J. HEPWORTH, J.P., M.P.

President of the Institute.

Mr. Hepworth served his apprenticeship with Thornton & Crebbin, Limited, engineers, of Bradford, and after this period was appointed manager of the firm of E. B. Grandage, tool makers. He held this position for twelve years, and then, with his father, he founded the company of Hepworth & Grandage, Limited, of which he was managing director until 1933. A Justice of the Peace, Mr. Hepworth was elected to Parliament in 1931, and was re-elected in 1935 as a National Conservative. His present industrial activity is mainly connected with the Bradford Piston and Piston Ring Company, Limited, Bradford, of which he is the Chairman. In the sphere of sport Mr. Hepworth is Chairman of the Bradford Northern Union Rugby Football Club, whilst he has always interested himself in motor racing, and has won many trophies.

PROCEEDINGS OF THE . . . INSTITUTE OF BRITISH FOUNDRYMEN.

VOLUME XXXI. 1937-1938.

Containing the Report of the Thirty-Fifth Annual Conference, held at Bradford, June 14th, 15th, 16th, and 17th, 1938; also Papers presented to Branch Meetings held during the Session 1937-1938 and Discussions thereon.

Edited by T. Makemson.

Published by the
Institute of British Foundrymen.

General Office:
Saint John Street Chambers, Deansgate, Manchester, 3.
(Registered Office: 49, Wellington Street, Strand, London, W.C.2.)

THE INSTITUTE OF BRITISH FOUNDRYMEN

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Oliver Stubbs. 1923.
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S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford.

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These Sections are part of the Branches with which they are associated. The Presidents and Secretaries of Sections receive invitations to attend meetings of the Council.

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A. Hares, 648, Stapleton Road, Bristol, 5.

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ITALY.

Dr. Ing. Guido Vanzetti, 73, Corso Venezia, Milan.

SOUTH AFRICA.

A H. Moore, Standard Brass Foundry, Benoni, Transvaal.

AWARDS 1937-38

THE "OLIVER STUBBS" GOLD MEDAL

1938 Award to Mr. S. E. DAWSON, F.I.C.,

"in recognition of the many valuable Papers which he has presented to almost all the Branches of the Institute."

The Oliver Stubbs Medal has been awarded as follows :—

1922.—F. J. Cook, M.I.Mech.E.
1923.—W. H. Sherburn.
1924.—John Shaw.
1925.—A. Campion, F.I.C.
1926.—A. R. Bartlett.
1927.—Professor Emeritus Thomas Turner, M.Sc.
1928.—J. W. Donaldson, D.Sc.
1929.—Wesley Lambert, C.B.E.
1930.—James Ellis.
1931.—John Cameron, J.P.
1932.—J. E. Hurst.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.
1935.—No Award.
1936.—F. Hudson } Two Awards.
E. Longden }
1937.—P. A. Russell, B.Sc.
1938.—S. E. Dawson, F.I.C.

MERITORIOUS SERVICES MEDAL

The Meritorious Services Medal has been awarded as follows :—

1933.—F. W. Finch.
1934.—J. J. McClelland.
1935.—H. Bunting.
1936.—J. Smith.
1937.—No Award.
1938.—No Award.

THE "E. J. FOX" GOLD MEDAL

1938 Award to Mr. J. E. HURST.

The E. J. Fox Gold Medal has been awarded as follows :—

1937.—Professor Emeritus Thomas Turner, M.Sc.
1938.—J. E. Hurst.

DIPLOMAS OF THE INSTITUTE

were awarded to—

Mr. A. TIPPER, for his Paper on "Naturally Bonded or Synthetic Moulding Sands," presented to the Birmingham Branch.

Mr. A. PHILLIPS, for his Paper "Some Points on Non-Ferrous Foundry Practice," presented to the Lancashire Branch.

Mr. P. FASSOTTE, for his Paper on "Trends of Continental Steel Foundry Practice," presented to the London Branch.

Mr. B. MacDOUGALL, for his Paper on "High-Duty Iron —Some Experiments with the Rocking Arc Furnace," presented to the Scottish Branch.

