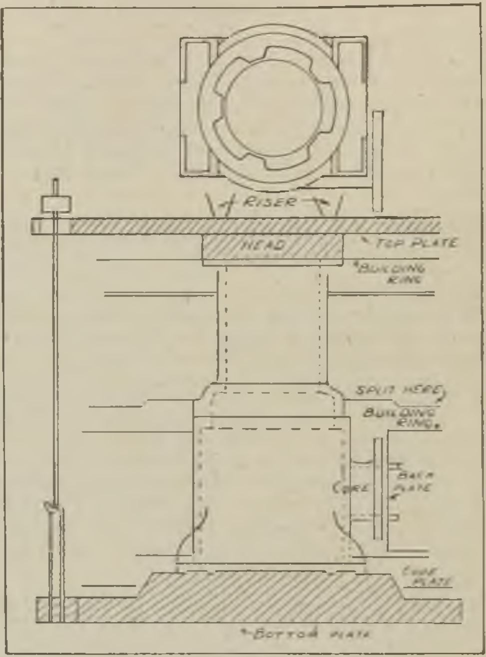

Fig. 3.

After having made a bottom plate and a cope ring (Fig. 3), the moulder can strike the seating for the job from a centre spindle. He must then allow the mould to set overnight. It is then ready for the cope ring, and, having set the four feet, the moulder can build up to the flange bottom of the branch. It is good practice to allow the patternmaker who is in charge of the job to set the branch, the moulder setting the gates on the other side of the branch.

When the branch and gates are in place the mould is ready for bricking up to the joint, having procured building-rings and box-plates for the branch for binding the bottom-part together. For his own purpose the author splits the mould, where shown in Fig. 3, when putting the job together.

For the branch this must be faced with a space of about 3 in. all round for the back plate to fit against. This is shown quite clearly in Fig. 3. It will be seen that the first building-ring, just under the first joint, forms the plate for the top side of the flange of the branch, and another for the bottom. This gap can be made a round one, similar to the flange, but, of course, with the necessary bearing; but the author prefers a square one, as it is much better to set and pack, and if this type of job is not well packed and stopped in, the metal will break out.

For the first joint, where the building of the job is split, another lifting ring is required to lift the top portion of the mould away. Having made this ring the night before, it is quite ready for placing on the joint. The board must then be spun round and that all is clear be ascertained. Carrying the over-lapping joint, the moulder is on the straight barrel till he reaches the flange. Here he must not forget he requires 4 in. for the head on the top of the casting. Having placed another building-ring in this top portion, he need have no fear of this casing coming apart when carried about, but if the chain should slip—and this has happened—it would mean making a fresh start.

Now the moulder can make the top-plate, which is prodded as shown in Fig. 3, with two riser holes, a vent hole for the core, and a square prodded-plate for the branch. These plates are daubed with loam, after which they are ready for stoving.

After ascertaining that all joints are marked and that the spindle is out of the way of the casing, the moulder can commence to pull the coping off the seating, leaving the seating still in position. The branch pattern and four feet are removed, and the casing is finished ready for the stove, where it will require to remain for two days.

Next the spindle must be placed back into the socket, the board forming the core is fixed on, after which the moulder can build up what forms the inside of the casting. It must be remembered to keep to size, ascertaining that the five building-in pieces are about half-way up, and that the 4-in. of head has been added to the coping. Additionally 4 ins. must be added to the core.

Two building-in rings will be required for strengthening the core, which will be carried out in the same manner as the cope when the core is built. Now the coping can be brought from the stove, and the seating with the core on returned, remembering the five building-in pieces.

The next job is to finish coping the top plate and the plate for the branch. These three are then returned to the stove for the last time, and the core is brought out, after which it requires finishing, blacking, and returning to the stove to finish drying.

Preparing the Pit.

The method of putting the mould together on the top of the pit and then lifting it into the pit is a bad principle, as when it is lifted with the crane it is liable to be cracked in places, and the metal will get into the cracks and vents, resulting in a bad casting, and, perhaps, someone being seriously burned. The method of putting the mould together in the pit is a much better one—that is, of course, for jobs which require ramming up and not prodded jobs, as the latter are put together and cast on the top.

First the seating with the core is put on in the pit, seeing that this part of the mould is "plumb." The bottom cope must then be put over the core. This cope having been split, the moulder here has the advantage of being able to see all round the bottom.

The gates and branch being complete, the moulder can now fix the core in the branch and put on the covering plate of the flange. This must be well stopped in while the job is warm. The top cope can now be put on to the marks previously made. This being done, the mould is ready for the top plate. It must be ascertained that the core touches this plate and the risers are correct. All the joints can be made up with wet loam, and then the job is ready for bolting up with shackles and bolts—not clamps, as these sometimes "give," and the metal is then liable to run out.

Having made the gates and risers up with waste, the moulder can put the rings around the mould and commence to ram up. At this juncture the moulder must see that the back plate belonging to the branch is well packed, or the metal will escape when it begins to flow. If this method is strictly adhered to there is no reason why this mould should not give a perfect casting.

MAKING A CONDENSER CASTING IN SKIN-DRIED SAND.

This casting, when made by skin drying, is built up in two parts, as shown in Fig. 4. The top part is made from a jobbing pipe-pattern with flanges, one in the socket and the other on the body. Holes are drilled, so obviously it requires very little pattern-making on this half of the job. The other half of the casting—the bottom part—is made by fixing up the core on a barrel, so as to form the inside of the casting; then the thickness is put on the core to form the pattern. The same loose feet and branch patterns are required if made this way.

A hole must now be made in the foundry floor sufficiently large in every way for the job required, but 2 ft. deeper than the face of the mould, as the branch goes on the bottom. This will allow the cinders to be out of the way. The sand is well rammed on top of the cinders, so that there will be no strain marks when the casting is fetched out.

The pattern-maker having nailed the four feet on the core pattern, the moulder is now ready for this, and it can be put in the hole made in the floor. The pattern must stand halfway above the level of the foundry floor, so it can be carried half away in the top box.

Having the pattern well staked at four corners and well rammed up to the joint, it may now be lifted out and a hole prepared for the branch. This must be set by gauge and staff, as the branch must be in the centre of the two feet and a distance up the body of the casting. The flange on the branch must be covered with a loam cake, which must be well spiked down, or it will lift. If all the holes in the flanges are drilled, the moulder cannot go wrong, as he can drill the holes to suit the centre of the feet and branch.

Now the moulder can again return the core pattern into the stakes by removing the stakes and making good the holes and the joint. The top box can now be put on. This, taking half the pattern, requires many lifters and a good ramming. This done, the moulder must stake, in four places, and lift off the top box. He must then lift the core pattern out of the mould and take it back into the core-shop. The core-maker is required to take off the thickness of loam which forms the thickness of metal. The core remaining on the boad is blacked, as this is to form the inside of the casting.

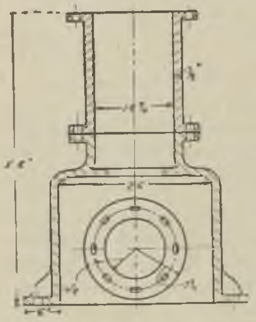

FIG. 4.

Returning to the mould, the moulder can draw out the four feet and branch body, finish, and black the mould with a black wash, the constitution of which is one bucket of plumbago, two buckets of common blacking, one handful of gum, and one gill of core oil. This should be well mixed and allowed to stand overnight.

On the bottom part of the mould fires are lit and hung over the top box for about one hour. When it is thought to have had sufficient drying, the fires must be taken off. Having placed the top on bricks, the moulder cleans out the cinders, puts in the branch core, then the body core, ascertaining that these two cores touch. After trying on the top box, it is lifted off again, and if everything is satisfactory the top box can be returned for the last time. The barrel is scotched and well stopped in at each end; the gates made up, after which the mould is ready for the metal. The casting is run by sprags on the joint.

Made in this fashion, the job does not require any more pattern-making than it did in loam, but with the latter method it would require plates and tackle, which denote extra cost. A comparison of the moulders' time taken by the two methods is set out below.

LOAM.

	Hours.
Moulder	62
Labourer	62
Dresser	5

Weight ... 6 cwt. 0 qtrs. 25 lbs.

SKIN-DRY SAND.

Moulder	25
Dresser	6

Weight ... 11 cwt 0 qtrs. 22 lbs.

MAKING A DYE GIG IN LOAM.

It is probable that the making of this job in loam is unsuitable, taking into consideration time, risk and price. On assuming the management of a foundry, the author found that two castings had to be made off such a pattern, one had been already made and the other one just started. An enquiry as to the time each job had taken, revealed that for the first, for which plates were required, no fewer than 196 hrs. were absorbed. For the second it was reduced to 138 hrs., or 167 for each.

These two were the last cast this way. This casting, the same "over the scales," is now made in dry sand in 54 hrs., and is found to be equally as good, associated with less risk.

The loam job, when made from a skeleton pattern, requires the following tackle for the two castings required :—A bottom plate; cope plate; two building plates; plates for core; one building plate; a prodded plate for top of core; and a top plate with 2-in. prods cast on. Seven plates in all. This necessitates about 8 tons of metal being melted, cast and broken up. This is a cost which has to be considered, and there is still required loam bricks and labour to make the mould, which will be in and out of the stove for three or four days.

After putting the job in the pit, with the top and bottom plates bolted together, and with every joint fastened, it is ready for ramming round with black sand up to the top plate. It will be seen from Fig. 5 that this job cannot be cast on top or in the pit without ramming, as there are no prods on the plates. When this is done, the moulder must make up the gates on the top plate, after which it is ready for casting.

The next job is liberating the casting, by taking out some of the inside bricks. This must be done about one hour after casting.

MAKING A DYE GIG IN SKIN-DRIED SAND.

Making the same job in a skin dried mould, with the same pattern, but with the gaps filled in with plain wood, it will be noticed there is very little difference in the pattern-making.

After digging a hole in the foundry floor large enough to take the job, the moulder first makes a suitable cinder bed, then he levels a sand bed on the cinders. The pattern is then placed downwards on the bed feet, the top of the pattern coming level with the foundry floor. Having made a grid with prods one foot long attached, it is placed inside the pattern with the prods downwards. The moulder commences to ram up, inside and out, to the top of the grid, having put sufficient packing on the grid to meet the box bars, and bolts to come through the bars for fastening the grid.

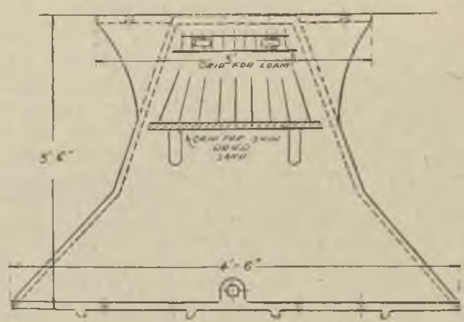

Fig. 5.—When Made in Loam it is Moulded as Shown, but when Made in Dried Sand the Job is Inverted.

The mould is vented down to the cinder bed all round the outside; the gates are placed in at one end—one on both sides the thickness of the metal three inches deep. The up-gates are bushed round all the way up.

Having ironed and rammed up to the top of pattern, the moulder makes the joint and puts on the top box. After this is rammed up, the bolts from the grid are screwed up, the top lifted off, ascertaining that it is well staked three feet above the box. This is most important, as a good guide is required. The moulder can then draw the pattern, finish the mould top and bottom, wet black, and dry with bucket fires. The top is hung over the bottom, and left suspended from the crane over-night.

Next morning the cinders are cleaned out; the top is tried on, paying special attention to the feet and thickness. The gates and the mould are made up weighted, after which it is ready for the metal. After casting the bolts are liberated and the top box removed and the grid taken out.

MAKING A DYE GIG IN GREEN SAND.

It sometimes happens that three different sizes of this casting are being made simultaneously. They are made on the bath principle. In a jobbing foundry, a special box cannot be used for every job, so each gig is made in the floor, and the mould is skin dried as stated. The making of a dye gig in green sand in a box, however, presents several interesting points.

The bottom part is a full box with two flats, one at each end, about 3 ins. wide. These two flats slide up the end plates of the middle box part in a grove as shown in Fig. 6. The middle box incorporates two end plates and two perforated side plates with bars which reach within $\frac{1}{2}$ in. of the pattern.

The casting is made from a wood pattern with loose boards for the circle top of the pattern. It is moulded by placing the bottom box on the foundry floor—properly levelled—then a 3-in. layer of cinders is put in the bottom box, which is rammed with black sand to the joint of the bottom box. The pattern is placed in position, and the outside joint is dusted with parting-sand. After placing on the middle box, it is part-rammed, whilst at the same time the inside of pattern is also rammed. After reaching the top and after having vented to the cinders in the core, the loose boards that form the circle of pattern, is placed on; then the top joint of the middle box is made, dusted with parting-sand, and the top box is put in position, inserting two rows of spikes—six in a row—for gits. The four feet, two at each end, are placed in position, and the top box is rammed up.

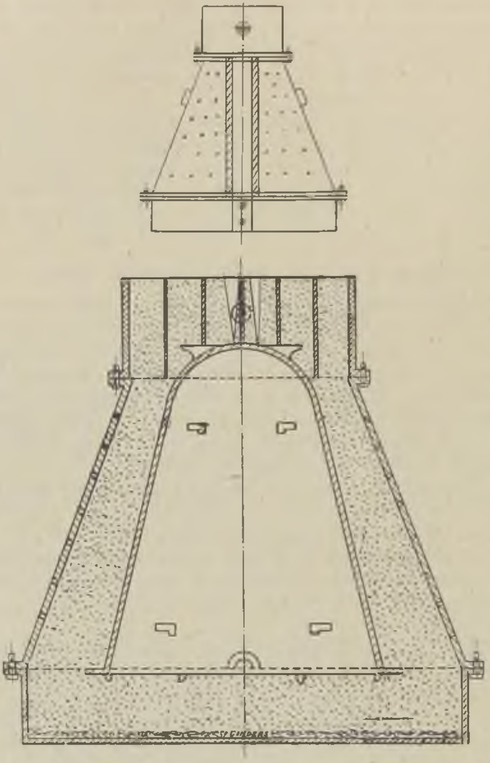

FIG. 6.—SHOWING THE MOULDING OF A CASTING IN A BOX.

The top box, being removed, it is placed on four bricks. The middle box can now be removed, and it must be put on four props to enable the moulder to work on its inside. After replacing the top box on to the middle, it is essential to go inside and make good the joint of the top box and middle, and to see that the gits are all clear, and the four feet are out. Blacking cannot be done at this part of the mould.

Returning to the pattern, the loose boards are taken off the pattern, withdrawn, and the core or bottom part of mould finished. As little slaking as possible is advisable, and it is preferable to dust with a small quantity of best plumbago, as there is only $\frac{5}{8}$ in. thickness of metal. The mould is now ready for the top and middle together. It is here where the two flats or guide-pieces guide the box until it reaches the pins in the bottom box. Everything being complete, all that is required now is to cotter up and make up the runners. If this method is strictly followed this should be a good casting.

Birmingham and East Midland Branches.

PIG-IRON: ITS CHARACTERISTICS AND USES.

By H. Field, Member.

The following Paper has neither been written as a treatise on pig and cast iron, nor as a thesis on microstructure and macrostructure, nor a defence or destruction of inherent properties, nor even yet as a critical comparison between the value of analysis and fracture but simply and solely because the word "iron" still conveys to many foundrymen only as much distinctive information as does the use of the word "stuff" when applied to that wide range of materials which the fair sex so deftly and effectively adapt to their adornment. To many who daily handle the ferrous metals, all which is not white as aluminium, or red as copper, is iron and iron only. Behind them lies another class to whom the use of the word may conjure up visions of steel, wrought iron, malleable iron or cast iron, but to the intelligent foundryman it presents a hundred possibilities and iron to him is anything but iron unless it is the one particular brand, fracture, analysis, strength and fluidity which he desires.

The object of this Paper, then, is to help any foundry worker who, daily seeking and perhaps handling tons of pig or cast iron, still lacks knowledge or imagination to understand why (over and above the reasons of trade competition) there are "brands" of iron, why one brand is preferred to another, why pig-iron should be carried the length and breadth of the country, and lastly why various castings around him in the foundry are cast from different mixtures. The "savants" will please remember that this is an elementary Paper, and be tolerant accordingly.

In considering the location of various industries throughout the country, it is apparent that some have sprung up in a district because of local needs for their particular products, whilst the interests of others are vitally bound up with imports or exports. The scattered nature of the iron making industry is due to Nature's abundant but widespread provision of two essential raw materials—iron ore and coal. Wherever to-day there are blast furnaces, it may be taken for granted that *there* originally was found either one or the other of these, and in fact often both of them. Some of the ore fields are more or less exhausted—the South Staffordshire iron making district being an example. The direct use of coal no longer obtains, having given place to coke, the manufacture of which being scarcely so widespread as the original distribution of coal, hence we find in many cases to-day fuel being transported long distances for smelting purposes. Therefore there are a few instances where neither fuel nor ore are now found on the spot, and many more where only either one or the other remains. The former class are struggling for existence against a sealed doom, the latter are working under a heavy disability. It may be that in the future new centres will develop, *e.g.*, the mining of coal in Kent may enable ore to be imported from France.

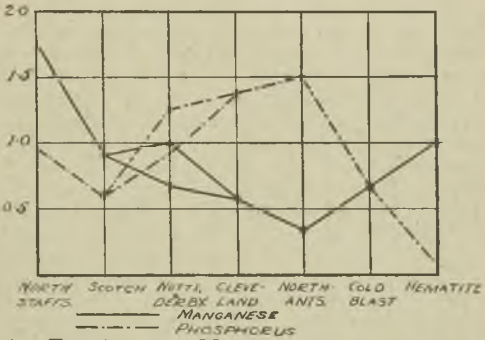

FIG. 1.—THE AVERAGE MANGANESE COMBINED PHOSPHORUS CONTENT OF BRITISH FOUNDRY PIG-IRONS.

The principal ore fields of the United Kingdom are now Cleveland, whose famous ironstone yields only about 30 per cent. iron; Scottish Blackband with a similar iron content, but, as its name denotes, high in organic matter: Northamptonshire and surrounding counties providing brown hematite with 45 per cent. iron; Cumberland and Forest of Dean, red hematites with a valuable iron content reaching to 65 per cent.; and Staffordshire, with a 35 per cent. clay-ironstone in the South, and a high manganese blackband in the North, both being in relatively small quantity. In addition to these, imported ores are more or less largely used, but not in the production of foundry irons, and no further mention of them is needed.

Value of Ores.

As will be seen later the amount of iron in an iron ore is not the only important feature any more than the actual amount of iron in pig-iron is a criterion of its value or properties. Although it is of first importance that the ore should contain sufficient iron to make its extraction profitable, there are nevertheless rich iron-bearing materials—such as iron sulphide or "Blue Billy"—in which the impurities are such, both in quality and quantity, as to render them useless for smelting purposes. It is therefore important to notice the high manganese in Staffordshire blackband and the gradual increase of phosphoric oxide in passing from hematite on to Scotch and Staffordshire ores, and then to Cleveland and Northamptonshire ores. It is also important to bear in mind that although the combined moisture may be driven off from brown hematite and the organic matter from blackband, there is no method of removing phosphoric oxide from any iron ore.

Distribution of Blast Furnaces.

The blast furnaces of the United Kingdom are equally widespread, and their main distribution is shown from Table I compiled from the very useful sheet issued quarterly by THE FOUNDRY TRADE JOURNAL. A large amount of the iron made from these furnaces goes to the steelworks, and so is not important to the founder, practically the whole of the South Wales and Lancashire outputs being thus accounted for. As is well known, the chief foundry iron centres are Scotland, Cleveland, Derbyshire, Northamptonshire, and the lesser ones Lincolnshire, Notts and Leicester, North and South Staffs. Of minor importance are the Shropshire furnaces, whilst white hematite pig for malleable work comes from the North-East and North-West Coast. An experienced practical man knows that every one of the classes or "brands" mentioned has its valuable features, either in price or quality, and a survey of typical analyses would confirm his judgment. Of course, the districts shown are sub-divided into many works or groups of furnaces, e.g., Northamptonshire with Cransley, Islip, Butlin, Lloyds, Kettering, Rixon; and Derbyshire with Stanton, Butterley, Clay Cross, Denby, Awsworth, Sheepbridge, and Staveley. One or other of these may be preferred by various users, but each field has nevertheless its broadly constant yet peculiar product.

TABLE I.—*Distribution of the Blast Furnaces of the United Kingdom.*

Area.	Sept. 30th, 1923.		
	Built.	In blast.	Foundry and forge iron.
Scotland	102	44	33
Derbyshire	43	23	23
Cleveland District ..	74	32	16
Northamptonshire	21	9	8
South-West Yorkshire ..	17	8	6
Notts, Leicester	8	5	5
North Staffs.	20	11	4
South Staffs.	30	10	3
Shropshire	6	2	2
Durham, Northumberland	40	14	—
South Wales, Monmouth ..	36	10	—
Lancashire	30	14	—
Lincolnshire	23	18	—
West Cumberland	30	11	—
North Wales	4	3	—
Gloucester, Somerset, Wiltshire	2	—	—
	486	214	100

The various "brands" named above vary widely both in analysis and in physical properties. Northamptonshire iron is weak, but very fluid and admirably suited for light and ornamental work; Cleveland and South Staffs common iron are a little higher up the scale; Notts and Derbyshire give an iron moderately strong and admirably suited for machinery work; Scotch iron is still stronger, but it is found that fluidity has given place to strength, in fact to such an extent that the Scotch makers of light castings use iron from Cleveland and even Northamptonshire in preference to their home product. Strength and fluidity are not commonly found in the same pig iron.

In addition to these wide classes there are on the market a number of "special" irons, often highly recommended for cylinder and other high-pressure work. Some of these are made by admixture of high-class ores, some by a refining process in open-hearth furnaces, and some by melting steel with pig iron in either cupola or open-hearth furnace. Examples of these are the South Staffs irons "Titan," "Capponfield," "1X.L.," etc. Again beyond these there are the cold-blast irons, such as Lowmoor and Lilleshall, which are renowned for a strength begotten by purity through the cold blast used. Table II shows details of modern South Staffordshire practice for which the author is indebted to an anonymous friend.

These irons have one quality in common—high price—and considerable discretion is required in purchasing, for there are irons round about us which are being advertised as "Special" but which possess no virtues worthy of the name. It is very easy for the founder to grow into a habit of calling for special irons thinking that they will solve all his troubles, but this rarely happens.

The Movements of Constituent Elements.

The various elements which together make up the complex product known as pig iron are derived from the ore by reduction, or from the coke by absorption, during smelting in the blast furnace. Phosphorus is mainly derived from calcium phosphate in the ore, silicon and manganese from their respective oxides, sulphur mainly from the coke, and carbon wholly therefrom. The laws governing the transfer of these elements into the pig are not the same in every case. Only a small fraction of the silica in the ore is reduced to silicon, the proportion being greater in hot working furnaces; and only one-twentieth or thereabouts of the total sulphur passes from coke to iron. On the other hand, manganese passes almost entirely into the iron, the loss being greater with small percentages. Phosphorus, too, is transferred even more completely from ore to iron, the only exceptions to this rule being when the slag is excessively rich in ferrous oxide or when there is over 3 per cent. phosphorus in the ore. The former exception is an undesirable one, owing to the effect on furnace lining, and the latter is an unusual one, as very few ores contain over 1 per cent. phosphorus. It is unfortunate that so stern a law governs the reduction of phosphorus, for it would be greatly advantageous if low-phosphorus iron could be produced from phosphoric ores, and would raise considerably the value of much of British ore supply. The truth of this statement with regard to phosphorus is seen by a survey of the amount of this element in various Northamptonshire irons, when one is struck by the small variation found.

TABLE II.—*Raw, Natural and Finished Product of South Staffs. Pig Iron.*

South Staffs. Clay Ironstone.		South Staffs. Pig Iron.		
			Warm Blast.	Cold Blast.
FeO	45 to 50	Silicon	1.0	0.7
CO_2	30	Sulphur	0.10	0.12
SiO_2	10	Phosphorus ..	0.40	0.45
Al_2O_3	5	Manganese	0.65	0.80
P_2O_5	0.4	Total Carbon ..	3.3	3.0

How Carbon Enters Pig-Iron.

With regard to carbon, this element is derived from the coke, not directly, but through the decomposition of carbon monoxide, and sometimes carbon dioxide, whereby carbon is deposited on the spongy iron and passes down into the hearth. There is little or no direct control over the amount of carbon in the final pig. although this is limited by the amount of other elements present, by furnace temperatures and by other conditions, such as size of ore, rate of descent, etc. Generally hot working increases carbon so that siliceous irons are higher in carbon than white or mottled irons, and cold-blast iron is low in carbon. Carbon is also usually higher in low-phosphorus irons, so that Northamptons are lower than hematites, the high carbon in the latter being a drawback to their use.

Virtues and Drawbacks of Hematite Iron.

Many foundrymen believe that hematite is the most valuable iron in the foundry where high-class castings are concerned. The only fact which can be adduced to support such a belief is that this iron is very low in phosphorus and sulphur—not only very low, but reliably low—and fairly high in manganese. It has no other virtues, however, and has this considerable drawback, that it is not made for the foundry but for the steel-maker, and *he* does not mind what the carbon is so long as sulphur and phosphorus are under 0.04 per cent.

It is furthermore believed that these furnace conditions influence not only the amount of carbon but also the structural or physical properties of the deposited graphite, which, if correct, would help to account for some of the apparent vagaries of irons of similar analysis.

TABLE III.—*Phosphorus-classification of Pig Irons.*

Non Phosphoric.	Medium Phosphorus.	High Phosphorus.
Hematites from East and West Coasts, Forest of Dean.	Scotch South Staffs. Specials : I X L Titan, etc. : Most cold blast iron Notts., Derby and Leicester, Lincolnshire.	Cleveland. South Staffs. Northamptonshire.

The differences noticeable amongst various brands of pig-iron are therefore due firstly to the use of different kinds of ore, and secondly to the diverse conditions obtaining within the furnace. These latter are again divisible into (*a*) variations within one furnace from time to time, this producing differences in one brand of pig, such as those already referred to under silicon and carbon—and (b) intentional variations in practice between one furnace and another producing known differences in the respective irons. In spite of all these variations arising from many causes, there may still remain some constant feature attached to every furnace, and it is only by becoming acquainted with this determining element that the foundryman can readily appreciate the relation between the various pig-irons of the country.

Owing to the uncertainty in the reduction of silicon and its wide variation in one furnace over even small intervals of time, it is impossible to classify the various iron-producing areas of the country according to silicon content in their product. Neither can carbon be adopted for this purpose, for it is even more beyond control. Classification can only be made by taking as a basis an element which varies but little over a long period, and it has been shown that phosphorus alone comes definitely under this category and manganese to a less extent. It therefore becomes customary to divide the furnaces according to the average phosphorus content of their iron, which is dependent upon the ore smelted, the whole of the phosphorus passing into the iron (Table III).

Characteristics of Pig-Irons.

Examined analytically the characteristics of the principal foundry irons are as follows:—

North Staffs.—This is the highest manganese iron in the country, and is combined with rather high phosphorus (0.9 to 1.2 per cent.).

Scotch.—Manganese fairly high and phosphorus low (0.6 per cent.).

Notts, Derby and Leicester. — Manganese medium (reaching to 1 per cent. in some cases); phosphorus medium (0.7 to 1.2 per cent.).

Cleveland.—Manganese lower (0.5 per cent.) and high phosphorus (1.3 per cent.).

Northampton.—Low manganese (0.3 per cent.) and high phosphorus (1.5 per cent.).

Cold Blast.—Low silicon and carbon: manganese and phosphorus low to medium; sulphur often high.

Hematite.—High carbon and manganese with very low phosphorus.

The matters so far considered have been those related to analysis, but these can only be of interest to the foundryman so long as they have any practical bearing upon his work. Speaking broadly, it may be confidently said that the physical properties of iron are related to, and dependent on, the chemical analysis, although there is much which at present analysis does not explain. The well-known characteristics of various brands of iron are due to the presence or absence of one or another of the elements usually associated therewith, and as has already been seen what these elements are, how they come to be in the iron, and how much they are likely to vary, one can now proceed to state for what property each element is responsible. On the basis of our general knowledge of the analyses from various districts, one can form a plan of the likely properties and so learn how to select a suitable district according to the properties required in the finished casting.

Influence of Phosphorus on Pig Iron.

Phosphorus is not the most important element in iron but it is the most dependable, and it will therefore be well to first see for what it may be held responsible. Some workers have sought to show that this element has a direct effect on carbon condition, causing the latter to be retained in the combined form and so giving hardness. The author is working continuously with the very lightest of castings made in iron with 1.50 per cent. phosphorus, and after experiment and comparison with lower phosphorus irons, cannot agree that the higher phosphorus causes harder metal. It is, in fact, possible to make several thousands of tons per annum of light castings with 1.50 per cent. phosphorus, and to give almost universal satisfaction to the machinists, a record on which no comment is needed. Possibly with very low-silicon irons phosphorus heightens or appears to heighten the effect of this low silicon. Beyond the fact of its comparatively low price, high-phosphorus iron is used in these light castings because of its great fluidity and its expansion on solidification. Fluidity is an indispensable property for light work, whilst expansion on solidification is also very valuable, for it enables an iron to take and retain the delicate impressions of the mould, an important factor in small machine parts where a high degree of accuracy is demanded and in ornamental castings with intricate designs. Not only does phosphorus impart fluidity, but also increases the range of temperature through which the metal remains molten, a distinctly different characteristic. This property is observed particularly in making large castings, and since it is an effect directly opposite to that of a chill, it causes, or allows to be formed, hollow shrinkage cavities within the mass of metal. It has been said that phosphorus has little effect on hardness, and it is also true that it has small influence on tensile strength. In mixtures containing steel the author obtains regularly 16 and 17 tons per sq. in. tensile with up to 1.50 per cent. phosphorus, using principally Northampton irons, and cannot see any marked improvement when this element is reduced, others remaining constant. On transverse strength it admittedly has considerable effect, causing a lowering thereof, and this incidentally suggests that the transverse test is a better reflex of the iron than is the tensile.

Its most noticeable effect on mechanical properties is seen in the shock test or impact test where an iron with 1.50 per cent. phosphorus will give only half the value of a low-phosphorus iron This effect is one which everyone who handles iron encounters.

These properties clearly explain the suitability of Cleveland or Northampton iron for light castings, but not for heavy work, and show why the Scotch founder comes to England for his iron. The user may justly blame the blast furnace if his iron is hard when he asked for it soft, but he must not hold the maker responsible for fluidity or shock weakness, as it has been shown that the blast furnace has no control over phosphorus, simply transferring it to the pig, and the founder must change his district if his iron is too low in phosphorus. This study of phosphorus also reveals why hematite takes so much more breaking than the cheaper and commoner irons.

Influence of Silicon.

With certain definite requirements in view, it is comparatively easy to choose the phosphorus and hence the brand of pig, but there is no district from which iron can be bought with the certainty that it will contain a desired amount of silicon. It is, indeed, a most unreliable element, and even in calling for iron of a constant quality from one furnace, the foundryman may easily receive running deliveries of iron varying over a range of 2 per cent. silicon. It is not actually the most important element in pig iron, for carbon assumes this *rôle*, but because of its effect on this latter element, which is always at the mercy of an interloper, silicon becomes the element to which chief attention must be paid. The influence of silicon has been so much stressed that "grading by analysis" has been generally abbreviated to "grading by silicon," and it has come to be assumed that if the silicon content were specified by the buyer and supplied by the maker, the foundryman's millennium would be almost at hand. This is certainly a too-hopeful view of the case, but it has come about through the generally wide variation in the silicon content of almost any and every brand of pig, making it impossible for the founder to rely upon the most vital properties of his material. It may not be the most important element, but in buying pig-iron it is the most troublesome. Nevertheless, and in spite of all the preceding remarks, the writer is having exceedingly good deliveries with silicon varying only a few points, but this result has only come after persistent pressure.

The direct effect of silicon is so small, and its indirect effect so large, that the former is rarely taken into consideration. Of itself, it hardens iron to a small extent but adds to soundness in casting. Up to 3 per cent. silicon appears to increase fluidity, whilst over this amount the iron becomes "kishy," although it is notable that even then the molten metal flows more freely than its appearance would suggest. Other things being equal, the best skin is obtained on castings when silicon is between 2 and 3 per cent., this being superior both to the harder irons and to the high silicon or "kishy" irons mentioned above.

As an indirect influence silicon ranks first amongst the usual constituents, for by its aid the condition of the carbon can be almost perfectly controlled. It must certainly be admitted that silicon is not infallible in this respect, since foundrymen know that an iron with as much as 3 per cent. may be chilled to the point of whiteness, whilst on the other hand very low-silicon irons are occasionally grey. These latter anomalies are found in pig-iron, but it is rarely that they persist after remelting. Upon the final relationship between the two forms of carbon, *i.e.*, the hard form in combination with iron and the soft, weak, free graphite, may be said to depend the usefulness of the iron, and this ratio under normal conditions may be controlled by the silicon content. The total amount of carbon in pig-iron is important—perhaps more so than foundrymen at present understand, but it is not a factor entirely under control in making either pig-iron or castings. Efforts to bring down this amount below 2.75 per cent. are not successful, for even if in cupola working as much as 50 per cent. mild steel be included in the charge, carbon is absorbed during descent and melting until it reaches, at any rate, over 2.6 per cent., and a similar increase takes place if a low-carbon mixture from an open-hearth furnace is remelted in the cupola. Furthermore, the form of the graphite in pig-iron is also a factor in making castings, for there would still seem to be retained after remelting some of the structural peculiarities or effects of the graphite. This is the only so-called " inherent " property for which there seems at present any foundation, but the important point is the amount of combined and graphitic carbon, for on this depends chill hardness, machinability, strength, soundness, and shrinkage. The condition of the carbon is influenced equally by section, for there are some sections so thin that they can scarcely be cast grey, and others so thick that it is difficult to retain them white without chills, and it is therefore impossible to show a definite relation between silicon and combined carbon or silicon and graphite. Turner, in his classical researches, has shown the amounts of silicon for maximum hardness, crushing strength, transverse and tensile strength, and machinability, but these figures only admit of literal interpretation into foundry practice when taken in conjunction with casting section. Keep, too, has given us curves showing the strength and shrinkage to be expected with varying degrees of silicon, but these are shown in the same curves to be variable according to the thickness or section of metal under consideration.

Influence of Sulphur.

Sulphur is an impurity which is often found to vary widely in what should be the same grade of iron, although more generally it varies inversely with silicon and does not often reach 0.10 per cent. when silicon is over 2.5 per cent. The author has on occasions received batches of iron with 3 to 3.5 per cent. silicon and sulphur over 0.15 per cent. Foundrymen are coming to realise that this element is less harmful than was formerly considered the case, and that good castings can be made even when it is rather high, but few have yet reached the stage at which they welcome an overdose as an act of friendship. Generally it is specified to be at a minimum, and any variation being then in an upward direction is to the prejudice of the material. Its presence in pig-iron is not readily detected, since the closening of grain or external chill which it may cause are more usually attributed to low silicon, and therefore where the foundryman has not the advantage of an analysis he may be unable to take those steps which partially counteract its influence. With high silicon, *i.e.*, over 2.5 per cent., a high percentage of sulphur is required, certainly over 0.125 per cent. to cause a chill even in light castings, but the chief defect then caused by its presence is loss of fluidity, the metal becoming comparatively viscous and then giving unsound castings. Without definite figures it is unwise to attribute a melt of this character, accompanied as it is by a strong smell of sulphur dioxide from the ladle, to high-sulphur pig-iron, as it more frequently arises from the coke. If it is definitely known to be from the pig-iron, high sulphur must in these cases be admitted as detrimental and often unavoidably so, for foundries making light castings only do not usually stock high-manganese pig, and would not be well advised to use it indiscriminately even where it is at hand.

In low-silicon pigs, where higher percentages of sulphur are more usually found, the effect of sulphur is even more readily seen in its liability to produce unsoundness and blowholes, but the castings made from this class of pig will benefit generally from such manganese additions as are likely to be used to counteract the evil. Sulphur has been spoken of as producing a chill, but this is only by its indirect effect on carbon, which is practically always, the hardness controller.

In addition to these defects—loss of fluidity, blowholes and chill—sulphur unaccompanied by manganese will also produce a degree of shrinkage which will cause cracking and flying in work of intricate design, and will cause a loss of strength in both tensile and transverse tests.

The key to avoidance of these troubles when exceeding the usually prescribed maxima for sulphur is the use of manganese in increased quantity. It has been seen that this element varies very widely when viewing as a whole the irons of this country, from 0.3 per cent. in Northampton pigs to 2.0 per cent. in North Staffordshire. This wide variation and the low percentage found in some brands makes it wise and even necessary to use a mixture of irons for almost any class of casting, for even with the commonest class of work it will be found that if low-manganese pig is alone used, it will not contain sufficient manganese to balance the sulphur, for it must be borne in mind that whilst manganese decreases with every remelt, sulphur increases. The actual amount of manganese for maximum benefit varies with the class of work in hand, being higher in heavier castings, but the two directions in which it exerts influence are both indirect—the one on sulphur as seen above, the other on carbon. Manganese helps to retain carbon in the combined or hard form, and hence toughens iron considerably, but it must obviously be used with moderation for light work. It has considerable influence on chill and shrinkage, independent of its action on carbon, and is used with advantage in chilled roll and similar work. In cylinder and similar work, manganese imparts a closeness of grain which enables a high degree of finish and polish to be obtained, but singularly this does not seem to apply to high-manganese pig-irons, which themselves are often very open in grain even when over 2.0 per cent. manganese. In fact, such a pig may be more open in grain than a Northampton iron with similar silicon but only one-eighth the percentage of manganese.

The properties laid to the credit of these various impurities are constant and unvarying, and may be relied upon to demonstrate themselves provided that the iron is normally melted and normally cooled. In cases where a certain feature present in a pig-iron—whether good or bad—does not remain after remelting, it may generally be said that this property is not the result of the composition of the pig-iron, but of some abnormal item in its production. The exceptions to this rule are the gains and losses in melting, which of course cause some alteration in analysis and may either bring some new quality into prominence or remove a feature before present.

Bearing this in mind, the pig-iron question can be surveyed with a much more open mind, for it becomes apparent that there is not nearly so much "bad" pig-iron as is often asserted. Of course, where a founder confines himself to one brand only, he feels the full effect of every variation, and must naturally condemn much of what he receives, but if he is in a position first to analyse his iron and then judiciously mix it, much that might in itself be useless becomes doubly useful, inasmuch as it may serve to make up some deficiency or other elsewhere. The trouble with pig-iron does not, in the author's opinion, lie in the amount of "bad" iron which the furnaces make, but in the faulty distribution of the iron, for "one man's meat is another man's poison," and whilst "A may be pining for silicon and receiving none, "B," who is situated but a few miles off, may be wondering what he is to do with a much softer iron than he requires, actually received from the same furnace. Nearly all pig-iron is good when used for that purpose to which it is most nearly adapted.

Effect of Composition on Properties of Cast-Iron.

From the foregoing summary of the characteristics of various brands and the effect of this analysis on properties, sufficient has been said to enable the following rules to be tabulated:—

(1) Castings of light section must have high silicon and those of thick section low silicon, in order to secure requisite hardness or softness.

(2) Castings of very light section must have high phosphorus to give necessary fluidity and length of life for pouring.

(3) Castings of heavy section should have lower phosphorus in order to shorten the range of solidification and limit segregation.

(4) Castings required to have strength above normal must have only medium silicon and phosphorus and low total carbon.

(5) All classes of castings should have manganese as high as is consistent with machinability in order to give close grain and neutralise sulphur.

(6) To resist wear it is of prime importance to keep silicon low and manganese high.

(7) For cylinder metals to withstand high pressures use low silicon and total carbon and high manganese to give close grain.

(8) To obtain chill use very low silicon, depending on section, low total carbon, fairly high sulphur (not over 0.15 per cent.), and medium phosphorus and manganese.

(9) To withstand high temperatures keep silicon and carbon low, medium phosphorus, and high manganese. This metal is hard and brittle, has a high contraction, and may need annealing.

Tables IV, V, and VI show respectively the uses of various brands for different types of castings, analysis required for a number of representative castings, and American standard analyses.

The suggestions as to brands to be used are put forward very tentatively, and only to show the choice offered for each grade of casting. There can be no truth in the assertion that any particular type of casting can be made successfully only from one definite brand or mixture, for it is found that similar types of castings are being made with success in every country where foundry practice is carried on. It will, however, be found that wherever a casting is made—that is successfully made—there is some relation in the final analysis of metal employed. Furthermore, analysis establishes a basis of comparison or communication

TABLE IV.—*Pig Irons to be Used for Various Castings.*

Type.	Composition.	Irons Used.	
		C—Cleveland. D—Derby (Common). N—Northants. H—Hematite.	CB—Cold Blast. SS—South Staffs. NS—North Staffs. S—Scotch.
Light Work	High P. and Si.	N.—C.—D.—S.S.	
Engineering—Medium heavy	Medium P. and Si. Low P. and Si.	S.—D.—C.—N. S.—D.—H.	
High Strength	Medium Si. and P. Low C.	C.B.—S.—Specials.	
High pressure and wear	Low Si. and T.C. high Mn.	C.B.—S.—N.S.—H.—Specials.	
Cylinder	Low Si. and T.C. Med. P. and Mn.	C.B.—H.—S.—Specials.	
High temperature	Low Si., Medium P. high Mn.	H.—N.S.	

between one country or another which cannot be similarly established by any other means, for whilst it might be of some guidance to pass on the analysis of a motor cylinder to a founder in Spain or in China, it would be of little use, either in theory or practice, to simply inform him that a mixture had been used of equal parts of Derbyshire, Northamptonshire, and Staffs cold-blast irons. Or, on the other hand, it would help a British founder very little to know that an American used "Hinkle" or "Warwick." In proceeding, therefore, to make any suggestions as to brands or types the author does so only with much caution and in a non-committal way.

Assuming that a foundryman has to make a quantity of any particular type of casting, he will first have to decide if this can be made from any mixture of iron at present in use or if the limits in requirements are so specialised and narrow that a new mixture will be required. In the latter case he will either have before him the specified analysis or will decide from the physical requirements the general outline of composition, and will then be in some position to select his irons. He will naturally desire to use local irons where possible owing to the considerable saving in railway carriage, but this cannot be made the first principle of selection. It has been shown that phosphorus is generally constant in the iron from one district, and that a furnace cannot supply phosphorus to specification in the same way as silicon. This does not apply to any element in

Table V.—*Analysis for Various Classes of Castings.*

Type of Casting.	Si.	S.	P.	Mn.	T.C.
Very light work ..	2.75	0.080	1.50	0.40	3.23
Sections 1 in. thick	2.25	—	0.75	0.50	—
Heavier than 2 in. ..	1.25	0.125	0.40	0.75	—
Motor cylinders ..	1.75	0.10	0.70	0.80	3.20
Motor piston rings	2.0	0.10	1.0	0.80	3.20
High temperature work	0.60	0.150	0.25	1.50	2.75
Chilled rolls ..	0.4 to 0.8	0.08 to 0.12	0.20	0.40	2.5 to 2.75
European malleable	0.70	0.25	0.08	0.20	2.80

TABLE VI.—*Analyses for Definite Classes of Castings.*

Castings.—	Light.					Medium					Heavy.				
	Si.	Mn.	S.	P.	T.C.	Si.	Mn.	S.	P.	T.C.	Si.	Mn.	S.	P.	T.C.
Acid-resisting	2.00	0.75	0.05*	0.20*	3.25*	1.50	1.25*	0.05*	0.20*	3.25*	1.00	1.25	0.05*	0.20*	3.25
Agricultural	2.50	0.60	0.06	0.75	3.75	2.25	0.70	0.08	0.70	3.50	2.00	0.80	0.10	0.60	3.25
Air cylinders	1.90	0.70	0.08	0.50	3.40	1.50	0.80	0.09	0.40	3.25	1.00	0.90	0.10	0.30	3.00
Annealing boxes ..	—	—	—	—	—	0.65	0.20	0.08	0.20	3.50	—	—	—	—	—
Automobile cylinders ..	2.25	0.65	0.08*	0.40*	3.25*	2.00	0.75	0.08*	0.40*	3.25*	—	—	—	—	—
Balls for grinding ..	—	—	—	—	—	0.75	0.50†	0.15*	0.40*	3.75†	0.50	0.50†	0.15*	0.40*	3.75†
Bedplates	2.00	0.70	0.08	0.60	3.75	1.75	0.75	0.10	0.50	3.50	1.50	0.80	0.12	0.40	3.25
Boiler castings	—	—	—	—	—	2.00	0.80	0.06*	0.20*	3.50*	—	—	—	—	—
Car wheels	—	—	—	—	—	—	—	—	—	—	0.65	0.50	0.08	0.35	3.50
Chilled castings	—	—	—	—	—	—	—	—	—	—	—	1.00	0.06*	0.20*	3.50*
Chills	—	—	—	—	—	1.00	0.50	0.05	0.20	3.00	—	—	—	—	—
Crusher jaws	—	—	—	—	—	1.00	1.00	0.04	0.20	3.50	0.89	1.25	0.06	0.20	3.25
Dies for hammers ..	—	—	—	—	—	1.50	0.60	0.05	0.20	3.00	1.25	0.80	0.06	0.20	2.75
Dynamo castings ..	2.50	0.50	0.05	0.75	3.75	—	—	—	—	—	2.15	0.50	0.06	0.50	3.25
Electrical work	3.00	0.50	0.03	0.60	3.75	2.75	0.50	0.05	0.50	3.50	—	—	—	—	—
Engine frames	—	—	—	—	—	2.00	0.60	0.08	0.50	3.50	1.75	1.00	0.10	0.40	3.00
Fire pots, grates ..	2.25	0.60	0.05	0.20	3.50	2.00	0.80	0.06	0.20	3.25	—	—	—	—	—
Fly wheels	2.00	0.50	0.05	0.50	3.50	1.50	0.60	0.06	0.40	3.25	1.25	0.70	0.08	0.30	3.25
Friction clutches	2.40	0.60	0.10	0.70	3.75	2.00	0.70	0.12	0.50	3.50	—	—	—	—	—
Furnace castings ..	2.40	0.60	0.05	0.60	3.75	2.15	0.80	0.06	0.50	3.50	—	—	—	—	—

Gas-engine cylinders ..	2.00	0.70	0.08	0.40	3.25	1.50	0.80	0.09	0.30	3.00	1.25	0.90	0.10	0.20	2.85
Gears	2.25	0.60	0.08	0.70	3.75	2.00	0.80	0.09	0.60	3.50	1.50	1.00	0.10	0.50	3.25
Glass moulds, pipe balls	—	—	—	—	—	2.50	0.60	0.04	0.20	3.25	—	—	—	—	—
Grate bars	—	—	—	—	—	—	0.60	0.05	0.20	3.50	—	—	—	—	—
Gun iron	—	—	—	—	—	1.50	0.50	0.05	0.30	3.25	1.00	0.60	0.05	0.30	3.00
Hardware..	2.50	0.70	0.08	0.80	3.75	—	—	—	—	—	—	—	—	—	—
Heat-resistance-iron ..	—	—	—	—	—	2.00	0.80	0.06	0.20	3.25	1.50	1.00	0.06	0.20	3.00
Hydraulic-cylinder ..	—	—	—	—	—	1.50	0.80	0.05	0.40	3.25	1.00	1.00	0.08	0.20	2.85
Ingot moulds	—	—	—	—	—	—	—	—	—	—	1.25	0.80	0.06	0.20	3.75
Machinery castings ..	2.50	0.60	0.08	0.70	3.75	2.00	0.80	0.09	0.60	3.50	1.50	1.00	0.10	0.50	3.25
Mine wheels	—	—	—	—	—	0.90	1.00	0.10	0.20	3.00	—	—	—	—	—
Ornamental castings ..	2.75	0.60	0.06	0.90	3.75	2.25	0.70	0.08	0.80	3.50	—	—	—	—	—
Pipe (water)	2.25	0.60	0.06	0.80	3.75	2.00	0.80	0.08	0.70	3.50	1.50	1.00	0.10	0.60	3.50
Piston rings	2.00	0.70	0.05	0.60	3.50	1.75	0.80	0.06	0.50	3.25	—	—	—	—	—
Pulleys	2.40	0.50	0.05	0.70	3.75	2.15	0.60	0.07	0.60	3.50	1.90	0.70	0.09	0.05	3.25
Radiators	2.25	0.70	0.06	0.80	3.50	—	—	—	—	—	—	—	—	—	—
Rolls (chilled)	—	—	—	—	—	—	0.80	0.06	0.40	3.25	—	1.00	0.08	0.30	3.00
Soft castings	2.60	0.50	0.06	0.60	3.75	2.40	0.60	0.08	0.50	3.50	—	—	—	—	—
Soil pipe	2.25	0.60	0.08	0.80	3.75	2.00	0.80	0.10	0.60	3.50	—	—	—	—	—
Steam cylinders	2.00	0.60	0.08	0.50	3.50	1.80	0.80	0.09	0.40	3.50	1.25	1.00	0.10	0.30	3.50
Stove plate	2.50	0.50	0.06	1.00	3.75	2.25	0.60	0.08	0.80	3.50	—	—	—	—	—
Valves	2.25	0.60	0.07	0.50	3.25	1.75	0.80	0.08	0.40	3.00	1.25	1.00	0.09	0.30	2.85
White-iron castings ..	—	—	—	—	—	0.75*	0.20†	0.25	0.75*	2.50†	—	—	—	—	—

* Below. † Above.

the same degree, and therefore the author's suggestion is that phosphorus first be considered. If a high percentage is allowable, then cheap Northampton or Cleveland iron may be bought, but if only a low percentage then these are cut out at once. The rule is inelastic, for whilst no high-phosphorus iron could be used in obtaining a final 0.10 per cent. P. mixture, it is most inadvisable to use a proportion of such irons even where 0.50 per cent. is finally allowable, for it is not good practice to melt together very dissimilar irons, and such a proposition as that just mentioned would necessitate using hematite to balance the high-phosphorus component.

Influence of Carbon.

It has been shown firstly that there are few irons with low carbon, and secondly that even it the pig could be obtained very low in this element the advantage is largely lost in the cupola, where there will be an increase to at least 2.65 per cent. If the castings are to be specially strong or to withstand very high pressures, it will be necessary to keep the carbon low, and whilst there may be some chance of doing this with low-carbon pigs, there can be no chance if the carbon is high at commencement. The selection here may even assume a greater importance than in the case of phosphorus, and it may be necessary to abandon hematite, which is a high-carbon iron, and to turn to special cylinder irons or to cold blast. The special cylinder irons are often made in refining cupolas by the admixture of heavy percentages of steel, and the question may therefore arise of the possibility of a semi-steel mixture being adopted. The advantage of buying one of these steel-mix pigs is that the second melting in the foundry cupola ensures thorough uniformity where this may not be certain by merely melting pig with steel scrap, but in the author's opinion lower carbon may be obtained in home-made semi-steel than in remelted steel-mix pig. With moderate care there is no difficulty in melting semi-steel up to 50 per cent. steel, and the author has, in fact, been able to do this on a half-ton cupolette and obtain a metal suitable for even the most stringent requirements.

Semi Steel Mixtures.

The scope of this Paper does not include the consideration of steel mixtures, but the author cannot leave this part of the Paper without saying that the use of steel in cupola mixtures opens up for the foundryman an entirely new field of material, and *that* without using expensive pig-iron. It is for this reason that the table of suggested brands is put forward only with hesitation, because it is felt that steel mixtures could be used alternatively with those mentioned and at a considerable saving, and had the Paper allowed for this, a new set of mixtures might have been put forward. Nearly every requirement of the foundry can now be met by the admixture of steel with various classes of pig-iron.

If a moderate percentage of manganese is required, it may be necessary to go outside the immediate locality to obtain this, even if phosphorus and carbon are suitable in the local supply. It has been shown that Scotch and Lincolnshire irons contain well over 1.0 per cent. manganese; some Derbyshire also up to 1.2 per cent. and North Staffs up to 2.0 per cent., so that in no case is it necessary to bring Scotch iron to Birmingham, etc. The North Staffs high-manganese pig is in some cases too high in phosphorus for foundry requirements, and needs to be melted along with a lower-phosphorus iron or with steel.

The consideration of silicon requirements may be left until last in selecting pig-irons, as wherever the founder may have to go for high or low phosphorus, manganese, or carbon, he will find generally a sufficient range of silicon content to meet his particular requirement, and will in fact probably have examples of this wide range brought to his notice in a comparatively short time. There are, of course, some furnaces which only make high- or low-silicon iron to special requirements, but these are the exception, and therefore, although silicon is so important, it need not be the first consideration.

Assuming that the mixture will require 25 per cent. each of Northampton and Derbyshire irons, the user is left with considerable latitude in the actual selection of his furnaces. This will, in fact, vary from time to time with market supplies and conditions and with the rate of delivery required; but it will be found that although the irons from any given district have much in common, they cannot always be freely interchanged. In the Northampton irons, for instance, with 2.5 per cent. silicon, there is a marked difference in grain between certain of the irons with which the author is in contact, and the same is true of other districts; but generally there is plenty of scope for interchange, thus giving to the purchaser a freedom of action which he would be denied if tied to one brand.

Some foundrymen make their mixtures by the use of a small proportion of each of a large number of irons, relying upon some form of the law of averages to level up the inconsistencies and eccentricities of any of the brands which may be behaving unseemly. These people never change their brands and are thus in the hands of the sellers. Other foundrymen keep the same brands always, but vary the proportions with the fractures, which is more scientific than the first method, but is open both to error, as all fracture-mixing is, and to abuse from the furnaces. Others again wait until trouble comes and then add some "dope," to which they pin their faith because of its high price. Still others work to a fixed analysis, and so long as this is obtained are regardless of the components thereof; but this method has been shown by various workers to fail at times, for vast changes in physical properties have accompanied the substitution of one iron by another of apparently similar analysis. The author has always worked to a narrow range of analysis and has kept constant as far as possible the proportions of iron from various districts, but freely interchanging the brands from each district so far as possible. But few exceptions to this practice have been found, mostly in cases where it at present appears that a certain brand of iron displays a strong tendency to draw or to give dirty castings. In not every case has a sufficient reason been assigned for the restriction of liberty in interchanging all components so long as a desired analysis is obtained, but no foundryman likes to acknowledge that no other iron but the one he is using will meet his case.

London Branch.

THE MANUFACTURE OF PEARLITIC CAST IRON FOR HIGH TEMPERATURE ENGINES.

By Arthur Marks, F.I.C.

The manufacture of castings for parts subjected to high temperature, such as internal combustion engine cylinder covers and pistons, has called for a cheap material to withstand exceptional conditions. This Paper gives the writer's attempts to produce pearlitic cast iron in the cupola with a view to obtaining the strongest material possible for this class of casting.

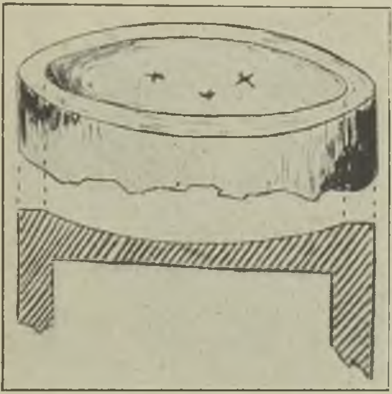

Fig. 1.—Star Cracks in Piston.

An examination of the cracks which occur in pistons and which are shown in cylinder covers shows that there are two main causes of failure. (1) Star crack radiating from a local centre (Fig. 1); and (2) cracks which extend right across the piston or between holes in the covers (Figs. 2 and 3).

Cracks of the first type are the most interesting from a metallurgical point of view. These are associated with oxidation of the graphite in the material and items in the composition, such as sulphur and phosphorus.

The second type of crack is usually associated with casting conditions, and can usually be overcome by modification of the method of casting the job. They are, in fact, structural strain-cracks due to chilling the material in order to obtain a dense and close metal where the piston or cover is fairly thick and consequently likely to be subject to porosity. Generally speaking, the problem of maintaining a long life in such parts has to be tackled, first, by considering the production of a metal which is not hot-short; second, by production of a metal which will stand up to a chill or cast without the use of chills; third, by producing a metal in which the planes of graphite weakness are absent. The production of a material without planes of weakness leads the author to the conclusion that the line of development to take was to produce pearlitic cast irons.

The work given below was carried out some years before the publication of Diefenthaler's patent.

Analysis of typical fractured engine pistons gave:—(1) T.C., 2.93; G.C., 2.37; C.C., 0.56; Si., 1.3; S., 0.090: **P.**, 0.78; and **Mn.**, 0.61 per cent.,; and (2) T.C., 4.0; G.C., 3.3.; C.C., 0.7; Si., 1.26; S., 0.075; **P.**, 0.75, and Mn., 0.80 per cent. Most of these failed by excess graphite and shrinkage.

In connection with steel it has long been understood that the highest tensile strength without undue brittleness can be obtained by means of structures which are pearlitic in character or are modifications of the pearlitic structures such as sorbite and troostite. For instance, in the manufacturing of wire which is specially drawn to give high tensile-strength, manufacturers have for many years carried out secret heat-treatment of the steel in order to give a pearlitic-sorbitic structure which, whilst in the early days it was not understood in theory, was fully understood in practice. As progress in the use of cast iron has been made engineers have always had in mind a cast iron which shall have the tensile properties of steel. The foundryman knows as a matter of practice such materials involve excessive difficulties in the foundry such as are only met with in the casting of steels. Many attempts have therefore been made to improve the tensile strength of cast iron and approach the properties of steel. Whilst one is approaching the properties of steel in the material one is at the same time losing the exceedingly useful properties of cast iron such as (1) low melting point; (2) fluidity when molten, and (3) expansion on solidifying, which make it a material capable of being easily cast in the foundry. One of the most important of these attempts was in the early days of last century when mixtures of steel and cast iron were manufactured under patents by Sterling in 1846. An attempt was then made to manufacture semi-steel by a partial refining of the iron. Later, in 1855, Nicholls and Price introduced a method of mixing refined iron and ordinary iron in the cupola, thus endeavouring to produce a stronger material. These two patents may be considered the basis of the material which is now known as semi-steel, and whilst the ideal semi-steel has not been attained in direct melting from the cupola the ideal to be aimed at in such a manufacture is a pearlitic cast iron.

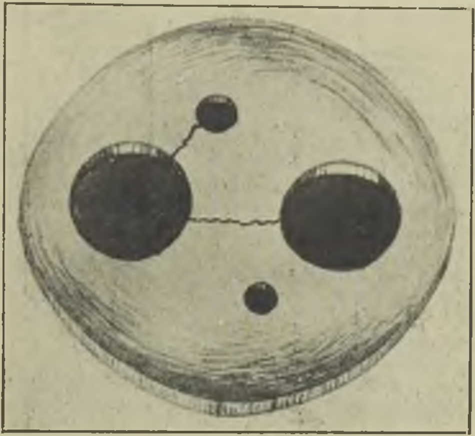

FIG. 2.—CRACKS BETWEEN HOLES.

The ordinary cast iron contains among its chief metallographic constituents the substance graphite, which is formed during the slow cooling of the iron; which lowers the melting point of the iron, and therefore enables it to be cast readily at low-temperatures in sand moulds without undue searching effect, and which also gives to the iron its readily machinable properties. On melting together pig-iron and steel under suitable conditions, the first noticeable item is the reduction in the graphite content and an increase in the strength of the material owing to the fact that the planes of weakness caused by the graphite are reduced. If the conditions are kept consistent the strength will increase directly with the proportion of steel added and the amount of graphite present. The addition of the steel, however, reduces the silicon-content so that unless means are taken to keep the silicon content high an iron with no machinable properties is gradually being approached, that is a hard iron. By proper adjustment of the silicon in the mixture it is easily possible to make a machinable iron using as much as 50 per cent. of steel. These materials, as ordinarily produced, however, are not pearlitic cast irons, although the pearlitic areas increase very considerably with increasing the silicon, and in general practice it is found that it is impossible to eliminate the graphite formed simply by addition of steel if machineability is to be maintained. If the silicon-content of the iron is kept high graphite absorption always occurs in the cupola, so that the resulting product appears more nearly related to an ordinary cast iron than it does to steel. Immediately the graphite is reduced by the addition of steel, difficulties are encountered owing to the quickness with which the metal will chill, and therefore it has been found in practice for semi-steels that 20 per cent. of steel is the amount which can be conveniently added for the purpose of manufacturing machineable castings without undue difficulty in adjusting the mixtures. Attempts have therefore been made upon different lines in order to produce pearlitic cast iron with a view to increasing the strength and at the same time avoiding any difficulties in casting. Two methods used are:—(1) To adjust the furnace running so that the graphite absorption is reduced to a minimum and the graphite-content of the metal kept below the limits required for excessive separation during the cooling, and (2) to manufacture a material in the cupola with a low graphite-content, subsequently annealing the casting so as to render it machineable.