Mr. J. CAMERON, June., for his Paper on "Equipping a Fettling Shop," presented to the Scottish Branch.

Mr. W. J. REES, for his Papers on "Refractories," presented to the Burnley Section of the Lancashire Branch, and on "Some Fundamental Properties of Moulding Sands," read before the Lancashire Branch.

Mr. F. WHITEHOUSE, for his Paper on "A General Engineering Foundry," presented to the Bristol Section of the Wales and Monmouth Branch.

THE "EDWARD WILLIAMS" LECTURE

The following lectures have now been delivered —

1935.—"Man and Metal" (delivered at Sheffield.—Sir WILLIAM J. LARKE, K.B.E.

1936.—"Cast Iron and the Engineer" (delivered at Glasgow).—Prof. A. L. MELLANBY, D.Sc.

1937.—"Factors in the Casting of Metals" (delivered at Derby).—C. H. DESCH, D.Sc., Ph.D., F.R.S.

1938.—Not delivered.

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The Institute of British Foundrymen

THIRTY-FIFTH ANNUAL CONFERENCE, BRADFORD

JUNE 14, 15, 16 and 17, 1938

The thirty-fifth Annual General Meeting of the Institute was held at the Bradford Technical College on Tuesday, June 14. Mr. C. W. Bigg (retiring President) presided.

ANNUAL GENERAL MEETING

The minutes of the preceding Annual General Meeting, held at Derby in June, 1937, were taken as read, confirmed and signed.

The Annual Report of the Council for the session 1937-38 was then presented.

ANNUAL REPORT

This report covers the period May 1, 1937, to April 30, 1938, and the Statement of Accounts for the year ended December 31, 1937.

The past year has been one of the most successful in the history of the Institute. The record membership announced twelve months ago has been substantially increased, and is now 2,220; the finances are in a sound condition, and every department of the Institute's work has made progress. This happy position is due largely to a recognition of the increasing value of the Institute to the industry, and to a rapidly growing recognition by the individual foundryman of the value of membership.

Table I shows the changes in membership which have taken place during the year, and an analysis of the present membership is given in Table II, the figures for the previous year being given in brackets for comparison.

Deaths

The Council regrets to report the deaths of fourteen members. Included in this number are many who had taken an important part in the work of the Institute and were widely known throughout the industry, including:—

Mr. G. B. R. Taverner, a well-known member of the London Branch.

Mr. T. B. McBride, of Wallsend-on-Tyne, who at the time of his death was Senior Vice-President of the Newcastle Branch.

Mr. H. Stead, a former secretary, and at the time of his death the assistant secretary, of the Lancashire Branch.

Major R. A. Bull, of Chicago, who was a prominent member of the American Foundrymen's Association, and a member of this Institute since 1922. In 1923 he presented the American Exchange Paper to the Annual Conference of the Institute.

Mr. J. B. Johnson, a Past-President of the Birmingham Branch.

Mr. G. H. Oxley, a prominent member of the Sheffield Branch.

Mr. F. Bainbridge, a member of the Middlesbrough Branch, and a Carnegie Gold Medallist of the Iron and Steel Institute.

Mr. E. H. Tyson, a well-known aluminium founder and a Past-President of the Birmingham Branch.

Although not actually members of the Institute, several notable gentlemen associated with the industry have died during the past twelve months, and of these the following were particularly well known to many members:—

Sir John Dewrance, G.B.E., Past-President of the Institute of Metals and of the British

Cast Iron Research Association, who, at the 1929 International Foundry Congress in London, entertained the participants at a reception at the Guildhall.

Mr. G. Batty, a pioneer of electric-furnace steelmaking, and a well-known figure both in American and British steel-foundry circles.

Mr. T. E. Bashford, a founder and former treasurer of the Middlesbrough Branch.

Honours Conferred upon Members

Among the members who have been honoured during the past twelve months are:—

Mr. P. M. Booth, who was knighted by His Majesty the King, at the time of the Coronation last May.

Professor Dr. Mont Fr. Pisek, who was decorated by the French Government with the Cross of Chevalier of the Legion of Honour.