In the second method, the castings are made from a mixture which contains low silicon, but which, at the same time, has sufficiently been superheated to change the hard white-iron into a pearlitic form. The annealing is carried on at a low temperature, and is done whilst the casting is still in the mould; the moulds are heated to a temperature as high as possible before the metal is poured, and the moulds, whilst the metal is still hot, are removed to an annealing oven so as to maintain the temperature for a considerable time whilst the hard iron is changed into pearlite. Annealing in an oven is not a very convenient process in the case of large castings, and since the metal is hard it does not have the advantages which ordinary cast iron possesses in expanding on cooling and so reducing the shrinkage which, as mentioned above, is one of the important features of cast iron from the foundry point of view. The cost of manufacture is also increased, and the object of this Paper is to indicate lines upon which

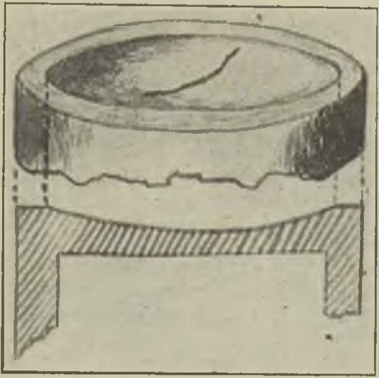
FIG. 3.—CRACKS ACROSS PISTON END.

the practical manufacture of pearlitic cast iron was attempted with a view to avoiding any annealing or other additional process than was ordinarily met with in the foundry.

In a Paper previously published by the writer it was shown that cast irons of a certain type could be made whch would stand a temperature of 500 deg. C. for a period of 36 hours without any sign of breakdown. Iron of this class is very important for the manufacture of superheated turbine casings, Diesel-engine castings, and other internal-combustion engines. In recent years it has been the practice to manufacture superheated turbine casings from steel which involves considerable increase in cost. Superheated steam turbine casings will be subjected to a temperature of 300 deg. C. throughout the working period of their life, and it has been shown that common cast iron, such as pipe lines, have given way at this temperature, and therefore engineers have been loth to make turbine casings from cast iron having these incidents in mind. Here again the wide variation in cast iron as a material of construction is realised. Cast iron is a term covering what should be considered to be a large number of materials. One cannot, for example, class together a No. 3 pig-iron casting and a high grade semi-steel casting, although to the mind of the average designer they would both be included in the term "cast iron." Such a metal would, undoubtedly, grow under low-temperature heat-treatment, and therefore one has to demonstrate to the users of these materials the fact that a large range of cast irons is possible, each one of which can be manufactured to suit definite requirements. The ideal pearlitic cast iron will be one in which the whole ground mass of the structure is pearlite and the composition of such a one may be as follows:—G.C., 2.75 to 2.5; CrC, 0.75 to 0.8; Si, 1.0 to 2.5; S, 0.05 to 0.13; P, 0.2 to 0.4; and Mn, 0.7 to 1.2 per cent.

In view of the low graphite and high combined carbon necessary, one is compelled to use low total-carbon irons in the mixture and also to make steel additions. A low phosphorus-content is also desirable.

It has been shown that sulphur was immaterial and could be balanced by suitable additions of manganese. While for low sulphur-content this is true, it is not a practical proposition to make castings of high-sulphur irons and balance the sulphur by manganese. Particularly is this the case with complex castings.

The high numbers of Scotch irons offer low phosphorus and low total carbon as a basis to commence work on pearlitic cast iron, and the writer used No. 7 of several well-known Scotch brands containing:—T.C., 2.83; CrC., 0.53; GrC., 2.30; Si, 0.91; S, 0.30; P, 0.4 to 0.7; and Mn, 0.3 per cent.

The charge was made up of 10½ cwt. pig; 4 cwt. steel; 45 lbs. ferro-silicon, and 3 cwt. scrap. The resulting metal gave an analysis of T.C., 3.6; GrC., 2.9; C.C., 0.7; Si, 1.4, S, 0.11; P, 0.13; and Mn, 0.94 per cent.

The material forged down under the hammer quite well from 2½ in. square down to ½ in. in thickness without fracture.

Other typical charges were:—8 cwt. No. 7 pig; 4 cwt. steel; 150 lbs. ferro-silicon, and 8 cwt. scrap. The analysis gave the following figures:—T.C., 3.55; G.C., 2.8; C.C., 0.75; Si, 2.6; S, 0.14; P, 0.34; and Mn, 0.8 per cent. The properties in this instance were not so satisfactory as in others.

A mixture which gave very good results was made up from the following charge:—10½ cwt. No. 7 pig; 4 cwt. steel; 100 lbs. ferro-silicon, and 5½ cwt. scrap. The analysis gave the following figures:—T.C., 3.2; GrC., 2.5; C.C., 0.70; Si, 2.76; S, 0.14; P, 0.39; and Mn, 0.6 per cent.

The tensile strength was over 18 tons, and the material readily forged without fracture. The elongation was 0.3 per cent., and the bend test on 12 in. by 1 in. by 1 in. bar took a permanent set of ¼ in. of arc at a load of 32 cwt. without fracture. To get the correct structure the necessary superheat for removal of any chilling effect is necessary, and with the correct mould-temperature it was easily possible to cast such metal on a 3½-in. chill without having subsequent difficulty in machining.

One interesting fact which came to light in this work was the lack of direct connection between Brinell hardness and combined carbon. Material with low-combined carbon gave Brinell-hardness figures higher than given by material with high-combined carbon.

The tensile strength of material of this class is of the order of 18 to 22 tons to the square inch, and can be compared with a good semi-steel running 14 to 16 tons per sq. in., and a good cast iron running 10 to 12 tons per sq. in. A material of this class can be manufactured directly in a reverberatory furnace. It can also be manufactured artificially in an electric furnace in both of which cases suitable superheat can be added to enable it to be cast without chilling. Castings, however, made in this way have to be subsequently annealed. The writer manufactured pearlitic cast iron directly in the cupola with the object of casting direct and also of avoiding any annealing process by method (1) above. It was found that the product obtained, whilst pearlitic in character, contained also temper carbon, small granules of graphite but less flake-graphite, and the whole question involved is one of control of the cupola. The iron, when cast, showed a very close-grained structure, and was entirely pearlitic with small particles of globular graphite spread amongst the ground mass. In each case the tensile strength taken on 2½-in. test pieces give 17 to 19 tons per sq. in. tensile strength.

Various complicated castings were run in this material and then broken up, but from several points of view were not satisfactory. The machineability was good; the tensile strength was good, but considerable blow-holes showed themselves in the intricate portions of the castings. The material did not require any annealing, but was cast in hot, dry loam-moulds. It showed, as anticipated, a fair tendency to chill, but when cast on 2½-in. chills of 2 ft. dia. was still machineable in the region of the chill on speeds usually found in heavy engineering practice. A comparison of this material may be made with centrifugal castings. In the manufacture of centrifugal castings the material comes out in the hard, white condition, and a subsequent annealing is generally necessary. As the castings are practically chill castings they are very close-grained, and the graphite which is formed on annealing is in a fine flake form. Comparatively high silicon-contents are used, and the ground mass has a high tensile strength, up to 22 tons being quite a common figure. In order to soften the castings rapidly high-silicon mixtures are generally used, resulting in very rapid deposition of graphite and consequent deposition in flake form.

The production of pearlitic cast irons in practice depends upon:—

(1) Correct adjustment of mixture for ferrite, silicon, and graphite; a combined carbon in the region of 0.8 per cent.; (2) the use of low silicon suitably proportioned to the casting thicknesses and temperatures; and (3) quick cooling of the metal through critical ranges and subsequent continued low temperature annealing in the mould.

The writer is indebted to Mr. G. Walworth, M.A., for assistance in preparing the diagrams and slides.

East Midlands Branch.

CAST IRON IN MOTOR CAR CONSTRUCTION.

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

The value of any class of material is measured by the importance of the uses to which it is subjected, and in motor car construction the importance of cast iron cannot be over-estimated. This will be readily understood when it is realised that the cylinder, on which, to a large degree, depends the active life of the car, is made in that most complex of all materials, cast iron. The extent to which the cylinder stands up to its work, retains its shape under alternate heat and cold, resists abrasion, vibration, and in many instances unexpected stresses due to bad driving borders on the miraculous. There should be included in this tribute to the efficiency of cast iron the pistons, piston rings and valve guides.

Sometimes the cylinder and head are cast in one piece; modern automobile practice is to make separate castings of the cylinder head and cylinder body. In a few cases the top half of the crankcase is incorporated in the cylinder body casting.

High efficiency engines of small capacity often run at over 4,000 revolutions per minute, whilst large capacity engines for touring cars have a normal speed varying from 1,400 to 2,500 revolutions per minute. When these figures are calculated out as piston travel, it seems wonderful that an engine will last even a few hours, let alone the years of service and many thousands of miles that most cars accomplish. With an engine of 5-in. stroke a speed of 2,500 revolutions per min. incurs a piston travel of nearly 700 yards per min., or 24 miles per hour. When this is kept up for hours at a time the pistons and cylinder walls must have a high resistance to friction, or undue wear will result.

Other parts of a motor car, where cast iron is utilised, are the flywheel, clutch plate, clutch cover, exhaust branch, certain chain wheels on the timing gear, brake shoes, liners for brake drums, bearing carriers, and small distance pieces and cover plates. To attempt to use one class of iron for all these parts would be courting disaster. For instance, the material in the flywheel must be such as will resist any tendency to disintegration due to centrifugal force. The clutch plate must have a high resistance to friction, and yet not so harsh as to cause a fierce action. The clutch cover must be proof against porosity, otherwise oil will leak, which, in addition to uncleanliness, will ultimately give rise to over-heating of the clutch mechanism. The exhaust branch must be non-porous, and free from any tendency to grow under repeated heatings. Chain wheels must resist abrasion, or the timing gear will soon become noisy. Brake shoes are usually covered with a fabric, such as Ferodo, but must be strong to resist distortion. Liners for brake drums must have a high coefficient of friction, whilst the wear due to abrasion must be slight. Bearing carriers have no great stresses imposed on them other than those due to constant heating up and cooling down again. When distance pieces are made in cast iron compression strength is necessary. Finally, there is cast iron used as cover plates, and here no definite stresses are set up.

Cast iron has the advantage of being comparatively cheap, and in many instances the cost of producing a casting is considerably greater than the value of the material put into it.

The principles underlying the moulding of cast iron are much the same whatever the type of casting, but to those who are not familiar with the production of automobile cylinders the delicate and intricate nature of the cores is a revelation. A cylinder head made in the Rover foundry some time ago had 31 separate cores, most of them very intricate, yet the casting only weighed 43 lbs. when completed. It is their practice to cast all cylinders in dry sand moulds, and other parts in green sand. The cylinder moulds are rammed up and blacked, dried in the stove during the night, then cored and cast the following day. Where the quantity warrants the initial expense, the ramming up is done on jolt machines from iron patterns. In the case of air-cooled cylinders a brass pattern and stripping plate is used on a jar-ram machine.

It is not proposed to deal with details of moulding practice, but to consider the technical and metallurgical aspects of the production of automobile parts, and the extent to which science can assist.

Melting Aspects.

The type of furnace almost universally used for melting cast iron is the cupola, which, although it has no peer as to low cost of production and flexibility of output, is subject to certain serious disadvantages. There is always an increase in the sulphur-content of the iron after melting; and unless the cupola practice is closely controlled grave irregularities in composition are possible. A quite recent development is the refining in an electric furnace of molten iron from the cupola, but the author has had no practical experience of this process at present.

Entrance of Sulphur.

The metallurgical functions of the cupola are fairly well defined, and a certain weight of cast iron requires a definite number of B.Th.U. to melt it and give it the correct degree of superheat. These B.Th.U.s are obtained by the combustion of coke in a defined volume of air, and herein lies one of the many difficulties. Coke, as supplied to the foundries, is a very variable item. A good cupola coke should contain at least 88 per cent. fixed carbon, not more than 10 per cent. ash and 0.8 per cent. sulphur. The reason iron gains in sulphur is easily seen. On an average it requires 100 lbs. coke to melt 700 lbs. iron. That 100 lbs. coke, on a normal analysis, contains 0.8 lb. sulphur. Assuming that only 25 per cent. of the total sulphur is absorbed by the iron, and the remainder either passes into the slag or is volatilised off with the chimney gases, it follows that 0.2 lb. sulphur is absorbed by 700 lbs. iron, giving an increase of 0.03 per cent. in the sulphur content of the iron. As it is quite possible that a higher percentage of the available sulphur is absorbed, and a coke with a sulphur content as low as 0.8 per cent. is an exceptionally good quality, it is within the bounds of ordinary practice to charge into the cupola an iron with an average of 0.08 per cent. sulphur, and tap out iron containing 0.15 per cent. sulphur. In addition to variations in composition, coke varies considerably in physical properties. It should be hard and strongly resistant to crushing, otherwise the weight of the various charges in the cupola will tend to powder the coke, with the result that melting will be slow and the metal not sufficiently superheated. The coke should be fairly porous, as if too close-grained it will not burn freely and evenly.

Pressure and Volume of Air.

The pressure and volume of air supplied to the cupola is an important item, volume being equally as important as pressure. If the pressure is high, uneven melting will result, and the metal in the centre portion of the cupola will melt before that at the sides. If the pressure is too low, the sides only will melt, and unmelted pig and scrap will descend in the centre.

If the volume of air supplied is insufficient, melting will be slow and the metal cold. If the volume of air is much greater than that necessary for the complete combustion of the coke in the melting zone, the iron will melt rapidly and hot, but a danger of oxidation is present. In connection with this point there is considerable diversity of opinion, some authorities stating that the presence of oxide in iron is a myth.

Tuyeres.

The shape and area of the tuyeres have an important bearing on melting, and the area of the tuyeres should bear a definite relation to the cross-section area of the cupola. It is generally accepted that the total tuyere area should be from one-fifth to one-eighth of the cross-section area of the cupola, the larger tuyere area being for small cupolas, and the ratio decreasing as the diameter of the cupola increases.

Bed Coke.

It is usually laid down in practice that the bed coke should extend from 18 in. to 24 in. above the top tuyeres. If in any doubt as to the correct height, the safest course to adopt is to take the time which elapses after putting on the wind for metal actually to flow from the tap hole. This time should be not less than 8 min. nor more than

12 min., but it is necessary to be sure that the bed coke had burned through before blowing commenced. The amount of coke on the bed should be adjusted until the first metal melts within these times.

Weight of Iron Charges.

An important item is the weight of iron per charge, and the ratio between the weights of iron and coke per charge. It is obvious that the weights are governed by the internal diameter of the furnace. It has been demonstrated that, when the cupola is working to the best advantage, the bed coke is reduced in depth from 4 in. to 5 in. for each charge of iron. and this loss of coke has to be replaced each time a fresh charge of iron is fed into the furnace. The practice the Rover Company usually adopt is first to find the weight of coke required to fill a space equivalent to the inside diameter of the cupola by 5 in. deep, and use this amount of coke between each charge of iron. The weight of iron per charge can now be calculated, bearing in mind the type of iron to be melted, the size of the pigs, and the amount of superheat required. For cylinder work the author takes this weight as seven times the weight of the coke charge. Translated into definite figures, on one cupola 1¼ cwt. of coke is used for every 8 cwt. of iron.

Patching the Cupola.

It is necessary each day to patch up the cupola lining with ganister after chipping off excrescences of iron and slag. This patching must be done with care and discretion, or the ganister is liable to flake off and impede the melting.

Coke, Flux and Iron.

Attention must be given to the method of charging coke, flux, and iron. The flux most commonly used is limestone, and the author prefers to charge this on top of the coke, though some charge on top of the iron. The amount of limestone used must bear some relation to the ash content of the coke, and the amount of sand adhering to the pig and scrap in the charge. The slag formed has a decided effect on the physical properties of the iron when melted, and should have a refining influence.

The rate at which the metal is tapped out is important, and it should be the aim of the cupolaman to time his tapping out to coincide with the complete melting of a charge.

There are many difficulties in the way of getting good melting results, but it must not be imagined that these difficulties are insuperable. The large number of cupolas in daily use, with good results, negative this idea, but watchfulness, care, and an intelligent appreciation of the metallurgical processes involved are very necessary to obtain hot, clean iron. The melting of iron in the cupola is not the simple operation it appears to the casual observer. At present no other system can compare with it on a basis of cost of output, and until some other method, equally as cheap and flexible, but more fool-proof, is devised, despite its drawbacks, the cupola will remain the universal melting unit for cast iron.

Testing Cast Iron.

In the testing of cast iron the usual tests specified are transverse or tensile test. Useful as such tests may be for some purposes, they are of no practical value in an automobile foundry. Neither transverse nor tensile test give any indication of the probable life of a cylinder, nor, for that matter, of any other casting. At the very utmost they only give an indication of the class of iron used. The tensile strength of cast iron is a function of the size of the test piece. A bar ¼ in. dia. tested "as-cast" will give a totally different result from a bar 1½ in. dia. cast from the same shank. A transverse bar, cast square or rectangular, will give a result differing from that of a round bar. Whether "cast-on" or cast separately, the author considers test bars are of no practical value in motor-cylinder work. A high tensile or tranverse test will not ensure a long-life cylinder. For certain automobile parts an impact test might be of some practical utility, but this test has not yet been properly developed in connection with cast iron. The Frémont test, recommended at the Birmingham Convention by M. Ronceray, suffers from the same disabilities as the transverse and tensile tests, in that it only indicates the class of iron of which the casting is composed.

The mechanical test which can be most usefully applied to motor cylinders is the Brinell hardness test; and this has its limitations. Used spasmodically it is valueless, but used regularly on the same type of casting it will give some indication of the useful life of that casting. That is to say, when one particular cylinder pattern is regularly produced, as a repetition job, if the Brinell hardness is taken daily on a certain section of that cylinder, the readings so obtained will be of value in determining whether the casting will conform to the standard which has been adopted. This standard can only be decided upon after a lengthy practical experience of the particular casting under review. To elaborate this, the Rover Company has found that if the Brinell hardness taken on a certain area of their 14-h.p. cylinder is less than 175, undue wear is likely to take place. The figure sought for lies between 200 and 220. They have also found by experience that if the Brinell No. is over 240, difficulties are encountered in machining. The author has listened at different times to much adverse criticism of the Brinell test, but he is convinced that, used consistently and intelligently on repetition production, it is of some considerable service. It has the advantage of being cheap, does not spoil the casting, and results are quickly arrived at. Hence the author's practice is to cast on all cylinders a small test piece of standardised dimensions, which is rammed up and dried as an integral part of the mould. On the morning following casting, these test pieces are knocked off, and a number of them tested to see if they come within the range of Brinell numbers he has adopted as standard. Any serious discrepancy can be immediately investigated, and if necessary, an alteration made in the iron mixture.

Chemical Analyses.

Table I.—*Analyses of Cast Iron Taken from Three Different Parts of the Same Cylinder.*

	Foot. Per Cent.	Barrel. Per Cent.	Jacket. Per cent.
T.C.	3.53	3.58	3.52
C.C.	0.73	0.83	0.90
Gr.	2.80	2.75	2.62
Si.	1.34	1.36	1.38
S.	0.12	0.12	0.12
P.	0.59	0.58	0.59
Mn.	0.74	0.75	0.77

The Rover Company regularly takes analyses of the cylinder iron, and if properly interpreted, these afford a certain amount of useful information. The composition of cast iron for cylinders is a very open question, and with our present knowledge it is folly to dogmatise. It is possible for two irons to have practically identical analyses yet totally different properties.

Most engineers demand a hard surface in the bore of the cylinder. To the author's mind this is quite a mistake. The bore is usually the thickest section of a cylinder, and hence is softer than the water jackets and valve ports. Reverting to Brinell hardness, although the test piece may give a reading of 210, the bore may be only 150 or 160. To obtain a hard metal in the bore, it will be found that the water jackets, valve ports and seatings will be much harder, and often border on white iron. To overcome this trouble some founders use a soft iron and chill the bores. The use of chills in cast iron is always to be deprecated, as they often cause trouble from blowing and mis-placement. That there is not a very great difference in the analysis of the iron in different parts of the same cylinder is illustrated in Table I. This gives the analysis of the iron from the thick foot, from the barrel, and from the thinnest section of the water jacket. These figures are typical of many tests. As might be expected, the only difference is in the combined carbon and graphite content.

If the functions of a cylinder bore are carefully considered, it will be recognised that it is a bearing, and as such should not be glass hard. To operate as a bearing, the material should be soft but tough, if toughness may be admitted as a property of cast iron. Too often wear on a cylinder bore is due to incorrect piston-ring design, or inefficient lubrication, and to remedy a defect in design harder cylinder bores are called for. The physical form and distribution of the graphite mainly determines the life of a cylinder. It is not suggested that any soft iron is suitable for cylinder bores. An ideal material for cylinder castings would probably be one containing a high total carbon and low phosphorus. A total carbon of 3.6 per cent., with a phosphorus content of less than 0.2 per cent., undoubtedly will give a long-life cylinder, whether of the water-cooled or air-cooled type. There are certain difficulties in the way of casting, and a considerable degree of superheat in melting is essential, but once these difficulties are overcome, excellent results in use are possible. For an air-cooled cylinder to give the best results in use a very low-phosphorus content is most desirable. Phosphorus promotes fluidity, which is essential for casting air-cooled cylinders in order that the thin radiator fins will run up sharply; but the same or a greater degree of fluidity is possible with a low-phosphorus iron, provided the right amount of superheat is obtained.

Composition of Automobile Cylinders.

The correct composition for an automobile cylinder is a very debatable point, and considerable research work remains to be done. Such an investigation, if carried out by one of the recognised research associations, would yield information of prime importance to the automobile foundry trade.

The cooling curves of cast iron vary with different compositions. Recently Smalley has shown that on a Diesel engine cylinder iron, solidification commences at approximately 1,240 deg. C. and is complete at 1,160 deg. C., whereas with a locomotive cylinder iron solidification commences at 1,231 deg. C. and continues to 935 deg. C. The freezing range of the former is 80 deg. C., and of the latter 296 deg. C. In cylinder work it is eminently desirable to use those irons which have the shortest cooling range, otherwise parts of the casting are a long time in setting, during which time certain constituents are thrown out of solution with the formation of dirty patches and sponginess.

In deciding on mixtures for cylinder castings, many factors have to be taken into consideration. The amount of total carbon, the relation between the graphite and combined carbon contents, the form in which the graphite is present in the casting, the phosphorus and silicon content, and in a less degree of importance, the percentage of sulphur and manganese, all demand attention.

In connection with the composition of cylinder iron, the author had the opportunity, some time ago, of making an analysis of a cylinder iron which had been cast in 1840. Needless to say, this was not an automobile cylinder. The total carbon was 3.52 per cent., with a combined carbon of 0.70 per cent. Silicon was 2.15 per cent., sulphur only 0.02 per cent., and both the phosphorus and manganese were fairly high, being 1.18 and 1.14 respectively. This cylinder had been in regular daily work for 71 years.

The Rover foundry has been casting cylinders since 1906. During that time they have had opportunities of seeing how certain cylinder castings stand up to their work, and their length of service. Even now, after 18 years' experience of automobile foundry trade, the author is unable to offer any particular composition as being definitely the best. The Company has varied the composition from time to time, in addition to the small variations which naturally occur from week to week.

No definite limits in the constituents can be laid down, but that success depends on the balance of the constituents one with the other, in order that the cooling range may be short. Probably if the phosphorus content is low it is an advantage to have the total carbon high. With a high phosphorus content (and many of the special brands of iron sold for cylinder work contain up to 1.4 per cent. phosphorus), a low total carbon is preferable. This must only be taken as an expression of opinion. Considerable importance is attached to the sulphur content, and almost certainly this element has too often been given undue prominence. The author has failed to find any detrimental effect with sulphur up to 0.14 per cent., but above this amount there is an increasing tendency to form gas holes under the skin, causing the casting to be rejected after machining. As previously mentioned, sulphur in cast iron is increased by cupola melting; until there is a better alternative to the cupola, sulphur will continue to be a certain amount of trouble.

The casting of cylinders is a very troublesome job, and care in every operation of moulding, core-making, melting, and pouring is essential to obtain good results. However suitable the composition of the metal may be, carelessness in production will only result in defective castings.

Cylinder-head castings, whilst not always so intricate as cylinder bodies, demand the same attention to detail. The tendency of modern design is now in the direction of fairly simple cylinder body castings, and exceedingly complicated head castings. This applies more particularly to engines with overhead valves. Some of the cylinder-head patterns received during the past few months have been veritable works of art. Foundry work in connection with the motor trade is becoming more and more difficult, and the time is ripe for that close co-operation with the designer desired by the modern foundryman.

After fettling and sand-blasting, cylinder castings are tested in the rough for freedom from porosity. This operation is usually carried out on a small hydraulic pump at 50-lbs. pressure. Any indications of leakage are carefully examined. If the leak is very slight, the pressure is maintained for some minutes, the casting removed, allowed to stand for several days, and again tested. In many instances all signs of leakage will disappear. Castings which pass this test are sent into the machine shop, where, after being finished-machined, they are again tested at 50-lbs. water pressure. Cylinder castings after machining must be entirely free from blowholes, porous patches, or marks of any description in the bores, on valve-seats, and on joint-faces. The water spaces must be cleared from sand and wires, and "flash" between the joints of the cores eliminated. This latter is often an awkward job to complete in the rough casting, and may, with advantage, be finished after the casting is machined. The core holes and water connections are usually larger after machining, and it is easier to get a tool inside to knock out any "flash."

Pistons and Piston Rings.

The castings which rank next in importance to cylinders are the pistons and piston rings. To some extent aluminium is displacing cast iron for pistons; any reduction in weight of reciprocating parts being very desirable. At the same time, quite a large number of cars on the road have cast-iron pistons giving every satisfaction. It is the practice of the Rover concern to cast pistons in the same class of iron as cylinders. A piston does not require to be hard, otherwise there is always the risk of cracking. The difference in temperature between the head and skirt during the running of the engine is fairly considerable, and although there is not quite the same action as in Diesel engines, a fairly low phosphorus iron is to be preferred. As a rule, pistons do not present any serious difficulties in casting, and the permissible range of composition is wide. The castings are generally tested after machining for porosity with paraffin and oil; in addition there are the usual shop tests for weight, balance, and concentricity.

The manufacture of piston rings is rapidly becoming specialised. So many factors that call for special attention enter into the production of suitable castings. Most of the standard sizes of rings are now cast in chills in centrifugal machines. No hard-and-fast rules for composition of the finished ring can be laid down, as an iron that is suitable for sand castings is quite unsuited to centrifugal castings. In the latter the silicon content is high, generally in the neighbourhood of 4 per cent., whilst in sand castings the silicon runs under 2 per cent. The desirable property in piston rings is elasticity; a property which determines the pressure on the walls of the cylinder, and a considerable amount of research work on this type of casting has been carried out. The importance of the functions of piston rings cannot be over-estimated, and to the position of the rings on the piston, and the elasticity of the iron, are due much of the success of an engine.

A works test for piston rings which is rapidly coming into favour is that which determines the pressure required to close the gap. This test was devised by the British Piston Ring Co., who make a machine for the purpose. The ring to be tested is inserted in a frame in which the ring makes contact at three points, and pressure can be applied to the ring diametrically. The pressure required to just close the gap is read on a small pressure gauge or spring balance. Once the machine is set for any one diameter ring, several hundred can be tested in a very short time. For rings from 65 to 90 mm. outside diameter, a good reading is 8 lbs. pressure. A ring giving a reading of less than 6 lbs. pressure would be considered of low elasticity. A common workshop test for piston rings is to hold the ring at each side of the slot, bend it sideways in opposite directions, and see if there is any permanent set. This is a most unfair test, and one under which even the best piston-ring iron will fail. It is time such crude tests were discarded and more scientific tests substituted.

Motor Car Flywheels.

A motor-car flywheel may appear to be a simple casting, but it presents several interesting metallurgical problems. It might be thought that any sort of iron would be good enough for this casting, but its functions are peculiarly varied. The inside face of the flywheel often serves the purpose of transferring the drive from the crankshaft to the gearbox through the clutch plates; that is to say, the flywheel is part of the clutch. It is therefore necessary that the material should have a high co-efficient of friction, without undue wear taking place. The rim of the flywheel stores up energy, and is subjected to stresses tending to disintegration. It is obvious that a strong iron is essential. On the Rover car teeth are cut on the outer rim of the flywheel to engage with the pinion of the self-starter; on a stiff engine these teeth must stand up against considerable shearing stress. The flywheel thus has three duties to perform, each necessitating somewhat different properties. The castings are usually made from an iron containing approximately T.C. 3.2, silicon 2.0, with phosphorus and manganese each being 1.0 per cent.

Other Castings.

The only other castings which present any peculiarities are brake liners and exhaust branches. The former need to be a medium hard iron, the function of the brake liner being to develop frictional properties when in contact with a fabric or another metallic surface. Experience has taught us that there is no definite analysis which gives the best results, as so much depends on the thickness of the casting and the conditions under which it is cast. As a general rule, an iron of just over 3 per cent. total carbon, and silicon in the neighbourhood of 2.25 per cent. is sought. It is exceedingly difficult to define exactly the length of useful life such a casting should have, as conditions of use vary enormously, according as the car is driven. A very hard iron would tend to polish and not be an effective braking surface; a soft iron would give rapid wear, necessitating frequent adjustments of the brakes and early renewal of the liner.

Exhaust branches require to be fairly soft but close-grained, and not subject to growth or distortion from repeated heating and cooling. The requirements are physical rather than chemical, and any iron in which the graphite is in a finely-divided state should be suitable.

The particulars given in this paper may appear to be sketchy, but is not our knowledge of cast iron of a very sketchy nature? Let us consider for a moment some of the outstanding problems. What do we know of the actual changes involved during the melting of iron in the cupola?

What knowledge have we of the actions taking place in a mould from the time of pouring until the casting is cold? What is the precise effect of mass on the cooling of cast iron? How little we know of the effect of rate of cooling, and less still of the effect of rate of melting! Do we know what differences, if any, are caused in physical properties by rapid melting as against slow melting? Is not our knowledge of the effect of casting temperature on the physical properties of cast iron of the vaguest description?

Do we know if any differences exist in the effective life of cylinders due to temperature of casting? What is the extent of our knowledge of the balance of the various constituents of cast iron, and the possible effect of minute changes in chemical composition? What data have we on the "ageing" of cast iron?

Do we know anything of the possible changes wrought on cast iron by sand composition, grain size, refractoriness, and permeability of sand? What do we know of the changes which take place in the mould when iron is passing from the liquid to the solid state, and the disturbances possibly caused by local chill? Have we any definite information as to the changes which take place on repeated meltings? What knowledge have we as to the effect of atmospheric humidity on the cupola blast?

Are we able to state definitely in what manner the various constituents are split up or combined when cast iron is in the molten state? What is the extent of our knowledge on fatigue of cast iron, due to repeated vibrations; or the influence of chemical and physical composition on fatigue? These are but a tithe of the problems on which we seek enlightenment. A calm survey of the situation can only lead to the conclusion that, in connection with the physical and chemical properties of cast iron, our ignorance is colossal.

London and Sheffield Branch.

MOULDING SANDS FOR STEEL CASTINGS.

By A. Rhydderch, B.Sc., Member.

The data which will be presented in this Paper refers to moulding sands that are used in the making of steel castings of light, medium, and heavy sections. Naturally, many of the principles discussed will be applicable in various degrees to all ferrous and non-ferrous moulding sands.

Refractoriness.

The question of refractoriness is first and foremost in the selection of any suitable facing sand for medium and heavy work to be used in a steel foundry. To realise this the conditions under which these sands are used can be profitably studied.

Table I shows the melting point of medium and low carbon steels, and also that of manganese steel.

Table I.—*Steel Foundry Temperature Data.*

0.1% carbon steel melts about	1490° C.
0.3% ,, ,, ,, ,,	1460° C.
Manganese ,, ,, ,, (C 1.2%. Mn. 12%.)	1350° C.

Casting Temperatures.

For Mild and Medium Carbon Steels.

Less than ⅜ in. section ..	.. 1580—1640° C.
Between ⅜ in. and 2 in. ..	.. 1530—1580° C.
Over 2 in.	.. 1500—1550° C.

These results are the average of many determinations, and were taken with an optical pyrometer, the observed figures being corrected to true readings assuming Burgess' emissivity correction.

It will be noticed that the highest temperature a facing sand has to stand is in the neighbourhood of 1650 deg. C., whereas the lowest, except in the case of some alloy steel, is about 1490 deg. C. Of course, the casting temperature depends on the steel used to a very great extent, a dead-mild steel requiring a higher pouring temperature than a high-carbon or a high-manganese steel, such as Hadfield's "Era" manganese steel. This is governed by the degree of fluidity at a particular temperature, so as to enable the steel to fill the mould without cold lapping. Generally speaking, this fluidity is directly connected with the amount of super-heat above the melting point of the steel in question, although various other factors also affect the fluidity of steels. For example, nickel-chrome steels and silicon steels are very sluggish even at temperatures well above their melting point, whereas manganese steel is very fluid at 1450 deg. C.

From the above it will be seen that the refractoriness is of prime importance in the selection of facing sands for use in steel castings.

Raw Materials for Moulds.

The material used in the making of moulds for steel castings can be divided into 3 groups of 3 divisions: First of all there are the naturally-bonded sands, *i.e.*, sands which carry their own bond and have sufficient cohesiveness to be used without the addition of any external binder, as, for example, the Belgian and Cornish sands and some of the Bunter sands, such as Worksop.

Then there are the synthetic sands or the artificially-bonded sands, which are simply made by mixing a suitably-graded high-silica sand with a refractory fireclay.

Thirdly, there is what is commonly known as "Compo," which is used on the heavy-sectioned castings. These are generally made up of mixtures of ganister, well-burnt fireclay pots, retort bricks, bonded with fireclay, and their chief difference when compared with the true melting sands is a question of grain size. Some of the coarser "Compos" are comparable with gravel.

Naturally-Bonded Sand.

On analysis, naturally-bonded moulding sands are found to be composed of grains of silica covered with a thin layer of bond, part of which is of a ferruginous nature and part of which is of an aluminous nature. The mineral analysis of these sands reveals the fact that there are present free silica, feld spars, micas, hydrated iron-oxides, and clay, and numerous other minerals in very small quantities.

Unfortunately, these mineral intruders have a very low melting-point when compared with that of silica, and will, therefore, have a very detrimental effect on the fusion of a melting sand.

When a moulding sand is mixed with some water and shaken vigorously, then allowed to settle, it will be noticed that the sand will separate out into three or more distinct layers. The bottom layer, on analysis, proves to be nearly pure silica, and the intermediate layers gradually become lower and lower in silica until the fine, flocculated matter contains anywhere between 40 to 55 per cent. of silica.

From this it will be seen that the impurities in a moulding sand are invariably found in the very finest grade, which is termed the "clay-grade" according to Professor Boswell's definition.

Examination of Clay Grades.

Table II shows a series of analyses on the clay-grades of various moulding sands. These clay-grades were obtained by the process of elutriation of these sands, as detailed in Professor Boswell's "Memoir on Refractory Sands."

TABLE II.—*Chemical Analysis of Clay Grades of Some Natural Sands.*

Name of sand.	Silica. Per cent.	Alumina Per cent.	Iron oxides. Per cent.	Alkalies.	Loss on ignition.
French red	44.04	28.06	12.84	0.47	11.94
Worksop yellow	53.02	28.36	5.00	1.42	9.54
Worksop red ..	53.62	25.59	6.86	2.58	8.70
South Cave red	36.16	22.36	22.80	1.14	14.38
South Cave yellow	43.98	33.45	14.95	1.67	11.76
Hutton Ambo middle seam.	52.62	24.52	7.04	2.03	11.16
Belgian yellow	55.46	22.22	9.04	0.90	9.20

It will be noted that the silica in all cases is very low; the alumina varies from 22 to 29 per cent., the iron-oxide from 5 to 22.8 per cent., the alkalies from 0.9 to 2.58 per cent., and the loss on ignition from 8.7 to 14.38 per cent.

It will be noted that, generally speaking, the high loss of ignition has a rough relation to the amount of iron-oxide present, thereby indicating the presence of hydrated iron-oxides.

TABLE III.—*Analysis of Cornish Red Sand, Showing Variation with Grain Size.*

	Bulk Analysis.	F.S. mm. > .25 < .10	C.S. mm. > .10 < .05	f.s. mm. > .05 < .01	C. mm. > .01
SiO_2 ..	83.89	96.73	92.07	55.34	46.67
Al_2O_3 ..	5.38	1.04	3.02	18.87	20.78
Fe_2O_3 ..	2.31	.05	1.25	9.85	12.89
FeO ..	0.18		0.20	0.47	0.41
MaO ..	0.58	0.013	0.17	1.27	1.52
CaO ..	0.48	0.26	0.38	0.95	2.27
Na_2O ..	0.04	0.08	0.09	0.18	0.40
K_2O ..	2.20	0.38	0.89	2.02	2.29
TiO_2 ..	—	0.14	0.42	0.85	0.85
Loss ..	0.48	0.63	1.21	10.14	12.29

From Prof. Boswell's Memoir.

This shows very clearly how the impurities and less refractory minerals are found in the finer grades.

Now this fine material, which is flocculated in the test tube and the analysis of which is typical of what has been shown, exists in the sand chiefly as a coating of the silica grains. In other words, this is the part that gives the sand its cohesiveness or binding properties.

Table III shows the series of analysis on an elutriated moulding sand; and bears out the statement previously made that the silica content gradually gets less as grade becomes finer, and the impurities simultaneously increase.

To test the point for refractoriness of the bond, a few experiments were made to determine the fusion points of the bonds obtained from well-known foundry sands. The results obtained are shown in Table IV.

It will be noted that in some cases the first signs of fusion of the point were found at a very low

TABLE IV.—*Fusion Point Test.*

Sand.	Grade.	Sintering temp.	Squatting temp.	Remarks.
Belgian red	Sand	1520° C.	1640° C.	
	Clay	1480° C.	1540° C.	Probably on the high side.
Worksop	Sand	1560° C.	1640° C.	—
red ..	Clay	1340° C.	1520° C.	—
French red	Sand	1440° C.	1575° C.	—
	Clay	1380° C.	1465° C.	—
Mansfield	Sand	1500° C.	1620° C.	—
red ..	Clay	1240° C.	1300° C./ 1320° C.	—

(i) Rate of heating was 10° C. per minute; (ii) The sand grade was all passed through 80 mesh; (iii) Clay grade obtained by sedimentation, and (iv) Atmosphere reducing.

temperature, whereas in Belgian sands the bond was almost as refractory as the moulding sand itself. What does this mean? It simply shows how important it is to examine separately the bond of these naturally-bonded melting sands, as apart from a pure melting-point determination. Because even as low as 1280 deg. C. Mansfield sand shows signs of fusion, and this will result in a reaction on the silica grains, producing a fused-mass for which the fettling shop will have to pay heavily when the castings arrive there.

These remarks apply to the medium-sized steel castings that are made in naturally-bonded moulding sands. In dealing with very thin-sectioned castings, generally cast in green sand, the question of refractoriness is probably not nearly of such vital importance, because the cooling is so extremely rapid that there is not much heat to be dissipated, and moulding sand may not even reach within a hundred degrees of the temperature of casting.

Another point is that nearly all naturally-bonded sands seem to form a very thin slag-skin which, under these conditions, seems to adhere to the sand and leaves the face of the steel perfectly clean except at the bottom of a mould, when it is generally fused to the casting. Analysis of this slag-skin shows that it is chiefly a ferrous-silicate.

In manganese steel there is a very similar effect with any silica-sand, bonded with clay, resulting in the light manganese castings leaving the sand perfectly clean, free from any adhering patches of sand. The slag surface is always a complex iron-manganese silicate. As mentioned once before, it would be interesting to try to produce this stripping effect artificially by painting the face of the mould with a paint made up of a manganese salt, or oxide; but although this is the case with the smaller-sectioned castings in manganese, disastrous results are obtained with the heavier-sectioned castings, owing to the abundant formation of slag which will be found bedded in the face of the casting and other material must be used.

Stripping Properties of Sands.

By using a suitable mixture of semi-refractory bond and silica sand, a good skin can be obtained on light- and medium-steel castings, but it is essential that a good sand-cleaning process be used, otherwise the flow sand will gradually be tending towards a concentrated slag heap.

Unfortunately the question of why a sand should strip well is very difficult to explain. However, it is known that those naturally-bonded sands with an iron bond are far superior in stripping properties to synthetic sands with a fireclay bond. Even then, improper preparation of sands, such as insufficient milling, incorrect amount of water, can make a very large difference to the stripping qualities of a sand.

Again, some sands which do not strip at all when moulded green sand, behave quite well when used as dry sand. This seems to bear out the fact that the question of heat conductivity, or perhaps convection due to increased permeability, is a factor of some importance.

But that conductivity or permeability is not the deciding factor is well known; in fact, the most open sand the author has known was an exceptionally bad "stripper."

All that can be said is that the question of skin depends on the formation of a layer of slag which adheres to the sand in preference to the steel, and furthermore, that this action is favoured by the presence of hydrated oxides of iron—such as is found in the red and yellow sands—or by the presence of a manganese oxide.

It will be noticed that no mention has been made of the determination of the actual mineral contents of these sands. The reason being that it is extremely difficult to determine rapidly the minerals or the quantity of minerals in the finer grades where they most abound, although some recent papers have appeared of French origin wherein the authors claim that they have been able to predict accurately the behaviour of firebricks in practice. At present the easiest means to determine the behaviour of these sands is by a simple fusion-point test.

There is one other point before leaving the question of refractoriness, and that is whether the tests should be carried out in a reducing or oxidising atmosphere. Some experiments made by the author seem to indicate that there is a strong reducing action going on at the face of the mould.

Synthetically-Bonded Sands.

Synthetic sands are generally made up of very pure silica sand and a fireclay, the aim being to distribute the fireclay over grains of the sand, thereby imitating the conditions obtaining in naturally-bonded sands. Obviously, refractory fireclay must be chosen for this purpose.

"Compos."

A great deal of secrecy has been, and is being, observed about the ingredients in various "compos," and it is freely claimed that the success or failure of many a foundry is due solely to the mixings used on the larger-sectioned steel castings. Very little information is available, but it is found in Longmuir and McWilliam that they are generally made up of mixtures of crushed silica rock or ganister, firebrick and retorts, used fireclay crucibles, all bonded with clay or kaolin. Generally speaking, this is universal practice in Great Britain. In America there are no such things as "compos." All their large steel castings are made in moulds made of coarse-grained silica sands bonded with clay. In Germany they use something very similar to British compos, but there they use "chamotte," which is simply a hard-burnt fireclay bonded with the raw clay. This occasionally being diluted with small amounts of silica. The greatest difference between compos and moulding sands is the grain size.

Obviously the difficulty in preparing compos of such a composite nature is very great, and a very large amount of dust or silt is formed. They are generally prepared by using perforated pans and then grading very roughly the product. It is well established that grain-size materially affects the fusion point of any composite refractory material, this being quite apart from any change in the chemical composition, which it is assumed remains the same. In some cases it can even affect the refractory property by as much as 20 deg. C. The coarser-grained material having, generally speaking, the much higher fusion point. Why is it that "compo" is used on all large castings? It is difficult to find a reason, except for the fact that a mixture of silica and fireclay can be so arranged that there is no permanent expansion or contraction on drying the moulds. The reason being that silica has a permanent expansion and fireclay a permanent contraction. It should be stated here that "compo" moulds are generally dried anywhere between 400 and 600 deg. C., and at 575 deg. C. there is a considerable change in the volume of the silica. This implies that on drying the moulds may be liable to crack. Another reason is given that burnt fireclay breaks down in angular fragments without powdering, whereas silica sands fall to powder. This certainly has not been the author's experience, and he cannot bear out this statement. In fact, the very nature of silica results in angular fragments on casting.

Increased refractory properties due to increased grain size is an essential attribute when one considers what a mould, made for a very large, heavy steel casting, has to stand. Very often one finds the section of a casting as much as 20 to 30 in. in diameter.

Pressure and Refractoriness.

During fettling one always notices that the bottom part of the casting is invariably more difficult and more costly to fettle than the top part. Why is this? In a paper by Bradshaw and

Emery there is some very valuable information showing the effect of load on the question of refractoriness of a mixture of fireclay brick and silica brick. Fig. 1 shows the results obtained. It will be noted that their mixture of fireclay brick and silica brick, when mixed in certain proportions, lowers the fusion point to cone 19, and that under load of 25 lbs. per sq. in. this is reduced to cone 16 or 17. Further, those high in firebrick show much greater difference between fusion tests with and without load. Here is an explanation of why the bottom of the mould sticks to the casting. At the bottom of any deep mould there is a considerable ferro-static pressure, very often as great as 25 lbs. per sq. in., so that the actual fusion-point of the material in the region is very much lower than what it is at part of the casting near the head. But here again, as in the naturally-bonded sand, much depends on the refractoriness of the bond itself, which coats the grains to give it the necessary cohesiveness, and in this case a more detailed examination of this finer-grade often explains the failure of various compos.

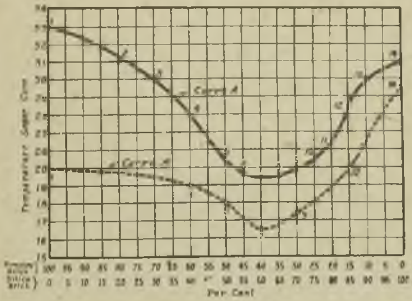

Fig. 1.—Influence of Load on a Mixture of Firebrick and Silica Brick.

From the above it will be clear that in using compo it is better to dilute the silica with fireclay to counteract contraction cracks in the mould than to work at the fireclay end of the mixture. It is realised that in making this statement the author is practically damning the modern Sheffield practice. America and Germany work at the extreme ends of the scale of the diagram, whereas Britain works at the middle and suffers accordingly. How often does one find that a chipping or fettling cost for one particular type of casting might vary anywhere between £5 to £15 per casting, due to the fact that such complex mixtures are so difficult to control. This is probably accentuated by a big variation of grain size which cannot be avoided in the production of such "compos." It would be interesting to know the origin of the use of "compo." The author believes that the behaviour of these complex "compos" is too variable to be of use in any progressive foundry.

Mechanical Strength and Permeability.

To determine permeability to gases and strength or cohesiveness, it is essential that there must be some method of testing which will give comparative figures which are reliable to a moderate degree of accuracy. These figures need not be of absolute dimensions, as long as some standard on which to work is determined. When the author first took an active interest in the subject of sand testing about six years ago, very little information could be found dealing with this subject. Numerous articles spoke very loosely of open sands and strong sands, but seldom, if at all, were any tests indicated whereby quantitative results could be obtained. And after all, it is only when foundrymen receive quantitative results that they can hope to investigate thoroughly the problem and to make any progress towards the production of more permeable sands. After numerous experiments, it was decided to use a method of ramming to a fixed density with a fixed percentage of water. The bars were then tested in compression in a modified cement testing machine, or by pushing the bar over the edge of the plate, termed the transverse method, or by breaking a bar supported at both ends with a load at the centre. Some of the results obtained by these methods have been quoted in Professor Boswell's book on British and American foundry practice, and were made when the author was a member of Messrs. Hadfield's Research and Technical Laboratory. It was realised, however, that this method was open to several objections for comparing sands from various sources and of varying grain-size and bond, though it served admirably for controlling the variation in one particular sand from day to day.

Controlling Variables.

In a large foundry that is the first essential, to fix as many varieties as possible, then the diagnosis of troubles becomes an easier matter. The permeability, or rather the impermeability, tests were made by ramming a 1-in. tube to give 2-in. lengths of sand. Altogether each tube was filled with five 2-in. lengths of sand, making 10 in. in all. Then forcing through the sand a definite quantity of air, noting the time taken and also the steady pressure set up. The back pressure is very important, because when the steady pressure becomes greater than that of the steel, the air will go through the steel instead of the sand. Of course, it is immaterial which standard one takes for a standard of reference. It was soon discovered that the transverse test was most easily handled and gave the most consistent results, generally within 10 to 15 per cent., which was considered satisfactory at that time. A large number of tests were carried out on each batch of sand and a grand average taken. It was always noticed, however, that the results always tended steadily to decrease or increase if a few hours were taken in the testing, and it was also noted that much more force was required to ram some sands than others. The progressive increase or decrease was put down to the drying of the sands with use, the used bars being mixed with the unused, which were kept in a humidor.

TABLE V.—*Effect of Amount of Moisture on Strength.*

The first	15	bars	tested	gave	200	grms.,	moisture	6.9%
second	15	,,	,,	,,	215	,,	,,	6.7%
third	15	,,	,,	,,	225	,,	,,	6.6%
fourth	15	,,	,,	,,	230	,,	,,	6.4%

This shows how important it is in testing any sand, under whatever method is adopted, to keep the water constant. The same, of course, applies to the sands prepared for actual use in the foundry.

Regarding the different force required to ram the various sands, that depended on the clay contents and the water present. It depended most of all on the nature of the clay present. Those clays that showed the greatest tendency to swell were generally the hardest to ram. In practice, it can be stated that the moulder rams on one particular job with a fairly constant pressure and does not vary the strength of his ramming to suit the sand. In order, therefore, to compare sands under similar conditions of ramming, it became necessary to ram either with a fixed pressure or a fixed blow, and arrange the quantity of sand used, so that the resulting bars would be of approximately the same thickness. This is necessary because moulding sands will not obey the laws of elasticity, and it is therefore necessary to fix a suitable size. In the author's case, he fixed 1 in. sq. as a size because of the previous tests which had been carried out on this basis. Therefore, as the sands became coarser, it is evident that a bigger cross-sectional area was required; certainly 1 in. would not do. In view of Doty's Paper, published in the A.F.A., 1922, it is extremely interesting to note that the same method of attack had been adopted, although Mr. Doty had refined the test very considerably, and it succeeded in repeating the results on the finer-grain sands to 5 per cent., which is excellent when one considers the nature of the material tested.

Standardisation of Testing Methods.

Since reading the paper of Doty's, the author has altered the apparatus and finds that the tests on fine sands used for light work certainly come easily within the 5 per cent. mark, though the medium and the coarser sands show greater errors. Of course, this can be understood by considering how a sand breaks. At the same convention, the American Foundrymen's Association put forward a method for testing permeability. This is very similar to the one used at Messrs. Hadfields, Limited, as can be seen from the description in Professor Boswell's book. The important point to bear in mind in connection with testing is that the members of the Institute of British Foundrymen must standardise these tests, so that they can discuss each other's troubles without indulging in a lot of vague platitudes. America, owing to her reliance on the synthetic sands, has been compelled to find a way. We in this country, with our unrivalled raw self-bonding sands, are satisfied, and one finds that all the papers published on the testing of sands are using different units. Certainly the results can be compared, but the operation is so tedious that it is seldom attempted. Why not publish in THE FOUNDRY TRADE JOURNAL and in the Institute proceedings the tests suggested by the A.F.A., to be brought up for discussion at the Newcastle Conference? We could then decide on our own standards and investigate on a quantitative basis the properties of our moulding sands. At any rate, the outcome of this is that by a series of comparative tests we are in a position to judge our various sands, compared with each other in strength and permeability.

TABLE VI.—*Effect of Density, or Hardness of Ramming on Strength and Permeability. Sand used—French Red.* 5% *Moisture.*

Density.	Transverse strength.		Compressive strength.	(Im)Permeability. in secs.
	Method "A"	Method "B"		
1.300	30	< 50	50	15
1.400	45	< 50	110	25
1.500	50	90	130	43
1.600	—	—	—	77
1.650	90	145	300	—
1.700	—	—	—	145
1.765	100	200	480	—
1.85	120	230	490	—

Similar information to this is required on every sand. Those sands which show the lowest rate of increase in (im)permeability are obviously the more foolproof in use.

Having thus briefly mentioned the method of testing, a few results are given in Table VI showing the effects of moisture and density of ramming on the properties of moulding sands. Table VI shows the strength and permeability of French red sand with a 5 per cent. added moisture-content. It will be seen that the increase in impermeability is out of all proportion to the increase in strength at the higher densities.

Figs. 2 and 3 show these figures on a graph. The important point to note on this particular sand is that the ratio of strength to permeability has a maximum value in the region of 1.4 to 1.5 density for dry sand at 100 deg. C. In practice this sand was actually rammed to about 1.58 to 1.65 density.

Fig. 3 outlines a test on the strength of sand rammed in a similar manner, *i.e.*, rammed under the same pressure, gradually increasing water percentages.

Without giving any further illustrations, it can be said that every sand has an optimum water content at which it develops maximum strength. It can also be stated generally that it is better practice to use the least amount of water rather than aim at the optimum water content. From the above, it will be realised what a very important part density and moisture play in the strength and openness of moulding sands, and after all, each foundry aims at using the best and, at the same time, the cheaper sand to be found in the locality. It is, therefore, important that all the properties of the local sand should be known, and as many variables as possible fixed.

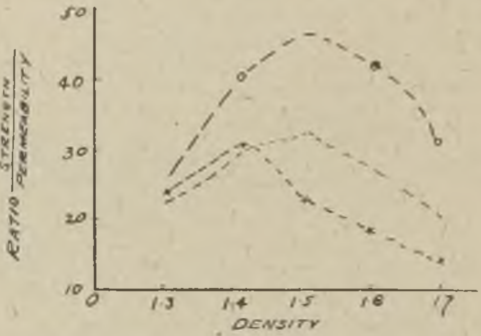

Fig. 2.—Tests Made on Bars Dried at 100 Deg. C.

Why should the ratio of the strength over the permeability plotted against density show a maximum in the region of 1.4 to 1.5 for dried sand? If this holds good for all sands, then this value can be used as a criterion in judging sands suitable for foundry work.

The density of ramming is certainly difficult to control, because every moulder rams with a different pressure. The shapes of the patterns in machine work also results in parts of the mould being rammed at very different densities. This is so, whether the man uses a jar ramming or a squeezer, but the moisture content can be controlled, and it is certainly of great importance.

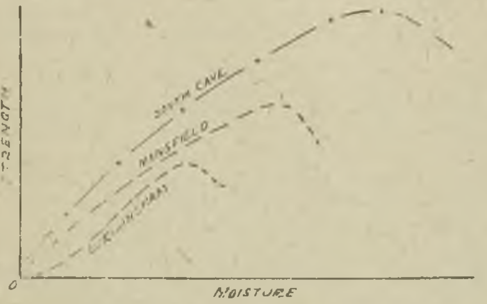

FIG. 3.—EFFECT OF MOISTURE ON STRENGTH.

It emphasises the necessity of specifying moisture content when speaking of strength.

It is also very important in selecting moulding sands to choose those that do not show a big variation in properties with small differences in ramming and moisture content. This is one reason why it is better policy to work with the sand on the dry side.

The Effect of Silt in Moulding Sands.

With the exception of one or two prepared synthetic sands, the writer has not come across any silt contents of greater than 7 per cent., and even the two experimental sands that did contain 14 per cent. of silt gave perfect castings in every respect. In view of this, he is not prepared to say to what extent silt is detrimental, except that it is unnecessary, and if it can be avoided all well and good.

Dealing with the grading of sands, it is necessary to grade these sands because it gives a good guide as to the trend of the sand and might eventually be useful. It might also explain why some results, such as variations in strength and permeability, are occurring, and then it is possible to adjust the mixtures accordingly. Regarding the "dye test," the author does not see its utility to the foundry manager. The essential properties of the moulding sand, such as strength and permeability, can be far more readily and reliably measured with simple apparatus.

TABLE VII.—*Effect of Clay Grade on the Permeability of Moulding Sands Tested in the Dry State.*

Sand.	Clay. Per cent.	Permeability.	
		Sand.	Sand washed free of clay.
W.Y.	4.4	38	31
S.C.Y.	6.3	235	150
W.R.	7.4	190	115
F.R.	9.3	200	90
H.A.	12.3	280	130
S.C.R.	15.1	120	70
B.Y.	17.0	290	140
B.R.	17.8	150	33

This shows the very marked effect of clay grade in a moulding in closing up the passages for the gases to escape. All the above sands are naturally bonded sands.

Preparation of Moulding Sands.

The method adopted in some foundries is too crude for words to express. Silica sand, as received, is thrown into the mill—so many shovelsful or so many barrows—then so much clay or naturally-bonded moulding sand. All the time the mill is working it is breaking down the silica grains very rapidly, making a much finer mixture. As soon as all the clay or loam is in, the man in charge prepares to open the mill to let it out again: water is added indiscriminately, and it is often carried out by a not-too-intelligent labourer. Oft-times the sand and clay are saturated with water before being put into the mill, and the result is slop and not a facing sand.

Facing sands are prepared for use in the foundry in various ways. First of all there is the old method, still used in many foundries, of treading

TABLE VIII.—*Effect of Milling Worksop Red Sand. Top row of Figures Refers to Large Mill; Bottom Row of Figures Refers to Small Mill.*

Time of Milling.	Mechanical Analysis or Grain Size.					Compressive Strength.		Transverse Strength.		(Im) Permeability.		Remarks.
	mm. < 1.0 > 0.6	mm. < 0.6 > 0.25	mm. < 0.25 > 0.1	mm. < 0.1 > 0.01	mm. < 0.01	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	
Raw sand	3.54	16.58	72.65	2.40	4.93	230	2800	60	950	69	50	Raw sands, very uneven.
	0.63	20.34	69.40	2.78	6.65	155	2050	40	1320	50	39	
5 mins.	0.57	5.13	76.06	5.96	12.28	510	4800	110	1450	87	64	Moisture test gave 4.7, 4.9, 5.1 in small mill.
	0.39	15.12	70.98	3.27	10.17	270	3300	88	1660	50	38	
10 mins.	0.79	5.81	72.65	4.68	16.1	540	5600	130	1820	81	60	Moisture, 5.0, 5.1, even texture.
	0.28	14.85	67.97	5.42	11.44	320	4000	100	2230	52	41	
15 mins.	0.68	6.65	71.85	5.20	15.63	550	5600	155	2250	76	54	Even texture.
	0.25	13.69	67.15	5.17	13.66	400	4030	124	1700	51	40	
20 mins.	0.51	5.88	72.21	5.50	15.87	610	5250	150	1950	77	57	Mixture getting lumpy.
	0.28	14.24	68.13	4.23	13.03	430	3930	155	1730	56	44	
25 mins.	0.61	5.68	71.74	5.68	16.31	640	5240	170	1880	77	57	
	0.26	13.20	69.21	3.7	13.55	480	3760	151	1830	59	47	
	0.81	5.32	71.97	5.5	16.3	630	5700	170	2220	78	58	
30 mins.	0.26	12.99	69.95	3.44	13.36	460	4100	174	1700	61	48	

Compressive and Transverse Strengths in Grammes per sq. cm. Permeability in Seconds.

the sands. Secondly, the introduction of a pan mill, the various constituents being thrown in and milled until the desired toughness is obtained. Thirdly, mixing in an edge-runner mill. Fourthly, proper sand-mixing apparatus, using a paddle arrangement.

But why is it necessary to perform all this operation on foundry sands, even naturally-bonded moulding sands? First of all, to get an even distribution of moisture and bond; secondly, to increase the strength or cohesiveness for use in the foundry; thirdly, to increase the "activity" of the bond itself.

It is well known that nature has not deposited foundry sands in an ideal manner. Various consignments are very irregular even in the case of our best moulding sands. Some are richer in the sand-grade, and at other times richer in the loam-grade. Often one finds solid lumps of the bonding material. This is very noticeable with such a well-known sand as the Worksop red sand. The result of using raw sands containing loamy lumps is very disastrous for the appearance of the casting. In addition, it is very painful for the moulder who uses them. So that, even with the naturally-bonded sands, it becomes necessary to redistribute the clay grade by causing it to coat the silicious grains, thereby carrying out to the full extent what nature has started to do. It is important to know how milling a sand is going to affect strength and permeability. Even a casual examination of the sand with a small magnifying glass shows that the bond is redistributed, apart from what the process of mixing might be.

To consider exactly what does happen in an ordinary milling operation, Table VIII shows what happened to Worksop red sand in a large pan mill holding 10 cwts. The sand was air-dried and a definite amount of water added, then mixed before being put into the mill. It will be seen that the water is not very evenly distributed after 5 min. milling, but after 10 min. it is nearly so, so that the sand in all parts of the mill will contain approximately the same water content.

The Strength of Sand as Affected by Milling.

It will be noticed that the strength increases very rapidly during the first ten minutes, and then it gradually settles down to an approximately constant value. The permeability certainly becomes a little worse, but the increase is not sufficient to create any difficulties in actual use. In fact, castings made with sands milled for various lengths of time did not show any blow-holes or pin-holes, and, what is more, they all stripped well at the time when the milling was 10 min. or over.

The effect on the grain size is very obvious. Even under these conditions there is a very decided crushing effect, but after 15 min. the crushing effect seems to cease. This undoubtedly is due to the formation of an elastic cushion of bond protecting each silica grain. This is a very important fact to bear in mind. Of course, it might be considered that the increase in strength is also influenced, not so much by the redistribution of the bond as by the variation in grain size, and also probably by the increased activity of the bond. To test this point a silica sand was graded into four parts in accordance with Table IX, and the mixtures made were tested by the ordinary transverse method.

TABLE IX.—*Effect of Grain Size on Strength of Sands*

						Breaking load.
1.	Through	10	mesh on	20	..	95 grams
2.	,,	20	,,	40	..	100 ,,
3.	,,	40	,,	60	..	120 ,,
4.	,,	60			..	135 ,,

Sand used—Crushed Silica rock:
Bond .. .. 10% Derby clay.
Water .. .. 5% ,,

Hand mixed for 10 minutes. This shows that it is not the thickness of the bond round each grain that gives the strength, but the surface contact, because the finer sand has a very much greater surface area than a coarse sand.