Sir Harold Carpenter, F.R.S., Ph.D., who received the Gold Medal presented by the Verein Deutscher Eisenhüttenleute.

Mr. C. W. Bigg, President of the Institute, who was elected a patron of the Derby Society of Engineers.

Mr. W. J. Rees, who was re-elected President of the Refractories Association of Great Britain in May, 1937.

Mr. Frank Russell, who was elected President of the same Association in succession to Mr. Rees in May, 1938, a few days after the period officially covered by this report.

Mr. A. C. Turner, who was re-elected President of the Foundry Trades' Equipment and Supplies Association.

The Council is also gratified to note that Mr. A. Brizon, President of the Association Technique de Fonderie, has had the Cross of Chevalier of the Legion of Honour conferred upon him.

Finances

The rapidly-increasing membership has had its effect upon the finances; expenditure has naturally increased, but this has been more than compensated for by the increased income. The excess of income over expenditure for the year ended December 31, 1937, amounted to the handsome sum of £372 9s. 3d., which is the largest credit balance for any year since 1922.

Technical Development Fund

At the opening meeting of the Derby Conference, the President announced the presentation by his co-directors of Qualcast, Limited, and himself, of the sum of £500 to form the nucleus of an endowment fund to be used for the promotion of the work of the Education and Technical Committees. The meeting gratefully accepted the generous gift and tendered its thanks to the donors. The Council now takes this opportunity to record its sincere thanks to the donors and its appreciation of this recognition of the value of the Institute's technical work.

At a meeting of the Council held in October, Mr. C. W. Bigg, Mr. J. Cameron, Mr. W. B. Lake, Mr. S. H. Russell and Mr. C. E. Williams were appointed Trustees of the Fund.

E. J. Fox Gold Medal

At the annual general meeting in June, 1936, the Council accepted the most generous offer of Mr. E. J. Fox, managing director of the Stanton Ironworks Company, Limited, of £500 for the establishment of a Gold Medal, which was to be presented to the individual who had contributed in some outstanding way to the progress of the foundry industry, with particular reference to foundry metallurgy. On the recommendation of the two assessors, Sir William J. Larke, K.B.E., and Prof. Sir Harold Carpenter, F.R.S., Ph.D., the Council decided to make the first award of the medal to Professor Emeritus Thomas Turner, M.Sc., "as a recognition of his work on the effects of silicon on cast iron, and his other contributions to the metallurgy of cast iron, which may be considered to have formed the foundation of modern foundry practice." The presentation was made at the Annual Conference in Derby last year.

TABLE I.—*Changes of Membership*, 1937–38.

	Subscribing firms.	Members.	Associate members.	Associates.	Associate students.	Total.
At April 30, 1937	66	864	987	121	27	2,065
Additions and transfers from other grades	8	92	117	27	9	253
	74	956	1,104	148	36	2,318
Losses and transfers to other grades	1	30	51	11	5	98
At April 30, 1938	73	926	1,053	137	31	2,220

This year the Council has accepted the recommendation of the assessors that the Medal be awarded to Mr. J. E. Hurst, Past-President of the Institute, to whom it will be presented at the Annual Conference at Bradford.

Awards

Oliver Stubbs Medal.—At the Conference held at Derby in June, 1937, the Oliver Stubbs Medal for 1937 was awarded to:—

Mr. P. A. Russell, B.Sc., "for his work in promoting the technical development of iron-foundry practice: (*a*) as Convener of the Cast Iron Sub-Committee of the Technical Committee; (*b*) for his work in connection with the preparation of specifications; and (*c*) for Papers given to various Branches of the Institute."

Diplomas.—At the Derby Conference last year it was announced that Diplomas for 1937 were to be awarded to the following gentlemen. The Branches before which their Papers were given are also shown:—

Mr. H. H. Shepherd, Birmingham and London Branches; Mr. S. A. Horton, East Midlands Branch; Mr. R. Ballantine, Lancashire Branch and Falkirk Section of the Scottish Branch; Mr. E. W. Wynn, Lancashire Branch; Dr. C. J. Dadswell, Mr. T. R. Walker and Mr. F. Whitehouse, joint authors of a Paper given before the Sheffield Branch.

Buchanan Medals and Prizes.—The Buchanan Medals and Prizes are awarded on the results of examinations organised by the City and Guilds of London Institute on Foundry Practice and Patternmaking. The names of recipients are given under the heading of "Educational Work" later in this report.

John Surtees Memorial Examinations.—These examinations were founded by Mr. W. Mayer, Past-President, in memory of the pioneer founder, John Surtees, who was connected with the Newcastle district. The examination is organised alternately by the Newcastle and Scottish Branches. This year the examination was held in Scotland, and the winner of the Senior Prize was Mr. A. M. Campbell, and of the Junior Prize, Mr. John Allan.

Branch Activities

Throughout the past year the Branches have been able to maintain the high quality of the programmes which are arranged. A large number of Papers have been presented covering all phases of foundry practice. An analysis of the subjects covered by the Papers shows that of the 77 contributions, 15 were on the subject of cast iron, 7 on steel, 6 on non-ferrous metallurgy, 1 on malleable cast iron, 9 on sand, 1 on refractories, 7 on the melting of metals, 2 on costing, 4 on patternmaking, 9 on general moulding practice, and 15 on general topics.

At the meetings which the Council has held throughout the year, it has been found that matters of a national and international interest have made increasing demands upon its time. It is realised, however, that the work of the Branches is of fundamental importance, and every effort has been made to give the maximum attention to this aspect of the Institute's work.

As was reported in the last annual report, a Branch has been established in South Africa, and, during the year under review, it has grown rapidly. A full programme of Papers was arranged for its winter session and there is every indication that this will develop into a most flourishing Branch. The two Sections, those in East Anglia and at Bristol, which were formed in 1936, are also making progress, and are now taking their full share in the work of the Institute.

The London and Birmingham Branches held a two-day joint meeting in Birmingham; joint meetings between other Branches have also taken place. The London Branch is to be congratulated on the enterprise which it has shown during the past twelve months in organising a Branch visit to Belgian foundries, and also for the tour of foundries in the West Country which it has arranged for May. The Lancashire Branch organised a very successful day visit to the works of Vickers-Armstrongs, Limited, at Barrow-in-Furness.

The Council expresses its thanks to all the Branch officials; to the authors of Papers; and the directors and staffs of works which have been visited by members of the Institute during the year.

Kindred Institutions

Apart from the many contacts which representatives of the Institute make with representatives of other similar bodies on numerous Joint Committees, there have been during the past year several joint meetings of the Branches with the corresponding local bodies of other institutions, notably the Institute of Metals and the Institute of Vitreous Enamellers.

As was reported in the last annual report, the Institute has co-operated with a number of other institutions of a similar character in establishing a Joint Committee on Materials and Their Testing. The first Conference under the auspices of the Committee was held in Manchester in October.

International Relations

The happy relations with foundry technical societies, which have been established for many years, have been maintained during the present year mainly through the International Committee of Foundry Technical Associations, of which Mr. V. Delport was President during the year 1937. A meeting of this Committee with Mr. Delport in the chair was held at the International Foundry Congress in Paris last June, and this Institute was represented by the President, Mr. V. C. Faulkner and the Secretary, who attended as Secretary of the Committee. A party of fifty members of this Institute, and ladies, attended this Congress, and the thanks of the Institute are extended to the organisers of the

TABLE II.—*Analysis of Membership, April 30, 1938.*

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Associates (Students).	Total.
Birmingham	8 (7)	151 (135)	156 (144)	17 (16)	7 (5)	339 (307)
East Midlands	4 (3)	64 (55)	87 (89)	4 (4)	1 —	160 (151)
Lancashire	14 (14)	115 (109)	210 (200)	32 (25)	— —	371 (348)
London	9 (8)	187 (182)	117 (106)	6 (6)	— —	319 (302)
Middlesbrough	1 (1)	23 (24)	34 (33)	9 (6)	7 (6)	74 (70)
Newcastle	7 (7)	34 (32)	29 (30)	49 (47)	10 (10)	129 (126)
Scottish	6 (6)	104 (101)	191 (187)	7 (9)	2 (1)	310 (304)
Sheffield	7 (7)	96 (93)	67 (59)	2 (2)	1 (1)	173 (162)
South African	10 (8)	36 (27)	17 (14)	7 (2)	— —	70 (51)
Wales and Monmouth ..	2 (2)	44 (43)	50 (45)	— —	3 (3)	99 (93)
West Riding of Yorkshire ..	5 (3)	51 (40)	79 (69)	4 (4)	(1)	139 (117)
Unattached	— —	21 (23)	16 (11)	— —	— —	37 (34)
	73 (66)	926 (864)	1,053 (987)	137 (121)	31 (27)	2,220 (2,065)