Part 1 broke at 95 grammes, part 2 at 100, part 3 at 120, and part 4 at 135. That is, the finer the grading the stronger the sand with the same amount of bond and water, so that although the coarser sand has the least surface area and therefore the greater thickness of bond on its surface, yet the finer sand with the greatest area, and therefore the greatest number of points of contact, shows the greater strength. This leads to the conclusion that in the preparation of sand a thin coating of clay is required on the grain, and that it is the surface contact and not the thickness that gives maximum cohesiveness. What this actual minimum thickness is, the author is not prepared to state without further experiment.

Table X.—*Effect of Milling French Red Sand. In a Small Pan Mill—One Plain, One Grooved Roller.*

Time of milling.	Grain Size.			
	< .6 mm. > .25 ,,	< .25 mm. > .10 ,,	<.10 mm. >.01 ,,	> .01 mm.
As received	11.6	74.1	2.0	11.3
5 mins.	9.9	76.5	1.8	11.7
10 mins.	7.2	78.0	2.9	11.6
15 mins.	7.4	78.3	2.0	12.0
20 mins.	8.6	76.5	2.2	12.0
30 mins.	9.0	75.6	2.3	12.8

The raw sand was tempered with 5% water and allowed to stand 6 hours before milling.

This result is extremely interesting because under these conditions we do not find a great deal of grinding, but simply a coating of the grains.

Table VIII shows a similar Worksop red sand which was milled in a very much smaller and lighter mill; one roll being plain and the other corrugated. Here again the effect on strength and permeability is very much the same, but the crushing effect is not nearly as serious. In other words, the smaller mill is more efficient in its redistribution of the bond than the larger mill. It will also be noticed that in this case the grain size reaches a constant value after about 15 min. milling. This, in the author's opinion, is one of the most interesting facts in connection with the question of milling sand, and the old idea of the continuous breaking down of the sand grains is obviously a fallacy; at any rate under these particular conditions. In order to test the breaking down of the sand grains in milling and how far it is affected by the amount of clay grade and moisture present, a French red sand was tempered with water and then milled in the small mill under the same conditions as the Worksop red sand. French red sand was selected because it contains a much higher clay content than Worksop red sand, and it is generally better distributed over the silica grains. Table X shows that the effect on the grain size is almost negligible, so that under these conditions the effect on the grain size can be controlled.

Amounts of Moisture Necessary for Naturally-Bonded Sands.

At the present time the method in use is simply to temper the sand until the sand is cohesive enough to hold together without leaving a sticky mess on the hands. What controls the amount of water that a sand will hold before it reaches its sticky state? By adding increased percentages of water to various sands, it has been shown that the strength gradually increases until it reaches a maximum, and then it gradually falls away. In other words, every naturally-bonded moulding sand has an optimum water content. Generally speaking, it can be stated that those with a ferruginous bond have a much higher optimum water content than those with a clay bond, that is, of course, assuming the same percentage of bond present. The amount of moisture required to produce this maximum strength can vary between 2 to about 40 per cent. of the clay grade present. Naturally, one would say at first glance that this is the best amount of moisture to add, but it is probable that the best practice is to work with the sands slightly on the dry side rather than to aim at the optimum water content. Tests on sands will bear this out, as mentioned previously.

The Mobility of Clay in Moulding Sands.

In view of the rapid strides that are being made in steel foundries in the use of green-sand moulding, the question of a correct amount of water to be added for each particular sand should be carefully investigated and determined. By means of methods of testing already described, it should be easy for any foundryman to determine the maximum permissible amount of water to be added to any of his facing-sand mixtures, and for uniformity of results it is fairly obvious that the amount of water in the sand should be kept within fairly definite limits. Now that the amount of water to be added has been fixed, the natural question that arises is how and when should it be added. From the above results relating to the effect of milling in crushing sand grains, it is obvious that the sands should be dry, mixed very thoroughly, and then a correct amount of water added. It must be borne in mind that there is a time-factor in the penetration of water into any loamy material, and during this penetration the sand gradually and steadily swells and increases in volume. The clay grade becomes more mobile, and upon the slightest application of pressure or rolling will spread very easily, so that when a sand is dry-mixed, the water added, and then allowed to stand for a matter of, at least, a few hours, there is a better chance when it is put into the mill of avoiding any alteration in the grain size. In fact, nothing would be lost by letting it stand even for a few days, so as to even up the moisture content of the whole mass. But even after milling a very large number of sands show loamy particles distributed very freely amongst the sand grains; that is, there has not been sufficient mobility in the clay grade itself to enable it to be easily spread. This is particularly so in the case of the synthetic sands. How often does one find, on examining a fire-clay by sieving, that a very large amount of the clay, after washing for many hours, is left in large lumps. Even after milling the same condition persists, so that the efficiency of the added clay is often not greater than 20 per cent. The object must be, therefore, to assist in the distribution of this bond by some means. It has already been suggested that this is aided by allowing the mixture to stand, and now we require some further aid. Here we can consider the action of alkalies and acids on clays. It is a well-known fact that alkalies and acids have very profound effects on the properties of clay; in fact, use is made of this point in the ceramic industry. The alkalies seem to loosen all the clay particles, thereby increasing their mobility or increasing their fluidity. Having thus separated the large lumps of clay into fine particles, it seems to protect them, causing the clay grade to remain in suspension instead of coagulating. Surecht found that the elasticity of a clay could be increased nearly four hundred per cent. by the use of suitable quantities of various alkalies, so that clay grade or coagule grades, as we consider them, will be spread much more easily by suitable treatment with alkalies. Only fractions of 1 per cent. are required to bring this about.

This principle has been used in some German and American foundries with the idea of revivifying used milling sands, and the results are stated to have been satisfactory. So that the first method considered is that of the mixing of the ingredients perfectly dry and then adding a very diluted alkaline solution to bring about the necessary mobility, and that this action will be considerably aided by allowing the mixture to stand at least a few hours before milling. This method can be described as the dry method.

The alternative method is the wet method, which has also been used in the preparation of synthetic sands. Here the plastic fireclay added is made into a slurry and emulsified and then added to the silica sand already in the mill. It is obvious that, unless there is sufficient clearance in the mill, a very great crushing action will take place before the grains are sufficiently coated to behave like rubber balls. Probably a better procedure would be to mix the fireclay-slurry with a silica sand in an ordinary paddle-type of machine, allow to dry, and then re-temper to the correct moisture before putting it in the pan mill. This procedure can be made infinitely better by reducing the bond added to a true colloidal state by means of some of the machines now on the market. The one thing that foundrymen must attempt to do is to coat the grain with a thin, even layer of bond without crushing the silica grains, resulting in the most cohesive sand compatible with the maximum permeability.

It is obvious from the remarks that have already been made that for uniformity of work and product it is essential that the distribution of the bond, the amount of moisture, and the grain size should be controlled, and that work must be directed in the direction of producing moulding sands of maximum permeability with the necessary cohesive strength.

Floor Sand.

The most perfect facing sand behaves just the same as the worst if a very inferior floor sand is used for backing. Consider a mould with, say, 10 in. of sand from the pattern to the edge of the box, the permeability of the facing sand can be considered to be 50, that of the floor sand 200, so that using 1 in. of facing sand and 9 in. of floor sand as a backing, a resultant permeability of 185 is obtained. In addition, the moisture in the floor sand is oftentimes very uneven, the bond irregular and weak. Numerous troubles are due to the quality of the backing sand, and every foundry should, in its own interest, control this point very carefully. Regarding the use of floor sand in facing mixtures, its strength and grain size should be carefully noted if it is desired to produce a standard facing sand.

Preparation of Compos.

With reference to the preparation of compos, here again the most important point is to keep close control of the grain size and, further, to ensure an even distribution of the clay added. In preparing crushed pots, etc., it is essential that a perforated pan be used, so that the finer materials are rejected immediately on formation. This will help to keep down an excessive formation of dust. The crushed rocks should then be graded through sieves or riddles and the dust blown away in an air channel. The bond is probably best added in the form of a slurry, the whole mass turned over by hand or mixed in revolving drums. This having been done, it is probably advisable to allow the whole mixture to dry and re-temper to a suitable consistency. If put in a pan mill, there should be ample clearance between the rolls and the bottom of the pan, so as to ensure no further crushing. The underlying idea here is to obtain a definite grading of the material and to ensure each grain being well coated with its bond.

Most compos are very variable in grain size, and on the whole highly impermeable to gases. This is due to the uneven grading of the moisture.

Before leaving the question of compos, it should be stated that there is an economical limit to the maximum size of the grains in a compos used as a facing mixture. If too coarse, then the face is likely to be easily disintegrated during casting, resulting in excessive fettling costs. As a general rule, it may be stated that the coarsest particles should not exceed ⅛-in. dia., or about 3 mm. dia., the remainder being suitably graded to give the required permeability.

Drying of Sands and Compo Moulds.

In considering this question, foundrymen must bear in mind two points. First that a very large amount of drying is done on machine-made moulds, because the work is carried out by unskilled labour and drying is therefore more a precaution than a necessity. Further, most work that has to be machined is dried to make sure of soundness in the machined parts. Most of this class of work is dried between 200 and 300 deg. C., irrespective of the sands used. With the larger work, we not only get drying, but even calcining and compos are stoved to 500 or 600 deg. C. Before the war, at Krupps, compo-moulds were even drawn at a red heat, but the question that interests us is, what happens on drying a mould? A few tables have already been shown where the strength and also the permeability, after drying at 100 deg. C., have been recorded.

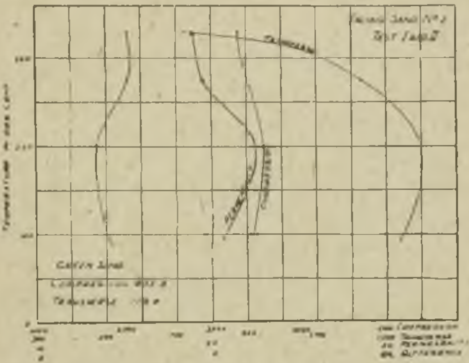

Fig 4.—Tests on Facing Sands.

Fig. 4. shows the results obtained on a synthetic mixture of silica sand and a fireclay. It will be seen that on drying at 100 deg. C., the strength has been increased from 260 grs. per sq. in to

3,400 grs. to the sq. in., and it is practically unaffected to about 200 deg. C. On further heating, the strength gradually gets less, but the decrease is not serious and the permeability is even less affected. This falling off in strength is probably due to the contraction of the clay film round the grains, thereby setting up fissures of weakness. Regarding the effect of drying on permeability in general, it can be said that drying a sand increases the permeability very considerably, an improvement of 50 per cent. being easily obtained in some sands. In practice the difference is probably still greater because the hot gases emanating from a green sand mould will naturally evaporate the water in the sand, setting up a much greater resistance than happens under the conditions of our test.

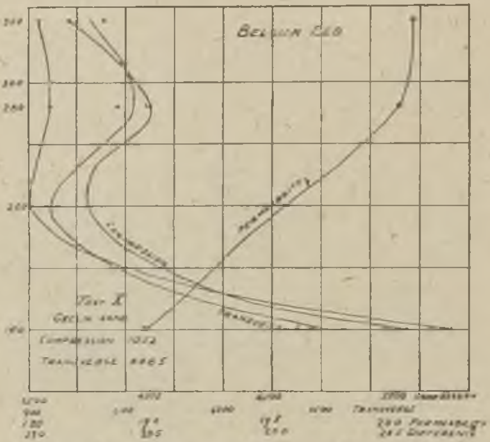

Fig. 5.—Tests on Belgian Red Sand.

With regard to the strength of sands on drying, this is increased from 2- to 20-fold, depending first upon the amount, and secondly upon the nature of the bond present.

Fig. 5 shows the effect of heating of Belgian red sand. It will be noticed that the behaviour of this sand is quite different from the previous one, and that, after 100 deg. C., there is a well-known fact that these naturally-bonded sands are much more easily burnt than those made of a silica sand and fireclay, and we have here a probable explanation of the cause.

Fig. 6 shows the effect of drying French red sand, which behaves in a very similar manner to Belgian red sand, although the loss in strength is not nearly as serious. For some unknown reason Worksop red sand does not show this behaviour to nearly such a marked extent. Up to 300 deg. C. there is hardly any change in the physical properties of the sand. Of course, there is less bond in Worksop sand than in French—probably this has something to do with the explanation, and also the amount and nature of the colloids. If moulding sands are tested for strength and permeability when hot, they give a very different figure from that obtained when cold. The sands are very much stronger, as much as 20 to 30 per cent., and more impermeable.

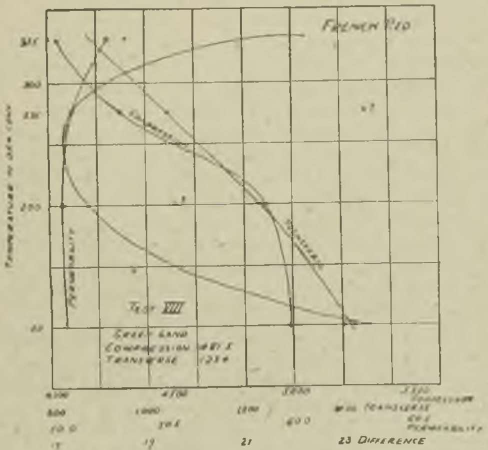

Fig. 6.—Tests on French Red Sand.

The conclusions to be drawn from this paper are that sands with a large amount of bonding material deteriorate much more rapidly on heating above 100 deg. C. than those with a small amount of bond, and that naturally-bonded sands show this behaviour in a very pronounced manner. Further, those with a fireclay bond will stand a great deal more fire than those with a natural bond or a ferruginous bond.

For the fixing of temperatures for drying ordinary moulds of naturally bonded sands or synthetic sands, it is not advisable to go beyond 205 deg. C., except in special circumstances where the mould has to contract under the action of the steel. In such cases, it might be necessary to go as near the rotting point as possible, but it must always be borne in mind that if the skin of these moulds is broken, patching is impossible, and the result is invariably a dirty and unsound casting. A sounder way is to arrange cavities in the mould and to dry at temperatures not exceeding 300 deg. C. It is to be regretted that the expansion or contraction of these sands was not determined during these experiments, but it is a fact that silica sands do expand and the size of moulds when dry and when green is seldom the same. One can see this daily in any foundry. Cores will not go into core-prints without filing or rubbing. Weights of castings very often differ, though the green-sand moulds are of the same measurement, this being due, of course, solely to the different temperatures at which the moulds were baked. In fine work, the question of the variation in the size of the moulds becomes an important point.

Regarding the rate of drying, this depends on the mass of sand to be dried. The larger the mass, the slower the drying. Further, the moulds must be very well vented to allow the steam to get away easily, otherwise badly cracked moulds are produced. In compos, this excessive cracking can also be caused by an excessive amount of fireclay ingredients, and it is obvious that if the fissures or cracks are of large dimensions, then the size of the mould must vary very considerably from what it should be, in fact, it is even possible to find a mould so changed in shape that the machining allowance has generally disappeared.

Regarding the drying of moulds generally, the points to bear in mind are to dry slowly and well vent all the moulds and, further, to keep the temperature of drying under close control.

Conclusions.

From the data given in this paper, it is fair to say that with our present information, and methods of testing, we are in a position to obtain reliable data regarding sands used for moulding purposes, and by a series of routine tests—all of a simple character—close control can be kept of the mixtures used. This will undoubtedly assist foundrymen in the tracking down of many mysterious foundry troubles.

Emphasis has been laid on the question of moisture in sands : Too little attention is paid to this side of the question, and this, in spite of the fact that a wrong moisture content can make a good sand a bad one.

The question of more careful control of floor sand has been touched upon, and it has been pointed out that numerous sand troubles are due to this and not to the facing sand.

The author has not seen many results on the drying of sands, and the effect of such drying on the properties of the sand. These results are, therefore, put forward in the hope that they will give all foundry workers some idea as to what happens on drying a moulding sand. An attempt has also been made to study the effect of milling sands, and it is hoped to investigate this question much more fully at an early date, especially in view of the interesting results obtained.

All foundry workers are searching for the ideal moulding sand—the panacea for all foundry evils—and it is hoped that the results presented in this Paper will be of some assistance to those workers.

It can be stated briefly that some of the essential properties of this ideal sand are :—

(a) That it be highly permeable if open to gases, and what is more important, the rate of increase of permeability with density of ramming or hardness should be low.

(b) It should also develop maximum strength, suitable for moulding, with a minimum amount of moisture.

(c) The bond should be mobile, that is, it should be easy to develop maximum cohesiveness with slight mechanical preparation.

Many other conclusions can be drawn from the published results on the properties of moulding sands, but in our interests it is essential that we should immediately agree upon some definite standards which are helpful to all foundrymen. Unfortunately, we have no fixed standard of testing, resulting in a great deal of confusion and, what is more unfortunate, in the inability to co-ordinate the various results published.

It is only by co-ordination that we can hope to make progress, and it behoves us, in our own interests, to take this matter in hand and decide on some definite standard for reference.

Lancashire Branch.

NON-MAGNETIC CAST IRON.

By S. E. Dawson, A.I.C.

In considering cast iron as applied to industry one is struck by the comparatively small field in which it is utilised. Up to recent years it was only considered where bulk and relative low mechanical and electrical properties were called for, but of late years, and due largely to a closer investigation of its potential possibilities, it has been to some extent raised out of this category. By the attainment of increased mechanical strength, by a better understanding of its electrical and magnetical properties, and by the more accurate production of castings to absolute dimensions and design, it is not now so lightly cast aside in favour of steel, bronze, etc.

As applied to the electrical industry its fundamental drawback was that it was magnetic to a greater extent than any other metal, but even this feature has now been overcome, so that we have a metal which at once becomes a competitor of brass, aluminium and other non-magnetic materials.

During the last few years cast iron has therefore entered into many fields for which it had previously not been considered, for one or other of the above reasons, and as further investigations which are now in hand develop it may be hoped that cast iron will obtain the consideration that it merits for industrial purposes.

Improvements in cast iron are being actively sought for by the British Cast Iron Research Association, as well as by private research students, and the placing of standard specifications for all types and uses of cast iron on a firm footing will materially help in this direction.

The average engineer knows little about cast iron beyond the chemical analysis, but as the usual method of expressing this is merely a statement of the "ultimate" content of various elements in which form, as a matter of fact, they do not in the majority of cases exist, no measure of the actual components of cast iron is indicated.

Each of the elements found by analysis are capable of combining separately with one another to form compounds which, as in the case of most inorganic compounds or salts, have properties and characteristics distinct from the individual elements. It is thus evident that the actual effect of the component parts of cast iron, other than

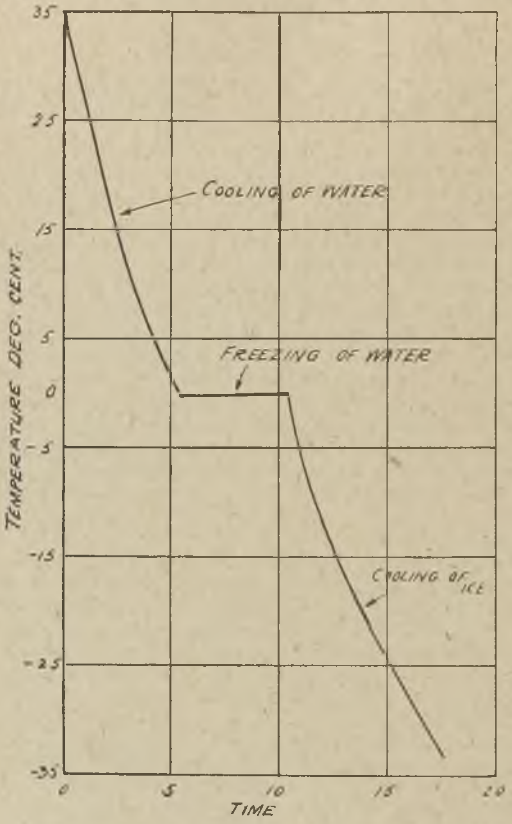

Fig. 1.

pure iron, may be vastly different from that of the individual elements, and with some of these this is actually the case.

Phosphorus, for example, could not exist separately in cast iron for obvious reasons. In the form of phosphide of iron, however, it can and does exist, and since this substance is very brittle and hard it constitutes a possible source of great trouble in the machine shops if not kept under very careful control as to its disposition throughout the metal. This compound of phosphide of iron has other features which, as will be seen presently, have a profound influence on cast iron. The effect, therefore, of a small percentage of phosphorus as revealed by the ordinary chemical analysis assumes a different aspect when viewed in the light of its effect as phosphide of iron, since the latter compound is approximately $6\frac{1}{2}$ times ($\frac{109}{31}$) that of the phosphorus content.

In the same way carbon, when combined with iron, form a compound about 15 times greater than the element itself, and as this carbide of iron is a hard material its effect might be, and sometimes is, very disastrous.

To visualise the compositions of a cast iron, one might usefully place side by side the chemical analysis as found in the laboratory, and the proportion of compounds derived therefrom by calculation. This is done in Table I.

TABLE I.—*The Ultimate and Rational Analyses of Cast Iron.*

	Ultimate analysis per cent.		Rational analysis per cent.	
Graphite Carbon	2.70	giving	2.7	Graphite.
Combined ,,	0.75	,,	11.2	Carbide of iron (Fe_3C).
Silicon	2.33	,,	7.0	Silicide of iron (FeSi).
Manganese ..	0.60	,,	0.6	
Phosphorus ..	1.10	,,	7.1	Phosphide of iron (Fe_3P).
Sulphur	0.08	,,	0.2	Sulphide of iron (FeS_2).
Total ..	7.56		28.8	

The manganese would be present as carbide or sulphide, but to avoid complications for comparison here, these latter are shown as all combined with iron and the manganese left as if free, though actually it would take the place of the iron similarly combined, but this arrangement will make little difference in the above figures.

The effect of 28 per cent. of compounds other than iron, and each with characteristics of their own, and differing greatly from iron itself, allows one to realise the importance of the "foreign" elements present in cast iron.

The Effect and Distribution of Constituents.

Having thus considered the vast possibilities for differences of cast iron, it is useful to investigate the effect of the various constituents, and the means of determining the manner in which they are located or distributed, so as to arrive at their probable effect on the mass as a whole. This is a matter which concerns all alloys and study of the equilibrium of mixed metals affords valuable information, which, when applied to cast iron, explains many of the problems which are met with in the foundry and machine shops.

On adding one liquid metal to another, the resultant mixture is usually homogeneous so long as the mixture remains liquid. The alloy, however, after solidification, may have more than one constituent from a structural point of view. Some of these various constituents, unlike chemical compounds, are not necessarily composed of the elements combined together in definite ratios and moreover vary with the physical conditions which have prevailed during the cooling-down period, and may further vary at a later stage even when solid by mechanical action.

When the alloy produced by adding one metal to another forms a homogeneous solution, the one resulting constituent is called a solid solution. In an alloy, then, there may be three constituents:—(*a*) A pure metal; (*b*) a chemical compound; and (*c*) a solid solution, and these may all exist at one and the same time in the same alloy.

The chemical compounds, however, do not always follow the law of valency, and may be considered more as molecular compounds, which are capable of being dissociated by conditions. They are not too powerfully united together, and unlike atomic chemical compounds, they do not differ greatly in appearance and properties from their component elements.

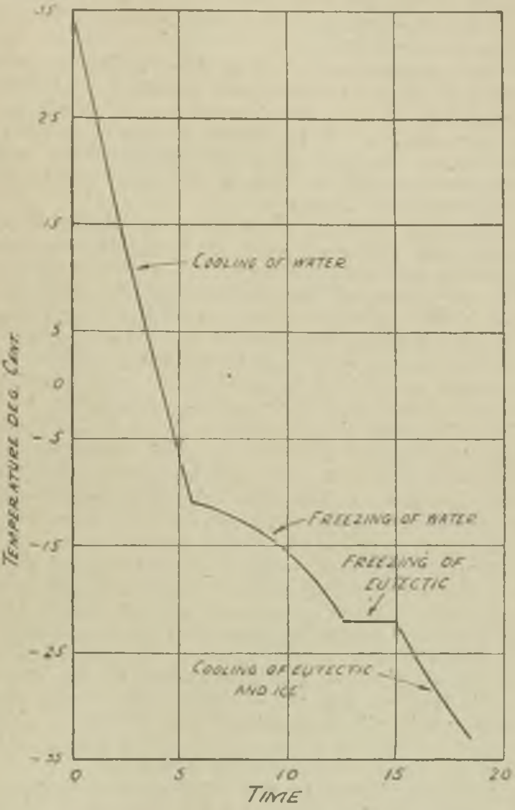

Fig. 2.

In the case of solid solutions, here, again, the forces holding the components together are relatively feeble, and each can be recovered by suitable mechanical or physical means, so that the appearance and properties of a solid solution are not very different from the individual parts dissolved in each other, and also solid solution like liquid solution does not take place in any fixed ratio. When we thus see what an alloy might consist of, the next step is to adopt means to investigate these conditions.

In investigating an alloy, then, means must be adopted to determine the proportion and characteristics of each of the constituents which may be present, and in producing a definite alloy an endeavour must be made to introduce the constituents in such a form as to give to the alloy the properties sought.

Chemical analysis, as already explained, whilst being the starting point or foundation of any investigation does not carry one very far towards the conception of the structure of an alloy, and one has to supplement the knowledge thus gained by other means. Microscopic examination marked a great advance in thus investigating alloys, but perhaps more direct knowledge can be obtained by an examination of their cooling curves.

To illustrate the usefulness of an investigation into the cooling curves of an alloy, we might consider the case of a pure metal, and to crystallise our thoughts on this also take the parallel case of a similar combination of common occurrence, namely, the cooling of ice and water.

When a mass of water is caused to cool down through its freezing point, the rate at which its temperature falls becomes slower and slower, that is, the curve takes the form of a hyperbolic curve as shown in Fig. 1. This curve will be quite even or smooth until a temperature of 0 deg. C. is reached, when the temperature will remain constant until all the water has solidified, after which the fall in temperature will continue until that of the cooling medium is reached.

This retardation in the cooling curve is due to a certain small amount of heat which is liberated in the water passing from the liquid to the solid state. This same phenomena occurs similarly when a metal or alloy undergoes any physical change, and, indeed, when it undergoes any change either chemical or physical whilst cooling down. For example, Fig. 1 might equally represent in general contour the cooling curve of any pure metal where only a change from the liquid to the solid state has taken place. Thus we see that the cooling curve gives an easy method of detecting a change taking place in a mass of metal when cooling down. To carry this further we might now take a parallel example of a binary alloy, that is an alloy of two components, and use the case of a solution of salt in water as our guide.

When a salt solution cools it does not freeze into a homogeneous mass of the same composition as the liquid solution as does pure water, but separates into the two components, water and salt, a fact known as selective freezing. Thus, the water first commences to freeze out to form more or less pure ice, leaving the salt to form a stronger solution or "mother-liquor" with the remaining water which, becoming more saline, and following the law of impurities, lowering the pure freezing point, has a lower ice freezing-out point still. This progressive enrichment of the salt solution continues until a temperature of −22 deg. C. is reached when the percentage of salt in the mother liquor becomes 23.6 per cent., and the whole mass freezes (since this is the percentage strength of lowest fusibility) without any regard to selection with a further retardation in the curve due to this further physical change. We thus get a curve as shown in Fig. 2, which again might equally represent the cooling curve of a simple binary alloy.

No matter what might be the percentage of salt in the solution, there is no further separation or freezing out of salt after this 23.6 per cent. point has been reached at a temperature of −22 deg. C., and any excess salt over and above this amount in the original solution freezes out before the retardation shown in Fig. 2. This percentage of solute to solvent is known as the eutectic (lowest melting), and is the most fusible part of the mass. Thus in some alloys there is a eutectic which has a constant composition, and which solidifies at a constant temperature.

In more complex alloys the eutectic may consist of a definite compound, interstratified with another metal, for example, cementite (Fe_3C) interstratified with pure iron in steel, or phosphide of iron (Fe_3P) interstratified with a solid solution of phosphide of iron in cast iron.

These considerations are all assuming that the conditions of cooling have been such as to allow all the changes to take place fully before a subsequent effect has commenced, and in investigating an alloy by this method the cooling must be sufficiently slow as to allow of the temperature change points recorded to be a true criterion of the full changes taking place.

These interstratified plates are capable, under certain conditions of heat treatment, of partial transfusion or segregation, and this may also take place during the cooling down of an alloy if the conditions are sufficiently prolonged to allow it to occur.

It will be clear from the previous remarks that the eutectic is the last constituent of an alloy to solidify, and that it will, due to the earlier crystallisation of the excess metal (that is, the excess over eutectic requirements), be found in between and round those crystals. As this earlier crystallisation takes place the tendency is for the still molten eutectic to be squeezed forward in the direction of solidification or cooling, that is, from the outside of an ingot or casting to the portion of biggest mass, incidentally taking advantage of any cavity due to shrinkage or other causes which it can occupy.

Phosphide Eutectic.

Now, in the case of cast iron the eutectic of lowest fusibility is a solution of phosphide of iron (Fe_3 P.) in pure iron, and this can be distinctly traced under the microscope and also by a careful chemical analysis, using the percentage of phosphorus as the guide. This squeezing out of the phosphide eutectic during the cooling down period is easily seen in the case of pig-iron, especially those which give a comparatively large proportion of eutectic, that is, the high phosphorus irons.

Here we find that the phosphide-bearing eutectic has been squeezed towards the centre of the pig so that the phosphorus content of phosphoric pig may be 2 per cent. at the centre whilst an average analysis may be only 1.5 per cent. This indicates the importance to be attached to the manner of drilling when sampling pig-iron for testing purpose. If taken down the centre of the pig from a fractured surface across the bar we shall certainly get a higher phosphorus content than taking drillings from the outside across the bar to the centre, and for complete control of the casting produced in the foundry it is essential to obtain a correct average sampling of all the constituents in the pig-iron and not drill into one section where we may expect a migration of the eutectic to have taken place.

When we consider that the phosphide eutectic in cast iron contains about 6 per cent. of phosphorus, we realise to what extent the eutectic itself forms part of the whole cast iron, for if the whole of the phosphorus in a 1.5 per cent. iron were in this form we should have about 25 per cent. phosphide eutectic, a quantity which may exert a profound influence on the structure as a whole. In foundry practice one does actually find that this low melting, very brittle and weak eutectic influences cast iron to a remarkable degree since, as already explained, during the cooling down process it passes between the excess metal crystals, filling up all available space and thereby producing envelopes and pockets and weakening by separating the crystal structure to such an extent, especially when the casting is subjected to alternating temperatures in, say, a gas engine cylinder, that planes of cleavage developing into actual cracks are produced in the casting.