Congress, the Association Technique de Fonderie, and to Mr. A. Brizon, the President, for their hospitality.

Arrangements have been made for members to participate in the next International Congress, which is to be held next September in Warsaw.

Members are reminded that the 1939 International Congress is scheduled for London. Many provisional arrangements have been made, and several of the Branches have promised to co-operate in arranging a post congress tour of British foundries. It is expected that the major details of the Congress, which will be held in June, 1939, will be available in the late autumn of this year.

The authors of Exchange Papers presented on behalf of the Institute to Overseas Conferences, were as follows:—

American Foundrymen's Association Convention, 1937, at Milwaukee.—Mr. J. Roxburgh.

International Foundry Congress, Paris, 1937. —Mr. H. H. Shepherd.

The authors of Exchange Papers at forthcoming Conferences will be:—

American Foundrymen's Association Convention, 1938, Cleveland.—Mr. W. J. Rees.

International Foundry Congress, 1938, Warsaw.—Mr. B. B. Kent.

Association Technique de Fonderie, 1938, Lyons.—Mr. T. R. Walker.

Papers were presented at the Derby Conference on behalf of the American, French, and German Foundry Associations, and all these countries will be represented by the Papers to be presented to the forthcoming Conference at Bradford.

Foundry Exhibition

At the Foundry Exhibition, held in conjunction with the Engineering, Marine and Welding Exhibitions at Olympia, London, last September, the Institute organised a stand which was used extensively by members visiting the Exhibition. Useful work was done in interesting non-members in the activities of the Institute, and as a result a number of new members were obtained. An official visit was also organised to the Exhibition, and many members, including the President and Vice-Presidents, were able to attend. The thanks of the Institute are tendered to F. W. Bridges & Sons, Limited, the organisers of the Exhibition, for the facilities they gave so generously in connection with the stand, and also for the generous hospitality to the Council and members.

Educational Work

The Institute has continued to collaborate with the City and Guilds of London Institute in organising examinations in foundry practice and patternmaking. The following are the results of these examinations which were held at the beginning of last year.

	No. of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
Patternmaking—Intermediate grade	30	8	13	70.0
Patternmaking—Final grade	23	11	5	69.5
Foundry Practice and Science	78	17	27	56.4

Prizes were awarded to:—

Patternmaking—Intermediate Grade:—

Mr. R. D. Cheyne, Constantine Technical College, Middlesbrough. Bronze Medal of the City and Guilds of London Institute.

Patternmaking—Final Grade:—

Mr. R. H. Francis, Coventry Technical College. City and Guilds of London Institute's Silver Medal, and Buchanan Book Prize of the Institute of British Foundrymen.

Mr. F. N. Rand, Constantine Technical College, Middlesbrough. Buchanan Silver Medal of the Institute of British Foundrymen.

Mr. S. Hodgson, Rotherham College of Technology and Art. Buchanan Book Prize of the Institute of British Foundrymen.

Foundry Practice and Science:—

Mr. W. C. Marshall, Derby Technical College. City and Guilds of London Institute's Bronze Medal, and Buchanan Silver Medal of the Institute of British Foundrymen.

Mr. J. D. Leishman, Sheffield University. Buchanan Book Prize of the Institute of British Foundrymen.

Mr. C. F. Lawson, Sheffield University. Buchanan Book Prize of the Institute of British Foundrymen.