According to Stead * pure iron may retain in solid solution only about 1.7 per cent. phosphorus corresponding to 11 per cent. phosphide of iron (Fe_3 P.) and above this amount of phosphorus the phosphide separates as a eutectic whose melting point is 980 deg. C. In the case of the iron-carbon alloys, the carbon facilitates the separation of the phosphide eutectic as strikingly shown by Table II. which gives his results.

Position of Eutectic Experiment.

To illustrate further the structure of cast iron, the Author carried out some tests to determine the actual position of the constituents after complete cooling down had taken place.

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* Iron and Steel Inst. 1900.

Table II.—*The Influence of Carbon on the Condition of the Phosphorus in Iron Alloys.*

Carbon per cent.	Phosphorus per cent.		
	Free as Fe_3P.	In solution.	Total.
0.0	0.0	1.75	1.75
0.125	0.18	1.37	1.55
0.18	0.59	1.18	1.77
3.7	1.00	0.75	1.75
0.8	1.03	0.73	1.76
1.4	1.16	0.60	1.76
2.0	1.18	0.55	1.73
3.5	1.40	0.31	1.71

The tests were made on an approximate sphere of 2 in. diameter and successive layers of metal 1/16-in. thick were taken from off the outside until the centre core was reached.

In order to show more clearly the effect on this comparatively small test piece, it was cast in a chill mould, so that the rate of cooling on the outside would be rapid, whilst that at the centre, by removing the chill almost immediately after pouring, would be slower, thus giving conditions approximating to a heavier casting. The results, together with a record of the hardness in Brinell numbers are shown in Fig. 3. It will be seen that the phosphorus content given in terms of the element itself reached the figure of 1.15 per cent. in the centre, whilst it was only 0.97 per cent. towards the skin. The comparatively sharp rise immediately under the skin was due to the annealing of the test-piece for machining purposes which caused a migration of eutectic outwards due to the internal pressure produced in the casting as cast in the permanent iron mould. This pressure, thus given freedom of action by the annealing process, was so intense as to force some of the phosphide eutectic right through the skin, where it emerged from between the crystals and formed pellets on the outside of the casting. The effect of the annealing is also seen in the total carbon content at the skin, where slight oxidising conditions had decarburised the material.

A further test to determine the weakening effect of the phosphide eutectic was carried out on specimens taken from the further samples of spheres, as above, and designed for compression tests. The size of these test-pieces was 0.3183 in. dia. (one quarter in. sq.), and two diameters high, two being taken out of the side of the casting close to the skin, but clear of chilling effect, and two from the centre of the casting. A load of 40 tons was applied in each case, and the reduction in height measured. Table III gives the results on both sand-cast and permanent-mould cast samples, the reduction in height being shown as a percentage on the original height.

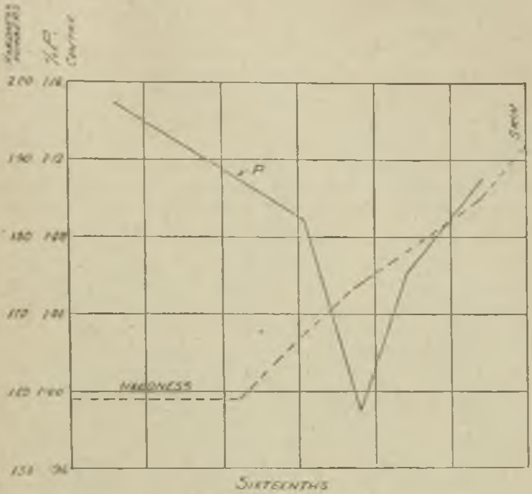

FIG. 3.

TABLE III.—*The Effect of Phosphide Eutectic on Compression Tests.*

	Sample taken from side of casting.	Sample taken from centre of casting.
Sand Cast ..	6.0% 6.4%	10.1% 9.0%
Chill Cast ..	5.2% 5.0%	6.4% 6.6%

Disposition of Silicide of Iron.

The disposition of the silicide of iron in a casting is also noted in Fig 4. Silicide of iron has the property of precipitating the graphite from its union with the iron, and since the lower density graphite occupies more space than the same carbon in combination, shrinkage and strains are reduced, producing sounder and stronger castings up to the point of the graphite precipitation being so great as to weaken the structure by undue separation of the crystal grains.

The element which has received the most attention from investigators of cast iron is carbon. This is rightly so, if only on account of the fact that the effects on most of the other components are produced indirectly through the carbon. Also the condition of the carbon compounds in cast iron is more than anything else responsible for the change of properties which may be brought about in cast iron, either mechanically, electrically or magnetically. In this it influences cast iron in precisely the same way as steel and a study of the properties of the various carbon compounds in steel directs one's investigation of cast iron at once along the right channels. In thus considering steel first, the hampering or partial masking effects of "foreign" components are reduced and conclusions closer to the truth can be arrived at.

Iron exists in several different allotropic forms accurately determined by the differences of temperature, and these limits are again influenced by the presence of "foreign" elements.

These changes can all be noted by careful observation of the cooling curve, and are usually more accurately determined by the differences of temperature method where the temperatures are read relative to that of a standard pure metal, usually platinum, cooling down under exactly the same conditions.

As mentioned when discussing cooling curves, certain of these change points, as they are sometimes called, occur at several temperatures, and certain of these points correspond to changes into various allotropic forms of iron. For simplicity the number of such allotropic forms are usually limited to three, gamma iron, above 900 deg. C., beta iron, between 780 deg. C. and 900 deg. C., and alpha iron, below 780 deg. C.

The various allotropic forms of iron also have differing magnetic and electrical properties along with mechanical differences, and it is the retention of the iron in any one of these states which constitutes the problem of producing steel with the particular properties sought. Of the three forms mentioned, the gamma variety is non-magnetic but, as seen, this property is lost when cooling below 900 deg. C. has taken place.

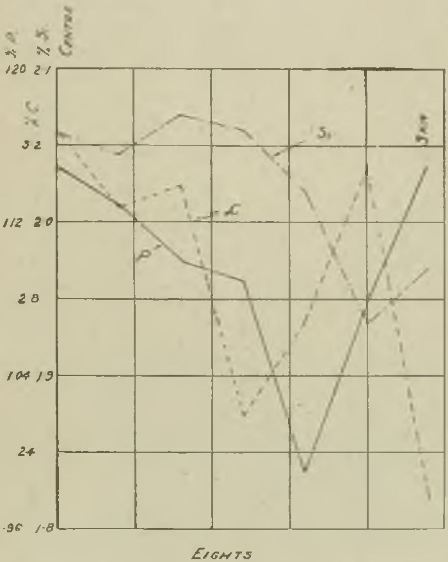

FIG. 4.

These temperatures, at which such profound changes take place, are greatly influenced by the presence of " impurities " or other elements, for example, an increase of carbon in pure iron up to 0.35 per cent. has been found to reduce the temperature at which the change from non-magnetic to the magnetic state occurs, to 760 deg. C.

This will give some idea of the extent to which these change points may be varied in a cast iron, where there may be as much as 0.8 per cent. combined carbon (the graphite not, of course, having any effect), as well as the other constituents usually present in cast iron. If the temperature at which the change from the non-magnetic to the magnetic state takes place can be further lowered, we may arrive at a point when this occurs at a temperature even below ordinary atmospheric temperatures.

The various iron compounds in cast iron, like those in steel, retain their general characteristics and properties when other elements are added, but the limiting temperatures of their existence may be greatly altered by those new elements.

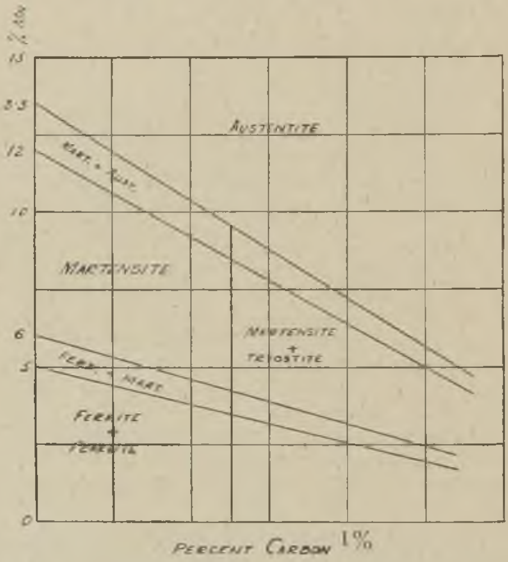

FIG. 5.—STRUCTURAL DIAGRAM FOR MANGANESE STEELS.

Osmond, Guertler and others have shown by their equilibrium diagrams that in a steel the critical change temperature from the non-magnetic to the magnetic state is lowered to about 200 deg. C. when the nickel content is raised to about 30 per cent., whilst under conditions of slow cooling both austenite and martensite may exist, both containing nickel in solid solution.

They found also that manganese acts somewhat similarly, but with about double the effect per cent. present. Chromium forms austenite or martensite with cementite, the carbide being very hard, whilst tungsten and molybdenum produce martensite and mixed cementites of carbide of iron and their own carbides.

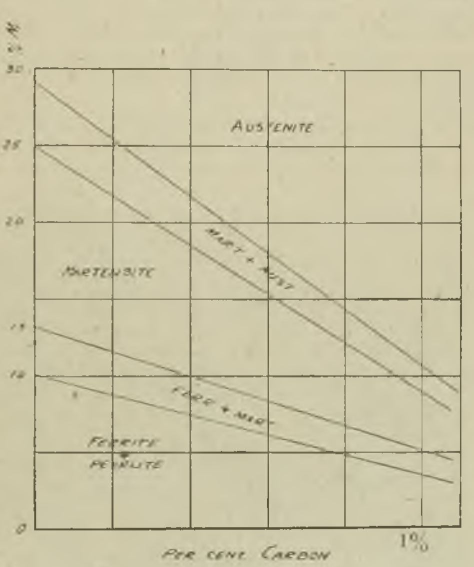

Fig. 6.—Structural Diagram for Nickel Steels.

The structural diagram by Guillet (Fig. 5) * shows the effect of manganese on carbon steels up to 1 per cent. carbon, whilst Fig. 6 † shows his diagram for nickel.

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* Gulliver, p. 325.
† Gulliver, p. 323.

All these considerations indicate that in order to produce a non-magnetic cast iron it is necessary to select as additional elements those which prevent or retard the change point to the greatest degree and also this effect will be very much different and perhaps more intense in the case of cast iron due to the effect of "impurities."

If we consider, for example, the addition of nickel to steel we note from Fig. 6 that about 25 per cent. would be required to produce the austenitic condition for low carbon steels, and from Fig. 5 that about 12 per cent. of manganese is required to have the same effect.

We should expect then in combination, that the effect would be produced by percentages which would total up to the equivalent of 25 per cent. nickel.

The position is somewhat obscure in the case of cast iron, but that the complete change can be brought about is evidenced by the various non-magnetic castings shown in the illustrations.

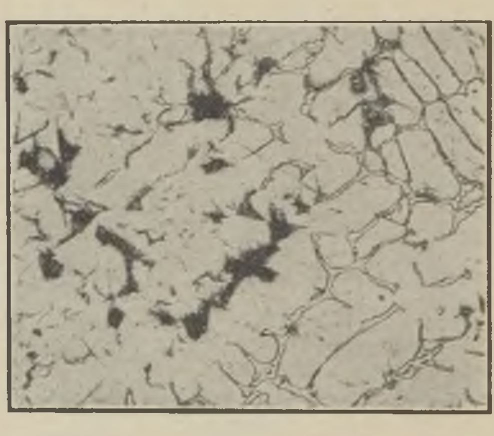

FIG. 7.—STRUCTURE OF NON-MAGNETIC CAST IRON SHOWING AUSTENITIC AREA × 220.

In this material the change point has been so effectively lowered that on subjecting it to the temperature of liquid air only a slight degree of magnetic permeability is obtained.

To determine now the extent to which the electrical and magnetic properties of cast iron might be turned to account the essential facts relating to magnetism as applied in the electrical industry must be considered.

It is well known that an electric current flowing in a conductor produces a magnetic force or field in the surrounding space. For practical and calculating purposes this force is represented by lines known as magnetic flux lines drawn in the direction of the force. This direction is at right-angles to the flow of current. The density of these lines indicates the strength of the magnetic field. Such flux lines form in all materials and substances, including air, but some materials offer much greater resistance to the lines than others—that is, their magnetic conductivity is less. This conductivity for any material is expressed by comparison with the magnetic conductivity of air. The ratio of the conductivity of the material to that of air is known as the permeability of that material. The permeability of air is taken as unity.

The permeability of cast iron, for example, is approximately 330, so that for a given current or magnetising force the magnetic field will be 330 times as strong in cast iron as in air. If a non-magnetic material such as brass, tin, wood or non-magnetic cast iron be placed in a magnetic field, the density and direction of the flux lines will be unaltered, as it would through air, but if a piece of iron or steel be substituted, the strength of the field will be increased by an amount depending on the permeability of that material.

By one of the fundamental electrical laws, a changing magnetic field produces an electric-motive force (E.M.F.) or electrical pressure. If the flux lines pass through a material which is an electrical conductor, the E.M.F. so produced will set up circulating currents depending on the resistance of the material in accordance with ohms law. These are known as eddy currents, and they cause a watts power loss in the material which is dissipated in the form of heat. This loss will depend on the electrical resistance of the material and the strength of the magnetic field,

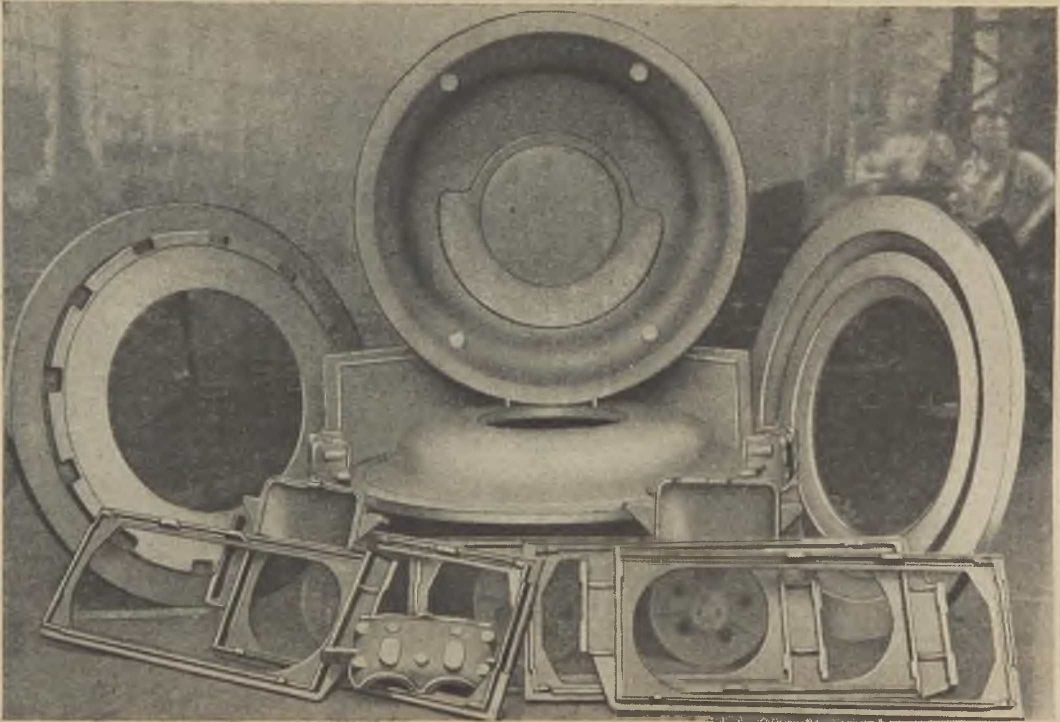

Fig. 8.—Group of End-Plates and Switch Gear Castings in Non-Magnetic Iron.

and hence on the permeability, and may seriously affect the efficiency of electrical machinery, giving rise to excessive heating with consequent loss of energy.

If the varying flux lines pass through a magnetic material (that is, permeability greater than 1), a certain amount of energy is required to change the direction of the lines. This energy loss is known as hysterisis loss, and exists in addition to the eddy current loss just described.

Electrical generators, motors, transformers, and all electro-magnetic machinery depend for their operation on the production of the magnetic field. So far as possible this magnetic field is controlled, and the flux lines are confined to the desired paths, but since there is no magnetic insulator or material opaque to a magnetic field (that is, no materials have a permeability of zero), it is not possible to do this completely. For this reason, and also because magnetic flux lines surround every conductor carrying current, there will be magnetic fields not only in the paths desired and provided, but also in the neighbouring places. Such magnetic fields are usually known as stray or leakage fields. The eddy current and hysterisis losses due to these fields decrease the efficiency, and frequently cause excessive heating in electrical machines of all kinds.

We thus see that non-magnetic iron with its unity permeability and high resistance gives a combination of properties which does not exist in any other metal or material, and is most useful in the manufacture of cable bushes, switch covers, busbar clamps, sealing bells, terminal supports, generator and motor end plates, insulator carriers and holders, etc.

These characteristics of non-magnetic cast iron are clearly seen in Table IV, shown in comparison with ordinary grey cast iron and brass.

Its high resistance also makes it admirably suitable for resistance grids, and its toughness, as shown by the Izod test* (which is 29 ft.-lbs. as compared with 14 ft.-lbs. for ordinary cast iron†), gives a grid capable of withstanding mechanical

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* Taken on Test Bar. 20 m.m. × 20 m.m. × 70 m.m.

† Silicon 1.8% ; phosphorus 0.46% ; tensile 14.9 tons per sq. in

shocks which it may receive in service and in handling to a remarkable degree.

Table IV.—*The Magnetic Characteristics of Cast Iron, "Nomag," and Brass.*

	Magnetic Permeability Maximum.	Specific Resistance. Micro-ohms. per cm. cube.
Ordinary cast iron	330.00	95.0
"Nomag" ..	1.03	140.0
Brass	1.00	7.5

These grids are used for various purposes in electrical engineering, chiefly as a means of regulating current values and for starting and controlling the speed of motors. For all kinds of traction work, railway, tramway and crane motors, etc., where starting, stopping, and speed variation is a frequent occurrence, resistance grids play an important part in electrical control. For this class of work the grids, in addition to having high resistance, must be very strong mechanically to withstand rough usage. The electrical resistance should not vary with the temperature—that is, the resistance temperature coefficient should be small.

In addition to its mechanical advantages, non-magnetic cast iron combines high resistance with low temperature coefficient to an exceptional degree. The resistance temperature coefficient for "Nomag," for example, is 0.09 per cent. per deg. C., as compared with 0.19 per cent. per deg. C. for ordinary cast iron.

Such grids made in non-magnetic cast iron of high electrical resistance are now in use in most of our principal tramway systems, and since their extra 40 per cent. resistance allows of (a) less grids being used, (b) thicker sections being employed, and (c) shorter paths between terminals, they result in a better air circulation, with consequently better removal of the heat produced, or a more robust grid.

An actual service test on such grids carried out at one of our most important and hilly tramway undertakings showed that, as already stated, the resistance did not increase with temperature to the same extent as ordinary cast iron grids did; in fact, after running the car on the resistance notch for long periods until the boxes were hot, no appreciable difference could be detected when feeding up on the controller. This is especially useful when a large number of stops have to be made, when bad acceleration is usually experienced due to the varying resistance.

FIG. 9.—ALTERNATOR END RING IN NON-MAGNETIC CAST IRON. IT WEIGHS 3 TONS 12 CWT.

As regards the effect on magnetic property of the so-called "impurities" in cast iron, Goltze says that combined carbon and manganese tend to decrease the permeability, although both silicon and manganese tend to increase the resistance. Nathusius in 1905 carried out a number of tests on a series of cast iron with varying combined carbon content, and found that the low combined carbon and high silicon raised the permeability. His figures were:—

				Induction at ampere turns per cm.			
	C.C.	C. Gr.	Si.	25	50	100	200
1. ..	0.24	3.19	2.83	7,100	9,200	11,200	12,900
2. ..	0.82	2.47	2.11	5,900	7,500	9,200	11,300

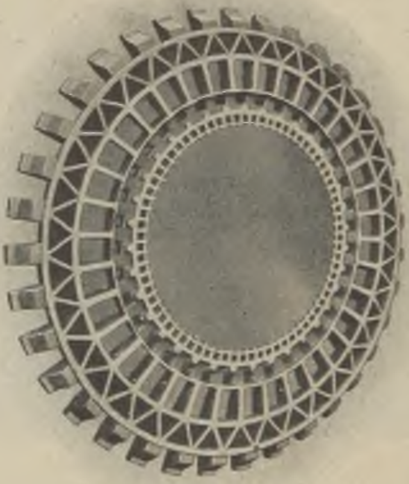

Fig. 10.—Alternator End Ring in Non-Magnetic Cast Iron. Its dia. is 5 ft. 6 ins.

Although the above figures do not indicate directly the permeability, yet the induction figures shown are proportional to permeability, and in the absence of a constant not indicated by Goltze, they do not represent absolute permeability, but they indicate on plotting that the higher combined carbon cast iron has regularly lower permeability for each of the currents indicated. Goltze also states that phosphorus and sulphur have no influence on this factor.

The coefficient of expansion of non-magnetic cast iron is somewhat higher than ordinary cast iron, and more nearly corresponds to that of mild steel. The relative figures on a given size of test-piece are shown in Table V.

TABLE V.—*Coefficient of Expansion of Various Alloys.*

Ordinary cast-iron	9.6 × 10^{-6} per 0° C.
Mild steel	11.0 × 10^{-6} per 0° C.
Brass	23.3 × 10^{-6} per 0° C.
Non-magnetic cast-iron	11.9 × 10^{-6} per 0° C.

APPENDIX.

During the progress of the lecture the magnetic and electrical properties of non-magnetic cast iron were demonstrated by means of various instruments, the most important being as follows:—

1. Solonoid. Bars of non-magnetic iron, brass and ordinary grey cast iron were successively placed in a powerful magnetic field set up by passing an electric current round a copper wire coil provided with a soft iron plate at one end. The ordinary cast-iron bar could not be removed from the plate until the current was switched off, whilst the other bars were not in the least attracted by the plate.
2. Permeameter. The current produced when the magnetic lines of force were quickly cut by drawing a bar of ordinary cast iron from a copper wire coil placed across the poles of the magnet were very clearly demonstrated on a galvanometer attached to the coil. No movement was observed when a brass or non-magnetic cast-iron bar was so used.
3. Faraday's Experiment. A disc made from a low-resistance material such as copper when spun between the poles of a magnet experiences a speed-retarding effect due to the reaction of the eddy-currents set up in the disc. The suppression of the eddy-currents by a high-resistance material such as non-

magnetic cast iron decreases this retarding effect, and was suitably demonstrated by two discs running on the shaft of a small motor. By interposing a magnet round the copper disc the motor was practically stopped, whilst there was little effect when placed round the non-magnetic high-resistance cast iron.

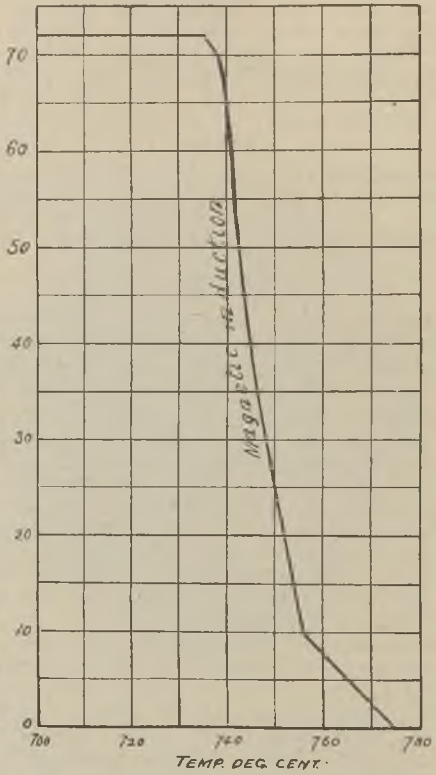

FIG. 11.—MAGNETIC VARIATION IN STEEL DUE TO TEMPERATURE. ITS COMPOSITION IS C, 0.65; SI, 0.094; MN, 0.33; S, 0.008; AND P, 0.017 PER CENT.

Several bars of non-magnetic cast iron plated with nickel, copper, and chromium were also shown, indicating by their particularly high finish the ease with which this material submitted to the ordinary plating processes.

An interesting practical use of the change from the magnetic to the non-magnetic condition of steel, and utilised by the Automatic and Electrical Furnaces, Limited, in their special heat-treatment plant, was described. The recalescence point or change of structure (and consequently "temper") is observed on a delicate galvanometer, which indicates the magnetic change point of the steel. Fig. 11 shows such a test taken on a sample steel.

DISCUSSION.

The Chairman (Mr. R. A. Miles) said they could all appreciate the trouble which Mr. Dawson had gone to in preparing this lecture. He was not, like most men, content with things as they were; he wanted them to be better, and with that object pushed his investigations to the furthest limits in order to learn all that was possible about the materials he used, and to put the knowledge so acquired to practical use. Other members had not the same opportunities. Mr. Dawson was fortunate in that he was in the service of an eminently scientific firm, who must appreciate his efforts to produce material suitable for a particular class of work and also less costly than that used by other firms for the same purpose.

Mr. J. S. Primrose sympathised with Mr. Dawson's comments on the indiscriminate fashion in which samples of pig or cast iron were taken for analysis. He quoted an instance which had happened during the war when he had been interested in the manufacture of some cast-iron "guns" for depth-charge throwing by the Navy. As the explosive force had to be directed round two right angles, the authorities had at first prescribed only 0.1 per cent. phosphorus in the iron, but finally agreed to accept 1.0 per cent. P. The mixing of the charge was under proper control, and ladle samples showed not more than 0.8 per cent. phosphorus. Although the 9.5-in. guns satisfactorily withstood the severe hydraulic test, they were all at first rejected on the ground that the analysis showed from 1.2 to 1.3 per cent. phosphorus. The reason for this was that the sample for analysis had been taken by the officials concerned from the centre of a 4-in. cube of the same metal which had to be cast with each gun and forwarded to the Sheffield test house. It was a considerable time before the proper method of sampling was adopted, and then all the castings were accepted.

The cooling curves of alloys were undoubtedly important for the information they gave; but the speaker considered the difference of temperature referred to by Mr. Dawson, *i.e.*, between the hot specimen and a neutral body, was really of no use for constructing a graph unless one also knew the actual temperatures at which these differences occurred.

Nickel in Cast Iron.

He had been specially interested in what Mr. Dawson had had to say on the effect of nickel on cast iron. At one time he had examined the effect of 18 per cent. of nickel on pig-iron and found it had precipitated nearly all the carbon in the form of very curly graphite, of which he had always been a strong advocate. When melted in a cupola charge to give about 6 per cent. of nickel in the resulting cast iron the graphite flakes were no longer curly, and the ground mass was composed of ferrite, in which the nickel as well as the 2.6 per cent. of silicon was dissolved, and surrounding this was an almost continuous meshwork of sorbitic pearlite. This made a very strong structure, and even the fins of metal were pliable when they came to be removed during the fettling operation.

This was no doubt a lower percentage of nickel than that used by Mr. Dawson, who aimed at the austenite-graphite structure, as shown by his photo-micrograph of Nomag metal (Fig. 8). Such a material might be called an alloy, but it certainly was not cast iron, for the first property of iron was that it was magnetic. The remarkable thing was that such material could be easily machined without annealing. It was also noteworthy that dipping this material into liquid air did not alter its structure and restore a state of magnetic constituents. He had found that certain manganese steels which, even when annealed, were perfectly hard—unmachinable in fact, and quite non-magnetic, with a martensite-austenite structure—had been rendered soft, perfectly magnetic, and largely sorbitic in structure by a short immersion in liquid air. This was a reversible transformation, but evidently the nickel used had been sufficient to render the iron alloy one with an irreversible constitution.

Vote of Thanks.

At the invitation of the Chairman, Mr. Field, of the Birmingham Branch, addressed the meeting. He said he had not come as a delegate, but he was sure if his fellow-members had known that he was coming they would have sent their cordial greetings to the Lancashire Branch. He was particularly pleased that he had been asked by the Chairman to move a vote of thanks to Mr. Dawson for this Paper, which embodied a great deal of technical matter on a most difficult subject. Mr. Dawson had explained it lucidly, but he had not conveyed to the minds of the members an adequate conception of the amount of work which had to be done to obtain the results shown by him. Years of study and work must have preceded it; quite a number of experiments and failures must have led up to the discovery of the successful method the explanation of which had been given in a lecture of less than two hours' duration. In these days the requirements made on foundry firms were becoming more exacting. He had even known them to be asked to produce castings which would be magnetic under certain circumstances and non-magnetic under other circumstances. They were expected to do much more than their forefathers did. So he was glad to have had the opportunity of being present and hearing Mr. Dawson put before the members material which would have a great effect on a large part of the work of the ironfounder, not only in connection with the electrical industries, but also to a large extent in constructional work. He would be very glad if Mr. Dawson would give a similar lecture before the members of the Birmingham Branch.

Mr. Masters, in seconding the vote of thanks, said quite recently the question of phosphide in iron was brought emphatically to his mind in connection with the casting of a hammer block. There was an oxidation on the plate of metal half an inch thick. The metal was quite stiff on the outside. He did not have it analysed, but from what Mr. Dawson had said he gathered that it was phosphide eutectic or phosphide of iron.

The vote of thanks was passed unanimously.

The Author's Reply.

In replying, MR. DAWSON said the addition of nickel to cast iron was being advocated for motor cylinders and other similar work when it was claimed that softness, together with closeness of grain and toughness, was obtained. The percentage added for this purpose varied between 1.0 and 3.0 per cent.

The effect of nickel on cast iron is similar to that of silicon (although probably not so strong) in that it precipitates the graphite, and also probably tends to reduce total carbon. For example, a cast iron with a total carbon of 3.89 per cent. showed 2.85 per cent. graphite with 0.87 per cent. nickel, 2.01 per cent. with 1.25 per cent. nickel, and 3.12 per cent. graphite with 5 per cent. nickel.*

Cobalt does not seem to have any effect on the carbon in this way. As regards magnetic effect, it acts in the opposite sense to nickel, and increases the permeability and hysteresis. Hence its use as an addition to magnet steels.

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* Bauer.

THE INSTITUTE OF BRITISH FOUNDRYMEN.

LIST OF MEMBERS.

September, 1925.

B.—Birmingham and West Midlands Branch.
E.M.—East Midlands Branch.
Lncs.—Lancashire Branch.
L.—London 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.
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.
N.	1921.	Armstrong-Whitworth & Co., Ltd., Sir W. G. (Subscribing Firm), Close Works, Gateshead-on-Tyne.

B'nch.	Year of Election.	MEMBERS.
N.	1920.	Arrowsmith, J. K., 4, Dean Road, South Shields.
Lncs.	1924.	Arstall, J., "Kenmarlean," Back, Bowes, 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.
—	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.
E.M.	1921.	Bates, W. R., United Steel Companies, Limited, Irthlingboro' Iron Works, Wellingboro'.
W. & M.	1922.	Bayley, J. P., "Ty-gwyn," Clytha Park, Newport, Mon.
L.	1920.	Beech, A. S., 97, Queen Victoria Street, London, E.C.
S.	1922.	Bell, G. S., 7, Hill Side, South Park, Lincoln.
Sc.	1910.	Bell, W., 1, George Street, Airdrie.
—	1922.	Bell, Wm. Dixon, 72, Avenue Road, Itchen, Southampton.
L.	1919.	Benbow, M., "Omborsley," Carrington Road, Dartford, Kent.

B'nch.	Year of Election.	MEMBERS.
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.
—	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.
—	1912.	Boote, E. M., 11, Lydgate Road, Coventry.
L.	1912.	Booth, C. C., Mildmay Works, Burnham-on-Crouch.
E.M.	1919.	Booth, J. H., Fletton Spring House, Peterborough.
L.	1920.	Booth, P. M., 4, 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., 20, St. Andrew's Road, Sharrow, Sheffield.
Lncs.	1914.	Bridge, W., 199, Drake Street, Rochdale, Lancs.
S.	1922.	Brightside Foundry Engineering Co., Ltd. (Subscribing Firm), Wicker Works, Sheffield.

B'nch	Year of Election.	MEMBERS.
Lncs.	1919.	Broad, W., 230, Dumers Lane, Radcliffe, Lancs.
S.	1922.	Brown, E. J., 11, Newlyn Place, Woodseats, Sheffield.
L.	1921.	Brown, E. R., "Roze" Dickley Hill, Harrietsham.
Sc.	1918.	Brown, N. M., Bogston, Greenock.
W.R. of Y.	1917.	Brown, P., Park Works, Lockwood, Huddersfield.
S.	1919.	Brown, P. B., 12, Gladstone Road, Sheffield.
W.R. of Y.	1922.	Brown, S. C., 12, Gledlow Wood Avenue, Roundhay, Leeds.
Lncs.	1924.	Bruce, A., "Rose Bank," Swanpool Lane, Aughton, Ormskirk, Lancs.
—	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., 27, Station Road, Prescot, Lancs.
E.M.	1910.	Bunting, H., 17, Marcus Street, Derby.
E.M.	1905.	Burder K. M., "Clavering," Ashby Road, Loughboro'.
B.	1922.	Burn, A. J. H., 34, Old Road, Llanelly, S. Wales.
W.R. of Y.	1922.	Burnley, H., Norcroft Foundry, Lister Hills, Bradford, Yorks.
S.	1923.	Butler, J., 63, Deepdale Road, Rother ham.
Lncs.	1918.	Butler, W., Borough Brass & Iron Works, Dukinfield, Manchester.
—	1909.	Caddick, A. J., 83, Borough Road, Middlesborough.
Sc.	1917.	Cameron, J. (Cameron & Roberton, Limited), Kirkintilloch.
Sc.	1919.	Cameron, T. P., (Cameron and Roberton, Ltd.), Kirkintilloch.
S.	1922.	Cammell Laird & Co., Ltd. (Subscribing Firm), Cyclops Steel and Iron Works, Sheffield.

B'nch.	Year of Election.	MEMBERS.
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.
Lncs.	1921.	Castle, Geo. Cyril, "Lindeth," Victoria Park, Wavertree, Liverpool.
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.
—	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.
Lncs.	1919.	Clayton, T., 14, Stansfield Street, Rose Grove, Burnley, Lancs.
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.

B'nch.	Year of Election.	MEMBERS.
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.
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.
Sc.	1922.	Couper, J. C., Milton House, Dunnipace, Denny.
Lncs.	1924.	Cowlishaw, S. D., 7, Temple Street, Basford, Stoke-on-Trent.
E.M.	1914.	Cox, J. E. (The Rutland Foundry Company, Limited), Ilkeston.
—	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.

B'nch.	Year of Election.	MEMBERS.
B.	1921.	Danks, A., "Northfield," Hucclecote, Gloucester.
—	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., 98, Bramhall Lane, Davenport, Stockport.
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.
N.	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.
—	1921.	Dicken, Charles H., 2, Ash Street. Daisy Bank, Bilston.
L.	1922.	Dickson, J., Mitcham Foundry, Evelyn Road, Mitcham, Surrey.
S.	1924.	Didden, F. G. J., 170/174, Attercliffe Road, Sheffield.
L.	1914.	Dobson, W. E., "Newlyn," Grand Drive, Raynes Park, S.W.
Lncs.	1918.	Doughty, E., 54, St. Mary's Road, Moston, Manchester.
Sc.	1911.	Doulton, B. (Life), 3, Berrylands, Surbiton, Surrey.
L.	1923.	Downing, D., c/o The Indian Iron & Steel Co., Hirapur Works, Asansol, E.I.R., India.
S.	1921.	Duckenfield, W., 47, Dunkeld Road, Ecclesall, Sheffield.

B'nch	Year of Election.	MEMBERS.
W.R. of Y.	1922.	Duckham, W. J., 4, Oxford Villas, Guiseley, Leeds.
L.	1925.	Durnan, F., 43, Grove Road, Millhouses, Sheffield.
S.	1921.	Edginton, G., Silverdale, St.Margaret's Drive, Chesterfield.
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., 6, Eckstein Road, Clapham Junction, London, S.W.11.
S.	1918.	Elliss, J. A., 217, Middlewood Road, Sheffield.
S.	1913.	Else, L. H., 79, Osborne Road, Sheffield.
Lncs.	1925.	English, J., 14, Malvern Street, Coppice, Oldham.
L.	1919.	Estep, H. Cole, The Penton Publishing Co., Penton Building, Cleveland, Ohio, U.S.A.
E.M.	1918.	Evans, W. T., Mount Pleasant, Sunny Hill, Normanton.
S.	1920.	Fairholme, F. C., Churchdale Hall, nr. Bakewell, Derbyshire.
L.	1908.	Faulkner, V. C., Bessemer House, 6, Duke Street, Adelphi, 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., Prior Bank, Cherry Tree Road, Sheffield.
S.	1914.	Firth, F. W., "Storth Oaks," Ranmoor, Sheffield.
—	1907.	Flagg, S. G. (Honorary), 1,407, Morris Buildings, Philadelphia, Penn, U.S.A.

Bnc'h	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.
S.	1921.	Flower, J. A., 147, Middlewood Road, Sheffield.
W. & M.	1907.	Fontaine, C., Dock Foundry, Newport, Mon.
Sc.	1917.	Forbes, J. T., 176, West George Street, Glasgow.
N.	1919.	Fortune, T. C., 76, Falmouth Road, Heaton, Newcastle-on-Tyne.
B.	1919.	Fosseprez, G., 3, Rue du Grand Jour, Mons, Belgium.
—	1920.	Foston, G. H., Ivy Bank, Balsall Common, Berkswell, nr. 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.
Lncs.	1922.	Garner & Sons, Limited (Subscribing Firm), Victoria Street, Openshaw, Manchester.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1922.	Garnett, N., Bury New Road, Kersal, Manchester.
Lncs.	1919.	Gartside, F., 18, George Street, Chadderton, Lancs.
W. & M.	1916.	Gibbon, O. R.
L.	1922.	Gibbs, A. F., 55, Gordon Road, Wanstead.
N.	1925.	Gill, C. S., Westbank, Consett, County Durham.
Sc.	1920.	Gillespie, P., "Glenora," Falkirk Road, Bonnybridge.
E.M.	1915.	Gimson, H., "Rhoscolyn," Toller Road, Leicester.
E.M.	1906.	Gimson, S. A., 20, Glebe Street, Leicester.
—	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.
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.
Lncs.	1920.	Grant, G. C. (Sir W. G. Armstrong, Whitworth & Company, Limited), Ashton Road, Openshaw, Manchester.
N.	1921.	Gray, C. R., 14, Latimer Street, Tynemouth.
L.	1920.	Gray S., 29, Crescent Road, London, S.E.
N.	1912.	Greensitt, R. H., 24, Stuart Terrace, Felling-on-Tyne.
E.M.	1920.	Greenwood, R., The International Combustion Engineering Co., Derby.

B'nch.	Year of Election.	MEMBERS.
N.	1917.	Gresty, C., 93, Queen's Road, Monkseaton.
W. & M.	1906.	Griffiths, H., 70, Partridge Road, Cardiff.
Lncs.	1923.	Grundy, Ltd., John (Subscribing Firm), Tyldesley, Lancs.
S.	1920.	Gummer, G., junr., 1, Moorgate Terrace, Rotherham.
S.	1910.	Hadfield, Sir R. A. (Hon.), Hadfields, Limited, Hecla Works, Sheffield.
Lncs.	1906.	Haigh, J., 9, Bradford Road, 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.
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.
Lncs.	1924.	Hardy, W., 36, Ribblesdale Place, Preston.
S.	1925.	Hardwick, H., Cemetery Road, Dronfield, nr. Sheffield.
L.	1921.	Harford, A. E., Capt., 85, Sumatra Road, West Hampstead, N.W.6.
—	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.
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.

B'nch	Year of Election.	MEMBERS.
N.	1921.	Hawthorn, Leslie & Company, R. & W. (Subscribing Firm), St. Peter's Works, Newcastle-on-Tyne.
Lncs.	1918.	Helm, R. W., c/o Francis Helm, Ltd., Victoria Foundry, Padiham, Lancs.
W.R. of Y.	1924.	Henry, Ltd., Joseph (Subscribing Firm), Manor Road, Holbeck, Leeds.
Lncs.	1923.	Hensman, A. R., 121, Plymouth Grove, Charlton-on-Medlock, Manchester.
N.	1913.	Herbst, M. B., 23, Saltwell View, Gateshead-on-Tyne.
Sc.	1917.	Hetherington, R., 105, West George Street, Glasgow.
W. & M.	1912.	Hird, B., "Woodcot," Upper Cwmbran, nr. Newport, Mon.
L.	1923.	Hobbs, F. W. G., Standard Brass Foundry, P.O. Box 229, Benoni, Transvaal, S.A.
Sc.	1919.	Hodgart, H. M., Vulcan Works, Paisley.
Lncs.	1923.	Hodgkinson, A., Ford Lane Works, Pendleton, Manchester.
Lncs.	1914.	Hodgson, A., 14, Park Range, Victoria Park, Manchester.
N.	1922.	Hodgson, G. W., 2, Beechwood Terrace, Sunderland.
Lncs.	1912.	Hogg, J., 365, Manchester Road, Burnley, Lancs.
W.R. of Y.	1922.	Holehouse, T. R., 14, Tower Road, Saltaire, Yorks.
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.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1922.	Howard & Bullough, Ltd. (Subscribing Firm), Accrington, Lancs.
S.	1918.	Hoyle, J. R. (Thos. Firth & Sons, Limited), Norfolk Works, Sheffield.
W.R. of Y.	1922.	Hull, T. E., 26, Macaulay Road, Birkby, Huddersfield.
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.
L.	1914.	Hurst, J. E., Centrifugal Castings, Ltd., Kilmarnock.
L.	1925.	Hutton, R. S., 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.
S.	1915.	Jackson, L., 2, Richmond Avenue, Park Lane, Sheffield.
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.

B'nch.	Year of Election.	MEMBERS.
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.
Lncs.	1922.	Jubbs, J. R., 71, Edward Street, Lower Broughton, Manchester.
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.
L.	1917.	Kesterton, Art., 151A, Englefield Road, Essex Road, N.1.
Lncs.	1907.	Key, A. L., 271, Reddish Road, S. Reddish, Stockport.
Sc.	1914.	King, D., Keppock Ironworks, Possi Park, Glasgow.
Sc.	1904.	King, J., 100, Wellington Street, Glasgow.
W. & M.	1924.	Kinsman, W. S., 116, Miskin Street, Cardiff.
Sc.	1919.	Kinnaird, George, 21, St. Ann's Drive, Giffnock, Glasgow.
S.	1925.	Kitching, W. T., c/o John Fowler, Don Foundry, Sheffield.
L.	1922.	Lake, W. B., Mount Place, Braintree, Essex.

B'nch.	Year of Election.	MEMBERS.
L.	1921.	Lambert, Wesley, J. Stone & Co., Limited, Deptford, S.E.
Sc.	1907.	Landale, D. (Life), 36, Great King Street, Edinburgh.
—	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.
S.	1913.	Little, J., 20, St. Ann's Square, Manchester.
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.

B'nch	Year of Election.	MEMBERS.
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.
Lncs.	1917.	Makemson, T., 21, Beresford Road, Stretford, Manchester.
S.	1921.	Mander, T. G., Norris Deakin Buildings, King Street, Sheffield.
Lncs.	1922.	Markham, C., "Ringwood," near Chesterfield.
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.
Lncs.	1923.	Marsden, F., 126, Hale Road, Hale, Lancs.
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.

B'nch.	Year of Election.	MEMBERS.
L.	1923.	Maybrey, H. J., B.A., D.I.C., 22a Gloucester Road, South Kensington, S.W.7.
Sc.	1918.	Mayer, T.
N.	1921.	Mayhew, C. M., 28, Grindon Terrace, Sunderland.
Sc.	1925.	McArthur, J., "Hawthorn," Shields Road, Motherwell.
W. & M.	1922.	McClelland, J. J., "Druslyn," Bishops Road, Whitechurch, 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.
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., 72, Elliott Street, Tyldesley, nr. Manchester.
Lncs.	1919.	Medcalf, W., 265, Manchester Road, Burnley, Lancs.

B'nch.	Year of Election.	MEMBERS.
L.	1922.	Melmoth, F. A., Fairmont, Coggeshall Road, Braintree, Essex.
L.	1920.	Melville, A. C., F.I.C.
Lncs.	1912.	Milburn, J., Hawkshead Engineering Works, Workington.
—	1919.	Miles, F. W.
S.	1921.	Miles (Major), R., Chapeltown, nr. Sheffield.
Lncs.	1916.	Miles, Rd. A., 46, Dean Lane, Newton Heath, Manchester.
Sc.	1921.	Millar, A. C., Parkview, Dalry, Ayrshire.
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). New York.
E.M.	1914.	Moore, H. H., Holmwood, Leicester Road, Loughborough.
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.
S.	1918.	Newell, Ernest, M.I.Mech.E., The Thorne, Misterton, *via* Doncaster.
N.	1912.	Newton, J. W., 19, Waverley Terrace, 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.

B'nch.	Year of Election.	MEMBERS.
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.
W.R. of Y.	1922.	Nuttall, H., Spring Edge, Halifax.
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., "The Drive," Nightingale Lane, Wandsworth Common, S.W.
L.	1919.	Otto, C. A., 22, Owenite Street, Abbey Wood, S.E.
—	1918.	Oubridge, W. A., A.M.I.M.E. (British Piston Ring Company, Limited), Holbrook Lane, Coventry.
S.	1921.	Oxley, G. H., Norton Grange, nr. Sheffield.
S.	1915.	Oxley, G. L., Vulcan Foundry, Attercliffe, Sheffield.
S.	1910.	Oxley, W., Vulcan Foundry, Attercliffe, Sheffield.
W. & M.	1924.	Padfield, S. J. C., 70, Caeron Road, Newport, Mon.
N.	1921.	Palmer's Shipbuilding & Iron Company Ltd. (Subscribing Firm), Hebburn-on-Tyne.

B'nch.	Year of Election.	MEMBERS.
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.
L.	1922.	Patchin, Geo., A.R.S.M., "Ashdene," Furzefield Road, Beaconsfield.
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., 100, Rosegrove Lane, Rosegrove, Burnley, Lancs.
Lncs.	1922.	Pellatt, D. L., 43, Hawthorn Road, Deane, Bolton.
S.	1924.	Pennington, A. H., 44, Dovercourt Road, Sheffield.
E.M.	1918.	Perkins, J. E. S., "Hillmorton," The Park, Peterborough.
—	1920.	Perks, C., Phœnix Castings, Ltd., Coventry.
Lncs.	1919.	Perryman, W., 17, Hurst Street, Bury.

Bnc'h.	Year of Election.	MEMBERS.
Lncs.	1922.	Place, J. H., "Girsie," 258, Manchester Road, Burnley.
—	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.
W.R. of Y.	1922.	Poole, W. H., Kings Grove, Villa Road, Bingley, Bradford.
Sc.	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., 47, Baird Street, Camelon, Falkirk.
B.	1924.	Pritchard, P., "Eastcote," St. Agnes Road, Moseley, Birmingham.
E.M.	1904.	Pulsford, F. C., "Kenmore," Sandown Road, Leicester.
N.	1917.	Punshon, J. J., 13, Longley Street, Newcastle-on-Tyne.
—	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.
Lncs.	1919.	Ranicar, W., 1, Parr Street, Tyldesley, Lancs.
Sc.	1923.	Rattray, W. J., c/o Burns & Co., Ltd., Howrah, Bengal, India.

B'nch	Year of Election.	MEMBERS.
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.	Reid, A. G., 15, Albany Terrace, Springboig, Shettleston, N.B.
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.
Lncs.	1919.	Richardson, W. B., Hope Foundry, Farnworth, nr. Bolton.
Sc.	1911.	Riddell, M., Dungoyne, 35, Aytoun Road, Pollokshields, Glasgow.
B.	1923.	Roberts, E., 39, Radford Road, Leamington.
—	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.	Robinson, S., Leafield, Derby Road, Widnes.
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.
S.	1918.	Russell, F., c/o General Refractories Company, Limited, Kelham Island, Sheffield.
E.M.	1924.	Russell, P. A., 88, Dulverton Road, Leicester.

B'nch	Year of Election.	MEMBERS.
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).
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.
N.	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.
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.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1924.	Simpson, H., 99, Peel Street, Rochdale.
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.
B.	1919.	Smith, C. R., "Milverton House," Riches Street, Wolverhampton.
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.
Sc.	1920.	Smith, J. C. J., 25, Cluny Drive, Edinburgh.
N.	1917.	Smith, J. E., 7, Lily Avenue, Jesmond, Newcastle.
W.R. of Y.	1922.	Smith, J. W., 96, Beech Grove, Clayton Road, Bradford.
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.

B'nch.	Year of Election.	MEMBERS.
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.
N.	1921.	Stothard, A., 66, Highbury, Newcastle-on-Tyne.
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.
W.R. of Y.	1922.	Summerscales, W. H. G., Rockfield, Keighley.
W.R. of Y.	1919.	Summersgill, H., Stanacre Foundry, Wapping Road, Bradford.
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.
Lncs.	1924.	Taylor, A., 84, Hornby Road, Blackpool.

B'nch.	Year of Election.	MEMBERS.
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.
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.
W.R. of Y.	1906.	Thwaites Bros., Limited, Vulcan Iron Works, Bradford.
—	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.
L.	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.
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.
N.	1914.	Vardy, G., M.B.E., The Pines, Hill Brow Street, nr. Petersfield.

B'nch.	Year of Election.	MEMBERS.
—	1922.	Varlet, J. (Hon.), Esperance Longdoz Works, Liège, Belgium.
S.	1924.	Varma, J. P., 48, Peveril Road, 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.
Lncs.	1924.	Walker, J. S.A., Major, Walker Bros., Ltd. Wigan.
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'nch.	Year of Election.	MEMBERS.
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., Sociedad Española de Construcion Naval. el Arsenal, Apartudo, No. 1, Ferrol, Spain.
S.	1910.	Wells, G. E. (Edgar Allen & Co., Limited), Imperial Steel Works, Sheffield.
S.	1914.	Wells, J. A. E., Moorlands, Ringinglow Road, Sheffield.
S.	1921.	Wharton, E., Rosemont, Station Road, Brimington, Chesterfield.
N.	1913.	Wharton, J., Maryport, Cumberland.
S.	1920.	Wheddon, A. L., 33, Osborne Street, Winshill, Burton-on-Trent.
S.	1916.	Whiteley, A., 7, Glen Road, Nether Edge, Sheffield.
Lncs.	1910.	Whittaker, C. & Company, Limited Dowry Street Ironworks, Accrington.
B..	1922.	Whyte, D., 8, Vale View, Porthill, Wolstanton, Stoke-on-Trent.
W.R. of Y.	1922.	Wigglesworth & Company, Limited (Subscribing Firm), Engineers, Clutch Works, Shipley, Yorks.
—	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.

B'nch.	Year of Election.	MEMBERS.
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.
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., 183, Moorside Road, 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.	1909.	Wood, E. J. (Patent Axlebox and Foundry Company, Limited), Wednesfield Foundry, Wolverhampton.
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.
N.	1914.	Young, H. J., F.I.C., North Eastern Marine Engineering Company, Limited, Wallsend-on-Tyne.

ASSOCIATE MEMBERS.

B'nch.	Year of Election.	
Sc.	1919.	Affleck, J., 21, Overdale Avenue, Langside, Glasgow.
B.	1915.	Aldridge, S., 91, Dale Street, Walsall,
Sc.	1918.	Alexander, D., 16, Kennedy Drive, Partick, Glasgow.
B.	1925.	Allen, Wm., Chuckery Foundry, Walsall, Staffs.
Lncs.	1907.	Andrew, F., 347, Blackburn Road, Darwen, Lancs.
N.	1913.	Archer, T. M., Fell Holme, Market Lane, Dunston-on-Tyne.
L.	1925.	Armishaw, W. J., 44, Cannon View, Letchworth, Herts.
Sc.	1920.	Armstrong, John, 31, Union Road, Camelon, Falkirk.
Sc.	1920.	Arnott, J., A.I.C., 14, Percy Street, Ibrox, Glasgow.
Sc.	1920.	Arthur, Wm., 226, Main Street, Camelon, Falkirk.
—	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.
N.	1922.	Askew, Jacob, 26, General Graham Street, Sunderland.
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., Thos. Andrews & Co., Ltd., Sheffield.
N.	1925.	Atkinson, G., 10, Queen's Drive, Whitley Bay.
E.M.	1923.	Austin, J. T., 24, Danvers Road, Leicester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1920.	Avill, Wm., 44, Albion Road, Rotherham.
S.	1912.	Ayres, J. A., "Aldbourne," Ecclesfield, Sheffield.
Sc.	1918.	Bacon, A. H., 228, Saracen Street, Possilpark, Glasgow.
S.	1924.	Bacon, P., 86, Bridge Street, Swinton, nr. Rotherham.
S.	1909.	Bailey, P. T., 17, Hallowes Lane, Dronfield, nr. Sheffield.
Sc.	1916.	Bain, W., Ardmore, Bonnybridge, Scotland.
N.	1918.	Bairnsfather, Geo., 182, St. Vincent Street, South Shields.
B.	1918.	Baker, W., 24, Church Hill Road, Stockwell End, Tettenhall, Wolverhampton.
Lncs.	1921.	Ball, G., Cheetham Fold, Gee Cross, Hyde, Cheshire.
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.
L.	1914.	Barrett, H. G.
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.
—	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.
L.	1921.	Baxter, Percy, L., 131, Ampthill Avenue, Benoni, Transvaal, S. Africa.
—	1911.	Bayles, R. (Douglas & Grant, Limited), Raith Engineering Works, Dunneedaw, Rangoon, Burmah.
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.
—	1921.	Beckett, J., Corner Anderson Street and Forest Road, Huntsville, Sydney, N.S.W.
Lncs.	1921.	Beecroft, J., 53, Culshaw Street, Fulledge, Burnley.
S.	1920.	Beeley, W. H., Clarence Lane Works, off Eccleshall Road, Sheffield.
—	1924.	Beeny, H. H., 57, Bramble Street, Coventry.
Sc.	1917.	Bell, J., 60, St. Enoch Square, Glasgow.
L.	1923.	Bell, John, B.Sc., Dept. E, H.M.S. Vernon, Portsmouth.
N.	1918.	Bell, R., 12, Albert Place, Washington Station, Co. Durham.
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.	1920.	Berry, J. W., 82, Two Trees Lane, Denton, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1917.	Berry, R. I., 31, Bury Road, Bamford, Rochdale.
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.	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., 6, Churchill Road, 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.
S.	1923.	Booth, J. T., "Edendale," Ringwood Road, Brimington, Chesterfield.
Lncs.	1924.	Booth, S., 31, Birchenlea Road, Hollinwood, nr. Oldham.
N.	1915.	Borthwick, T., Crookhall House, Leadgate, Co. Durham.
W.R. of Y.	1923.	Bostock, S., 15, Holly Street, Hemsworth, Wakefield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1920.	Bound, W. H., Wh. Ex. A.M.I. Mech.E., 12, Dufton Road, Middlesbrough.
Lncs.	1921.	Bowden, J., 72, Grange Road, Chorlton-cum-Hardy, Manchester.
L.	1906.	Bowman, A., 37, Carshalton Road, Norwich.
S.	1916.	Bradley, H., 94, Abbey Lane, Woodseats, Sheffield.
N.	1918.	Bradley, J. H., 7, Crawley Road, Wallsend-on-Tyne.
Lncs.	1922.	Brandrett, T., 35, Ryall Street, Regent Road, Salford, Manchester.
B.	1925.	Bradshaw, J. H. D., 4, Foley Street, Wednesbury, Staffs.
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., 3, Johnson Street, Old Trafford, Manchester.
Lncs.	1917.	Brown, J., 298, Milnrow Road, Rochdale.
S.	1909.	Brown, T. W., 9, Coupe Road, Burngreave, Sheffield.
Sc.	1914.	Bruce, A., 52, Ashley Terrace, Edinburgh.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1920.	Buckham, G. H.. "Harewood," Grange Road, Newcastle-on-Tyne.
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.
L.	1922.	Burningham, E. F., 1, Cambridge Road, Sidcup, Kent.
S.	1924.	Burkinshaw, J. W., 33, Calvert Road, Sheffield.
Sc.	1917.	Burns, J. K., 77, Sandy Road, Renfrew.
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.
S.	1924.	Callaghan, G. M., 51, Foljambe Road, Chesterfield.
S.	1920.	Cameron, N., Cavendish Villas, Devonshire Road, Totley Rise, Nr. Sheffield.
Sc.	1912.	Campbell, D. McGregor, Torwood Foundry, Larbert.
L.	1914.	Campbell, J., 9, Western Gardens, Ealing, W.
N.	1919.	Campbell, J. A., 12, Denwick Terrace, Tynemouth.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
Lncs.	1921.	Castree, R. J., 4, Kirkgate, Burnley.
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.
S.	1911.	Chope, H. F., 38, Church Street, Sheffield.
Lncs.	1921.	Christie, R. M., 21, Pendle Street, Padiham, Lancs.
N.	1920.	Clark, J. W., 133, St. Thomas' Terrace, Blaydon-on-Tyne.
Sc.	1911.	Clark, R., 34, Mungalhead Road, Falkirk.
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.
Lncs.	1921.	Coleman, J. I., West Dene, Brooklyn Road, Wilpshire, Blackburn.
S.	1920.	Coles, W. H., 2, Gordon Avenue. Woodseats, Sheffield.
—	1919.	Colgrave, W., 13, Windsor Street, Coventry.
S.	1916.	Collins, B.L., Folds Crescent, Abbey Lane, Sheffield.
Sc.	1920.	Colquhoun, John, 72, Balmoral Avenue, Cathcart, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1907.	Cook, A. H., W. Cook & Sons, Ltd., Washford Road, Sheffield.
E.M.	1916.	Cook, F., 168, Woods Lane, Derby.
S.	1923.	Cook, T., 39, Upper Albert Road, Meersbrook, Sheffield.
S.	1914.	Cook, W. G., Washford Road, Sheffield.
S.	1914.	Cooper, J. F., 176, Attercliffe Road, Sheffield.
L.	1925.	Cooper, M. J., 48, Empress Avenue, Woodford Green, Essex.
—	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.
Lncs.	1910.	Critchley, F., 631, St. Helens Road, Bolton.
S.	1912.	Critchley, T., 52, Limpsfield Road, Brightside, Sheffield.
S.	1916.	Crowther, A., 5, Sharrow Mount, Psalter Lane, Sheffield.
B.	1906.	Curnow, M. H., 41, Cemetery Lane, West Bromwich.
S.	1914.	Currie, J. A., Rose Cottage, Grindleford, Sheffield.
B.	1907.	Dalrymple, D., 20, Beeches Road, West Bromwich.
Sc.	1920.	Dalrymple, J., Bonhard Mill, Linlithgow.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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., 56, 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.
B.	1916.	Dean, S., 14, Dent Street, Tamworth.
Lncs.	1924.	Deeley, F., 52, Bewsey Street, Warrington.
W. & M.	1924.	Deitch, A.
Lncs.	1918.	Demaine, F. C., 9, Rising Lane, Garden Suburb, Oldham.
Lncs.	1922.	Demaine (jun.), F. C., 9, Rising Lane, Garden Suburb, Oldham.
W.R. of Y.	1922.	Derrington, H., 6, Victoria Terrace, Hopwood Lane, Halifax.
L.	1909.	Derry,L. B., 3, Preston Road, Yeovil, Somerset.
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'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
N.	1921.	Downing, J. R., 137, Windsor Avenue, Gateshead-on-Tyne.
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.
L.	1920.	Dunn, J. W., 5, Creighton Avenue, East Ham, E.6.
S.	1925.	Dunstan, C., 10, Addison Road, Firth Park, Sheffield.
Lncs.	1913.	Eastwood, J. H., 31, Samuel 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.
Sc.	1911.	Edmiston, M., Rose Vale, Windsor Road, Renfrew.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
N.	1920.	Elliott, J. V., 17, Oxford Avenue, South Shields.
E.M.	1909.	Ellson, J., Manor View, Ripley, Derby.
—	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.
—	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.
W.R. of Y.	1922.	Firm, P., 39, Parsonage Road, Laisterdyke, Bradford.
Sc.	1910.	Fisher, A., 20, Drumcross Road, Bathgate, Glasgow.
Lncs.	1922.	Fist, Thos., 17, St. Ann Street, Bolton, Lancs.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
—	1924.	Fotheringham, C., 5, Rowland Street, Rugby.
L.	1912.	Fowler, T. E., 72, Station Road, New Southgate, N.11.
—	1923.	Fox, F. S., 147, Foleshill Road, Coventry.
W.R. of Y.	1922.	Fox, Herbert, 36, Granville Road, Frizinghall, Bradford.
—	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., 2a, Stanley Street, Blue Bell Hill Road, Nottingham.
B.	1910.	Gale, W., 36, Salisbury Road, West Bromwich.
N.	1921.	Gallon, Thos., 57, Joseph Street, Newcastle-on-Tyne.
Sc.	1904.	Galt, J., Henry & Galt, Sneddon Foundry, Paisley.
Lncs.	1922.	Garside, A., 142, Albermarle Terrace, Ashton-under-Lyne.
B.	1920.	Gaunt, J. W., 101, Beeches Road, West Bromwich.
Sc.	1922.	Gibson, J. E., "Armont," Falkirk.
Lncs.	1923.	Gilpin, W., "Sunnyside," Birch Grove, Rusholme, Manchester.
E.M.	1924.	Gilson, A. J., 15, Marcus Street, Derby.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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., 210, Parliament Street, Derby.
N.	1922.	Gospel, W., 65, Seventh Avenue, Heaton, Newcastle-on-Tyne.
—	1923.	Goss, W., Ivy Cottage, King William Street, Coventry.
—	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.	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., 43, Jessamine Road, Shiregreen, Sheffield.
Lncs.	1920.	Greenhalgh, W., 86, Crosby Road, Bolton.
Lncs.	1924.	Greenwood, T., 10, White Platts Street, Todmorden.
L.	1918.	Gregory, E., 16, Mansfield Road, Beech Hill, Luton.
E.M.	1924.	Griffiths, S., c/o 88, Havelock Road, Derby.
Lncs.	1925.	Grieve, J. E., 24, Tindall Street, Reddish, Stockport.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1919.	Grimwood, E. E. G., 6, Balmoral Terrace, Glebelands Road, Ashton-on-Mersey.
Lncs.	1921.	Grundy, H. V., 47, Moreton Avenue, Stretford, Manchester.
Lncs.	1917.	Grundy, J. H., 14, King Street, Earlstown, Lancs.
L.	1920.	Gurney, S. J., 24, Burns Road, Battersea, S.W.
S.	1921.	Hagon, Wm., 35, Southgrove Road, Ecclesall, Sheffield.
Sc.	1920.	Haig, J., Taylor's Building, North Main Street, Stenhousemuir.
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.
Sc.	1922.	Hamilton, W.
B.	1924.	Hammond, G. A., 13c, Hill Top, West Bromwich.
L.	1921.	Hammond, L., 27, North Way, North Heath, Erith.
E.M.	1925.	Hancock. D., 43, Drewry Lane, Derby.
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.	1919.	Hargraves, R. R., (Grandridge and Mansergh, Ltd.), Wheathill Street, Salford, Manchester.
Lncs.	1911.	Harper, H., 28, Alexandra Street, Castleton, nr. Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1925.	Harrington, W. T., 21, Vernon Road, Stratford, London, E.15.
Lncs.	1922.	Harris, F., 18, Holland Street, Padiham, Lancs.
E.M.	1923.	Harris, F. C., 10, Great Central Road, Loughborough.
N.	1921.	Harris, Geo., Cleveland Avenue, North Shields.
S.	1923.	Harrison, John, 10, St. Helens Street, Chesterfield.
—	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.
Lncs.	1922.	Hasan, M. A., 459, Chester Road, Old Trafford, Manchester.
Lncs.	1917.	Haughie, C. M., 12, Grosvenor Street, Stretford, Manchester.
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,
S.	1922.	Hayward, Wm., 6, Littlemore Cres., Newbold, Chesterfield.
N.	1922.	Heap, G. H., 269, Bensham Road, Gateshead-on-Tyne.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.	1920.	Higginbottom, J., 6, John Street, Heyrod, Stalybridge, Lancs.
Lncs.	1925.	Higgins, J. D., 19, Lynton Avenue, Marland, Rochdale.
Lncs.	1915.	Hill, A., 114, Middleton Road, Heywood, Lancs.
Lncs.	1925.	Hill, H. G., 109, Princess Road Moss Side Manchester.
Lncs.	1921.	Hilton, F., 39. Mather Street, Radcliffe, Manchester.
E.M.	1917.	Hilton, H. J. S., 29, West Avenue, Derby.
Lncs.	1909.	Hilton, T. G., 171, Rose Hill Road, Burnley.
B.	1921.	Hinley, Geo. H., 53, Park Lane East, Tipton, Staffs.
W.R. of Y.	1922.	Hird, W., 10, Long Lane, Harden, Bingley, Yorks.
B.	1913.	Holberry, F., Hedley Terrace, Llanelly, S. Wales.
—	1918.	Holder, F. W., 131, Eagle Street, Coventry.
S.	1920.	Holland, G. A., Paten & Co., Church Lane, Norwich.
Lncs.	1922.	Holland, W., 14, Highfield Road, Stretford, Manchester.
B.	1917.	Hollinshead, A. E., 68, King's Road, Sedgley, Dudley.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.	1921.	Hopwood, Wm., 4, Off Redhouse Lane, Bredbury, nr. Stockport.
L.	1921.	Hotchkis, J. D., 29, Romberg Road, London, S.W.17.
—	1922.	Houghton, J., 15, Mayfield Road, Coventry.
Lncs.	1924.	Howard, E. J. L., 2, Queens Terrace, Clarence Road, Rusholme, 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.
Sc.	1920.	Howie, J., Burnside Cottages, Denny.
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.
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.
N.	1918.	Hutchinson, S., 4. Gladstone Terrace, Birtley, Co. Durham.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1920.	Irvine, A., The Point, North Main Street, Stenhousemuir.
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.
—	1909.	Jacques, W., 131, Wyley Road, Coventry.
B.	1914.	James, W., 96, Grove Lane, Handsworth, Birmingham.
L.	1925.	Jarvis, B., 50, Wenlock Street, Luton, 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.
N.	1925.	Johnson, N., 17, Chester Road, Sunderland, Co. Durham.
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.
—	1919.	Judd, G. H., 8, Ludlow Road, Coventry.
Lncs.	1922.	Kay, Wm., 9, Eastbank Street, Bolton, Lancs.
Lncs.	1924.	Kaye, A., 24, Wilson Street, Gorse Hill, Stretford, Manchester.
W.R. of Y.	1922.	Kaye, H., 6, Fryergate Terrace, New Scarboro', Wakefield.
Lncs.	1907.	Kemlo, R. W., Littleton House, Atkinson Road. Ashton-on-Mersey, Cheshire.
—	1921.	Kemp, J. A., 1, Fairfax Street, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
N.	1925.	Kirby, A. D., 6, Falshaw Street, Washington Station.
N.	1922.	Kirby, J. E., 31, Laburnum Gardens, Monkton, Jarrow-on-Tyne.
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.
L.	1922.	Klouman, F. A., "Bengarth," Hare Lane, Claygate, Surrey.
—	1919.	Klyver, F. D., 45, Farman Road, Coventry.
S.	1908.	Knowles, J. (c/o. Walkers), Manchester Road, Stocksbridge, Sheffield.
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., 54, Petre Street, Sheffield.
Lncs.	1917.	Leach, R., 53, Tower View, Lord Street, Stalybridge.
Lncs.	1914.	Leaf, J. W., 20, Clovelly Street, Newtown, Rochdale.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1913.	Lee, J., 38, Point Pleasant Terrace, Wallsend-on-Tyne.
—	1921.	Leech, Wm. Creighton (N.S.W. Gov. Railways), Wentworth and Rutledge Street, Eastwood, Sydney, N.S.W.
Lncs.	1907.	Leigh, A. P., "Netherlands," Upper Park Road, Broughton Park, Manchester.
—	1920.	Lengden, W. A., Plomont, Woodland Avenue, Earlsdon, Coventry.
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.
Lncs.	1925.	Lineker, A. W., 23, Thirlmere Avenue, Stretford, Manchester.
—	1919.	Linnett, A. T., 4, Earlsdon Avenue, Coventry.
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.
Lncs.	1921.	Livesey, T., 80, Church Street, Little Lever, nr. Bolton.
N.	1916.	Loader, W. S., 282, Stanhope Road, South Shields.
Lncs.	1925.	Lockett, E., 38, Jackson Street, Gorton, Manchester.
Sc.	1910.	Logan, J., 14, Chapelwell Street, Saltcoats, Scotland.
Lncs.	1920.	Lomax, J., 51, Thicketfield Road, Bolton.
B.	1921.	Longden, Ed., 80, Regent Road, Handsworth, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1922.	Longden, J., 11, Drumny Road, Clydebank.
W.R. of Y.	1922.	Lowe, E., 4, Rock Street, Woodhouse, 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., 52, Jackson Street, Stretford, Manchester.
Lncs.	1921.	Mallett, E., 1152, Chorley Old Road, Bolton.
N.	1924.	March, T., 25, Clifford Street, Blaydon-on-Tyne.
B.	1909.	Marks, J., 73, Crosswells Road, Langley, Birmingham.
Lncs.	1923.	Marlow, E., 97, Railway Road, Urmston, Manchester.
W.R. of Y.	1922.	Marsden, J.W., 20, Steadman Terrace, Bradford, Yorks.
Sc.	1910.	Marshall, G., "Fereneze," Russell Street, Burnbank, Lanarkshire.
L.	1922.	Marshall, H. C., 29, Westward Road, S. Chingford, E.4.
Sc.	1920.	Marshall, R., 159, Mungalhead Road, Falkirk.
Sc.	1913.	Marshall, W., Woodlands Cottage, Armadale, Scotland.
Sc.	1912.	Marshall, W. G., "Kyleakin," Larkhall, Scotland.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
—	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.	1919.	Mason, T., 29, Old Park Road, King's Hill, Wednesbury.
Lncs.	1917.	Masters, J., 2nd 17, Cheetham Hill Road, Stalybridge.
B.	1922.	Masters, T. J., 12, Glover Street, West Bromwich.
B.	1909.	Mathews, J., 20, Earl Street, Walsall.
B.	1921.	Mauby, R. A., Hopstone, Bridgnorth, Salop.
Lncs.	1920.	Mayoh, W., 90, Maslin Street, Newton, Hyde, Cheshire.
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.
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.
Sc.	1917.	McFadzean, J., 29, Fullarton Street, Kilmarnock.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
Lncs.	1925.	Meadowcroft, H., 14, Worcester Street, Rochdale.
Sc.	1914.	Mearns, A., 54, Nairn Street, Glasgow.
—	1921.	Meston, J. M., Priory House, Priory Street, Coventry.
S.	1913.	Millar, A., 90, Bawtry Road, Tinsley, Sheffield.
—	1921.	Miller, G. A., 68, St. Margaret's Road, Coventry.
Sc.	1912.	Milligan, A., 39, Bank Street, Greenock.
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.	1920.	Mitchell, J., 12, George Street, Barrhead, Glasgow.
W.R. of Y.	1923.	Mitchell, J., 16, Pincheon Street, Wakefield.
Sc.	1922.	Mitra, S. B., c/o Bengal Iron Co., Ltd., Kulti, E. I. R., India.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1918.	Moffat, J., 12, Dryden Street, Padiham, Lancs.
Sc.	1916.	Moir, J. D., Bo'ness Iron Company, Ltd., Bo'ness, Scotland.
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.
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.
W. & M.	1922.	Morgan, W., Bryn Derwen, Bryn Terrace, Porth, Glam., So. Wales.
—	1922.	Morris, H. J., New Shop, Heath Road, Swan Lane, Coventry.
S.	1924.	Morris, T. R., 3, Albert Street, Masboro', Rotherham.
Lncs.	1920.	Morrison, H., 88, Crete Street, Oldham.
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.
Lncs.	1925.	Needham, G. A., 11, Newbridge Lane, Stockport.
N.	1914.	Nekervis, J., 14, Broughton Road, South Shields.
Lncs.	1920.	Newport, F., 1428, Ashton Old Road, Higher Openshaw, Manchester.
Lncs.	1912.	Nicholls, J., 146, Hulton Street, Trafford Road, Salford.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1921.	Nicholson, J. D., 13, Taylor Street, South Shields.
W.R. of Y.	1925.	Neild, G., 3, Baden Terrace, Hough End, Bramley, Leeds.
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.
L.	1921.	Norman, A. H., 43, Dunvegan Road, Eltham, S.E.
B.	1924.	Northcott, L., The Den, Halesowen, Birmingham.
—	1921.	Nowland, J. E., 37, Provost Street, Holbeck, Leeds.
N.	1918.	Oakford, E. F., "Uplands," Birtley, Co. Durham.
S.	1921.	Offiler, G., 9, Ward Place, Highfields, Sheffield.
Lncs.	1921.	Oldham, Harry.
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., 27, Hamilton Street, Camelon.
Lncs.	1921.	Orme, R., 31, Stockport Road, Hyde, Cheshire.
Lncs.	1921.	Osborne, W. H., 51, Hufling Lane, Burnley.
S.	1924.	O'Shea, D. B., 98, Burngreave Road, Sheffield.
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'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1923.	Palmer, T., 5, Marmaduke Street, Oldham.
B.	1924.	Palmer, A., 14, Marsh Hill, Stockland Green, Birmingham.
B.	1925.	Parkes, I., 157, Whitehall Road, Greets Green, West Bromwich.
L.	1920.	Parnell, H., "Freda Villa," 25, Queen's Road, Burnham-on-Crouch.
B.	1918.	Parsons, A., 32, Cordley Street, West Bromwich.
Sc.	1914.	Patrick, A., 65, Mungalhead Road, Falkirk.
N.	1921.	Patterson, F. E., 17, Mariner's Homes, Tynemouth.
Sc.	1916.	Paul, R., 1, Bellfield Street, Barrhead.
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.
Lncs.	1914.	Pevitt, Hy., 75, Orford Street (Central), Warrington.
Lncs.	1922.	Phillips. A., 48, Harley Road, Sale, near Manchester.
—	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.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS
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 (Richard Johnson & Nephew, Ltd.), Bradford Iron Works, Manchester.
B.	1909.	Pugh, C. B., Ramsey House, Bescot, Walsall.
S.	1917.	Pugsley, T. M., c/o Post Office, Vereeniging, Transvaal, South Africa.
W. & M.	1924.	Raby, F. 119, Dodworth Road, Barnsley.
Lncs.	1920.	Ramsey, W., 9, Creswick Avenue, Rose Hill, Burnley.
Sc.	1904.	Rankin, R. L. (Sharp & Company), Lennox Foundry, Alexandria, Scotland.
L.	1920.	Rasbridge, W. J., 160, Evelyn Street, Deptford, S.E.
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., Hartley Brook Lane, Ecclesfield, nr. Sheffield.
W. & M.	1924.	Richardson, R. J., Llanblethian House, nr. Cowbridge.
N.	1912.	Richardson, W., 204, South Frederick Street, South Shields.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1924.	Richman, A. J., "Strathaven," Brooks Hall Road, Ipswich.
Lncs.	1911.	Riley, J., 3, Glen 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.
N.	1917.	Robinson, J. H., 22, Park Parade, Whitley Bay.
W.R. of Y.	1922.	Robinson, W. G., 5, Keswick Street, Laisterdyke, Bradford, Yorks.
N.	1919.	Robson, F., 44, Stannington Place, Heaton, Newcastle-on-Tyne.
N.	1916.	Robson, J., 21, Glebe Crescent, Washington, Co. Durham.
S.	1913.	Rodgers, E. A., 11, Bowood Road, Sharrow, Sheffield.
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., 33, Herbert Road, Bearwood, Birmingham.
E.M.	1913.	Roe, J., Globe Foundry, Stores Road, Derby.
—	1920.	Rogers, C. F., 28, Maycock Road, Coventry.
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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
S.	1913.	Samworth, E. A., 14, Hamilton Road, Firth Park, Sheffield.
L.	1923.	Sanders, H. H,, 21, Etherley Road, Harringay, N.15.
B.	1921.	Sanders, Horace L., 23, Alfred Street, West Bromwich.
B.	1905.	Sands, J., 27, Victoria Street, West Bromwich.
N.	1923.	Savage, R., 5, Winchester Terrace, Hendon, Sunderland.
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.	1921.	Scott, Henry, B.33F, Albert Road, Birtley, Co. Durham.
N.	1918.	Scott, W., 7, Lynwood Avenue, Blaydon-on-Tyne.
Lncs.	1925.	Self 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.	Shackleton, S., 22, Tivoli Place, Bradford, Yorks.
W.R. of Y.	1922.	Shaw, A., 28, Marlboro' Road, Shipley, Bradford.
Lncs.	1922.	Shaw, S., 35, Frog Lane, Wigan, Lancs.
Lncs.	1911.	Shawcross, G.N., M.B.E., M.I.Mech.E. Lakelands, Horwich, Lancs.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1924.	Shearman, F. E., 63, Summerfield Crescent, Birmingham.
—	1920.	Shephard, H., 6, Lydgate Road, Coventry.
S.	1923.	Sherratt, W., 39, Horndean Road, Pitsmoor, Sheffield.
L.	1924.	Shawyer, G. H., 81, Edward Street, Deptford, S.E.8.
E.M.	1915.	Shield, F. M., 11, Thoresby Street, Green Lane, Leicester.
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.
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'nch.	Year of Election.	ASSOCIATE MEMBERS.
—	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.
E.M.	1925.	Smith, W. F., Fireman's Houses, Colombo St., Derby.
Lncs.	1909.	Smith, S. G., 86, Barton Road, Stretford, Manchester.
Lncs.	1924.	Smith, W., 358, Halifax Road, Todmorden.
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.
Lncs.	1921.	Spencer, F. W., 159, Briercliffe Road, Burnley.
S.	1924.	Somerfield, H., 43, Frickley Road, Sheffield.
L.	1904.	Sperring, B. F., 244, Lake Road, Portsmouth.
Sc.	1920.	Spittal, J., 80, Norham Street, Shawlands, Glasgow.
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., 28, Daffodil Road, Shiregreen, 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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
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.
L.	1922.	Summers, H. G., 35, Perry Hill, Catford, S.E.6.
Lncs	1910.	Sutcliffe, A., 1, Firwood Grove, Tonge Moor, Bolton.
W.R. of Y.	1922.	Sutcliffe, A., 44, Ferney Lee Road, Todmorden, Yorks.
Lncs.	1919.	Sutcliffe, W., 3, Birkdale Road, Rochdale.
Lncs.	1923.	Swann, H., 31, Alexandra Road, Patricroft, Manchester.
W.R. of Y.	1922.	Swann, H., 5, Heywood Street, Great Horton, Bradford.
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.
—	1920.	Taylor, E., 19, Station Street, West Coventry.
B.	1925.	Taylor, E. R., 148, South Road, Handsworth, Birmingham.
W. & M.	1905.	Taylor, F. (Taylor & Sons, Limited), Britonferry, South Wales.
Lncs.	1921.	Taylor, H., 16, West Street, Dukinfield Manchester.
Lncs.	1921.	Taylor, James, 3, Tremellen Street, Accrington.
L.	1925.	Teasdale, I., Homeland, Norton Village, Letchworth.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1921.	Temple, G. T., 35, Grosvenor Drive, Whitley Bay.
Lncs.	1922.	Thatcher, E. H., "Trostrey," Wraxall, Somerset.
N.	1924.	Thom, J., 485, Shields Road, Walkergate, Newcastle-on-Tyne.
L.	1909.	Thomas, E., 41, Kingshill Road, Swindon.
W.R. of Y.	1922.	Thompson, E., Terryburg Street, Leeds Road, Bradford.
S.	1921.	Thomson, Thos. R., 8, Clifton Dale, York.
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.
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.
—	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'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1917.	Vaughan, G. A., 15, Green Street, West Bromwich.
Lncs.	1921.	Vernon, G. W., 11, Ashfield Road, Burnley.
N.	1914.	Wainford, E. H., High Row, Gainford, Darlington.
Lncs.	1925.	Walker, A., 119, 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.
B.	1916.	Wall, J., 15, Flavell Street, Wood Setton, nr. Dudley.
Lncs.	1915.	Wallwork, R. N., 9, Birch Vale Drive, Romiley, Stockport.
E.M.	1924.	Ward, J. C., 56, Danvers Road, Leicester.
—	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.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1921.	Weathers, J. H., 76, Stanton Street, Newcastle-on-Tyne.
B.	1923.	Webb, A. W. J., 1, Sidney Street, Gloucester.
E.M.	1921.	Webb, Ernest Alfred, 109, Warwick Street, Leicester.
S.	1909.	Webster, C., 34, Milton Road, Rotherham.
W.R. of Y.	1922.	West, W., 32, Oakfield Road, Manningham, Bradford.
B.	1911.	Westwood, J. H., 163, St. Paul's Road, Smethwick, Staffs.
Lncs.	1925.	Wharton, L., 11, Alexandra Street, Heywood, Lancs.
W.R. of Y.	1913.	Whitaker, E., 145, St. Enoch Road, Wibsey, Bradford.
Lncs.	1919.	Whiteley, B., The Moorlands, Tintwistle, Hadfield, nr. Manchester.
B.	1904.	Whitfield, C. O., King's Road, Tyseley, Birmingham.
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.
Lncs.	1919.	Whittle, P., 50, Victory Road, Little Lever, Bolton.
—	1919.	Whitworth, E., 274, Munition Cottages, Holbrook's Lane, Coventry.
S.	1925.	Wild, A. J., Midland Brass Foundry, Attercliffe, Sheffield.
B.	1920.	Wilkins, A. J. R., 149, Toll End Road, Ocker Hill, Tipton.
N.	1910.	Wilkinson, T., Stockton Street, Middlesbrough.
S.	1919.	Williams, A., 31, Burngreave Bank, Sheffield.
—	1919.	Williams, A. Morgan-, 43, Queen's Road, Coventry.
—	1923.	Williams, B. E., "Aldersey," Crick Road, Hillmorton, Rugby.
Lncs.	1925.	Williams, O., 6, Moss Road, Stretford, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
—	1923.	Williams, R., 166, Cross Road, Foleshill, Coventry.
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.
N.	1912.	Wilson, F. P., Parkhurst, Middlesbrough.
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.
Sc.	1924.	Winterton, H. T., "Moorlands," Milngavie, Dumbartonshire.
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.
E.M.	1921.	Wood, James H., 18, Alcester Road, Sheffield.
W.R. of Y.	1922.	Wood, John, 6, Hudswell Street, Sandal, Wakefield.
E.M.	1914.	Worcester, A. S., 27, Keythorpe Street, Leicester.
Lncs.	1917.	Worrall, J. N., 77, Ansdell Road, Turf Hill, Rochdale.
N.	1922.	Worth, J. W., 18, Tynemouth Road, Heaton, Newcastle-on-Tyne.
W.R. of Y.	1923.	Wright, L. L., 168, Oxford Road, Gomersall, near Leeds.
Sc.	1913.	Wright, W., Burnbank Foundry, Falkirk.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1924.	Wylie, J. F., 206, Stockport Road, Bredbury, Stockport.
Lncs.	1925.	Yates, J., 70, Victory Road, Little Lever, near Bolton.
Lncs.	1924.	Yeoman, Robert, 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.	1923.	Allcock, H., 164, H. S. Edwards Street, South Shields.
B.	1925.	Andrews, E., 214, Highfield Road, Saltley, Birmingham.
Sc.	1925.	Arnott, J., 14, Percy Street, Ibrox, Glasgow.
B.	1912.	Attwood, E., 42, Priory Villas, Hazlebeach Road, Saltley, Birmingham.
S.	1920.	Ayres, Sidney, 299, Bellhouse Road, Shiregreen, Sheffield.
N.	1920.	Banks, V. L., St. Cuthbert's Vicarage, Newcastle-on-Tyne.
Lncs.	1924.	Beattie, W. J., Brookfield, Bent Lanes, Davyhulme, nr. Manchester.
Lncs.	1925.	Becker, M. L., 15, Upper Lloyd Street, Manchester.
N.	1921.	Bentham, J. W., 9, Cumberland Street, Gateshead-on-Tyne.
N.	1924.	Betham, W. S., 9, South Frederick Street, South Shields.
B.	1922.	Bettley, H., 3, Regent Street, Willenhall, Staffs.

B'nch.	Year of Election.	ASSOCIATES.
N.	1913.	Bewley, J. E. T., 13, Woodland Terrace, Leadgate, Co. Durham.
S.	1924.	Blades, H., 37, Petre Street, Pitsmoor, Sheffield.
S.	1924.	Bolsover. C. A., 27, Pear Street, Sheffield.
N.	1922.	Boudry, C., 23, Esplanade Place, Whitley Bay.
N.	1922.	Bowden, F., 5, Holmwood Grove, West Jesmond, Newcastle-on-Tyne.
B.	1914.	Boyne, W., 157, Wood End Road, Erdington, Birmingham.
N.	1925.	Burrell, J., 2, Bede Crescent, Willington-on-Tyne.
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., 23, Cedar Grove, Cleadon, South Shields.
E.M.	1919.	Charlton. R. H., Wentworth House, Wentworth Street, Peterborough.
Sc.	1925.	Climie, C., 40, Delburn Street, Parkhead.
S.	1920.	Coates, L., 30, Oakwood Road, Rotherham.
S.	1921.	Cooling, Geo., W., 10, Osberton Place, Endcliffe, Sheffield.
Sc.	1924.	Coubrough. W. J., 68, Guthrie Street, Maryhill, Glasgow.
Sc.	1924.	Cummings. J., 27, Hillview Street, Shettleston, Glasgow.
—	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.
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.
—	1924.	Eardley, H. R. V., 6, White Friars Street, Coventry.
N.	1918.	Eglen, T., 22, Morley Street, Heaton, Newcastle-on-Tyne.
L.	1922.	Elder, Alex., 54, Ford End Road, Bedford.
L.	1922.	Ellis, J. P., 6, Eckstein Road, Clapham Junction, S.W.11.
—	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.	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.	1921.	Gobey, Wm., 3, Burnley Street, Blaydon-on-Tyne.
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.
—	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.
N.	1923.	Harle, J. E., 162, South Palmerston Street, South Shields.
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., 45, Halshaw Lane, Kearsley, near Manchester.
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.
Sc.	1916.	Irvine, J., 14, Clarence Street, Paisley.
Lncs.	1925.	Jackson, A., 27, Marlboro' Street, Accrington.
N.	1923.	Jennings, P., 23, Cullercoats Street, Welbeck Road, Newcastle-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
B.	1919.	Johnson, J. B., junr., Slater Street, Great Bridge, Tipton.
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.	1923.	Lewins, W., 90, H. S. Edwards Street, South Shields.
N.	1922.	Liddell, L., 7, Tyne View, Lemington-on-Tyne.
E.M.	1922.	Limbert, H., 15b, Factory Street, Loughborough.
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.	1924.	Martin, A. L., 31, George Street. City, Glasgow.
B.	1924.	Mason, J. L., 11, Kentish Road, Handsworth, Birmingham.
Lncs.	1923.	Masters, N., 2nd 17, Cheetham Hill Road, Stalybridge.
L.	1925.	Mata, C. H., 51, Grosvenor Road, Canonbury, N.5.
N.	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.
N.	1924.	McDonald, C. R., The Villa, Willington-Quay-on-Tyne.
N.	1925.	McDougal, T. D., 3, Westmoreland Street, Wallsend-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
Sc.	1924.	McGowan, V. M., 1, Albert Street, Paisley.
Sc.	1913.	McLeish, J., 7, Buchanan Terrace, Paisley.
Sc.	1913.	McLeish, R., 7, Buchanan Terrace, Paisley.
Sc.	1912.	McLintock, G., Woodhead Avenue, Townhead, Kirkintilloch.
Lncs.	1923.	Meadowcroft, H., 72, Elliott Street, Tyldesley, Manchester.
Sc.	1924.	Meikle, A. S., 207, Kent Road, Glasgow.
B.	1925.	Meredith, C., 4, Thomas Street, Smethwick, Birmingham.
S.	1913.	Middleton, Wm., 455, Jenkin Road, High Wincobank, Sheffield.
N.	1922.	Miller, J. G., 79, Clarence Street, Newcastle-on-Tyne.
—	1918.	Morgan, W. G., 51, Palmerston Road, Earlsdon, Coventry.
N.	1914.	Murray, J., 13, Dean Road, South Shields.
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.
E.M.	1916.	Radford, H. P., 151, Barclay Street, Fosse Road South, Leicester.

B'nch.	Year of Election.	ASSOCIATES.
N.	1917.	Rang, E. J., 8, Bath Terrace, Tynemouth.
N.	1922.	Redpath, J., 25, Burnley Street, Blaydon-on-Tyne.
Sc.	1923.	Reid, J. N. (junr.), Elmbank, Larbert.
L.	1922.	Rendell, R. J., 23, Royston Avenue, South Chingford, E.4.
Sc.	1923.	Riddell, J., Coventry Drive, Glasgow.
N.	1924.	Robson, J., 75, Neptune Road, Wallsend-on-Tyne.
N.	1923.	Rollin, C. N., Keys House, Gilesgate, Durham.
Sc.	1924.	Ross, H. R., 425, Keppochill Road, Glasgow.
N.	1923.	Sams, W. B., 6, North Terrace, Wallsend-on-Tyne.
N.	1925.	Scott, R. J., 5, Dene Avenue, High Farm Estate, Wallsend-on-Tyne.
N.	1923.	Sheret, N. L. R., 30, Rothbury Terrace, Heaton, Newcastle-on-Tyne.
S.	1925.	Smedley, C. C., 41, Abbey Lane, Woodseats, Sheffield.
Sc.	1911.	Smith, W. H., 19, Victoria Place, Airdrie.
B.	1925.	Smith, W. H., 21, Horsely Road, Tipton, Staffs.
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.
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.

B'nch.	Year of Election.	ASSOCIATES.
N.	1925.	Strong, Leslie, 59, Marine Avenue, Monkseaton, Northumberland.
E.M.	1915.	Styles, W. T., 52, Roe Street, Derby.
B.	1910.	Sutton, W. H., 147, Anthony Road, Saltley, Birmingham.
Sc.	1913.	Sword, J., 13, Paisley Road, Barrhead.
N.	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., "Norwood," Westwood Avenue, Heaton, Newcastle-on-Tyne.
S.	1922.	Tyler, G. H., 86, Pickmere Road, Crookes, Sheffield.
N.	1922.	Van-der-Ben, C. R., 169, Dunsmuir Grove, Gateshead-on-Tyne.
Sc.	1924.	Waddell, W., 9, Dunn Street, Paisley.
L.	1911.	Wells, G. E., 89, Larcom Street, Walworth, S.E.
N.	1924.	Wise, S. F., 45, Tenth Avenue, Heaton, Newcastle-on-Tyne.
L.	1922.	Wooding, J. F. 13, Highfield, Road, Chertsey.
S.	1920.	Wordsworth, W. A., 11, Coverdale Road, Millhouses, Sheffield.
L.	1924.	Worland, F. J., 48, Swete Street, Plaistow, E.13.
N.	1925.	Worley, E. R., 2, Primrose Hill, Low Fell, Gateshead-on-Tyne.
Sc.	1919.	Young, C., 74, Cramond Street, Glasgow.

Members changing their address are requested to notify the same immediately to the General or Branch Secretary of the District.

NAME INDEX.

SUBJECT INDEX.