National Certificates in Mechanical Engineering issued by the Board of Education and the Institution of Mechanical Engineers are endorsed by the President of this Institute in respect of those candidates who have been successful in special foundry subjects. Eleven National Certificates have been so endorsed during the last year, making a total of 155 since the commencement of the scheme.

The Degree Course in Foundry Metallurgy at the University of Sheffield has now been in operation for nearly three years, and the first students who have completed the Course are almost ready to enter industry. The number of students taking the Course is satisfactory, and the establishment of the Course has been fully justified.

The British Foundry School, which is in operation at the Central Technical College, Birmingham, and which was established mainly by the British Cast Iron Research Association, and its director, Mr. Pearce, is also completing its third year. This is a special, intensive course of one year's duration, intended for men who are already in the industry, and who wish to equip themselves for positions of greater responsibility. The careers subsequent to leaving of those students who have passed through the Course show that it is achieving the objects for which it was established.

Annual Conference, Derby, 1937

The Thirty-fourth Annual Conference, which was held in Derby last June, was one of the most successful which has been arranged. A particularly noteworthy feature was the introduction of a session devoted entirely to non-ferrous subjects.

The annual general meeting was held on Tuesday, June 8, and was followed by a civic reception at the Bemrose School. The Wednesday and Thursday were mainly confined to technical sessions and works visits which were of a very high standard.

Mr. Joseph Hepworth, J.P., M.P., and Mr. W. B. Lake, J.P., were the elected Senior and Junior Vice-President respectively.

This Conference was attended by a large number of overseas members and visitors, representatives from Canada, Australia, Sweden, Germany, Persia, Singapore and Belgium being present.

The thanks of the Institute are especially due to the Worshipful the Mayor of Derby, Councillor Mrs. Petty, J.P., and to the Corporation of the Borough of Derby, for the valuable assistance they rendered in many directions. In addition to entertaining the members and ladies at a civic reception, special facilities were given by the Corporation in connection with the banquet and other functions. Those who were present at the Conference retain happy memories of the gracious manner in which the Mayor welcomed the delegates at the reception and the opening meeting, and the manner in which she co-operated in other meetings and functions.

The Council extends its thanks to the firms whose works were visited; to the authors of Papers; to the subscribers to the Conference Fund; and to all those who in any way assisted in making the Derby Conference so memorable an occasion. The work of the Branch officials, notably Mr. W. T. Evans, the President of the East Midlands Branch, Mr. H. Bunting, Chairman of the Conference Executive Committee, and Mr. B. Gale, Secretary of the Branch and

Honorary Conference Secretary, is also appreciated by the Institute, for it is realised that the success of the Conference was in a large measure due to the enormous amount of work which these gentlemen carried out.

Edward Williams Lecture

Dr. C. H. Desch, F.R.S., Head of the Metallurgical Department of the National Physical Laboratory, delivered the Third Edward Williams Lecture on "Physical Factors in the Casting of Metals." It is regretted that at the Bradford Conference this year no Edward Williams Lecture will be given. An invitation was accepted by Sir Nigel Gresley, but unfortunately Sir Nigel's health has made it necessary for him to take an extended sea voyage, and he will not therefore be able to deliver the lecture. Arrangements are under way in preparation for the lecture to be given at the 1939 International Foundry Congress in London.

British Cast Iron Research Association

As was anticipated in the last report, the year 1936-37 created a new record. At the end of 1937, the President, the Rt. Hon. the Earl of Dudley, made an appeal to members and others in the industry for a sum of not less than £15,000 for the purpose of providing up-to-date accommodation and equipment for the Association's work, for which at least £30,000 is required. This appeal has the support and sympathy of the Department of Scientific and Industrial Research and all contributions made to date have been treated by the Department as grant-earning and by this their value has been doubled. The provision will meet a pronounced need for equipment for highly specialised work.

During the year steps have been taken to strengthen the connection between this Institute and the Association, and the B.C.I.R.A. has also carried out co-operative work with the Institute of Welding and the Institute of Vitreous Enamellers.

Council

Four meetings of the Council, and more than twenty meetings of special and standing Committees have been held during the year, such meetings having been held at Derby, Manchester, Bristol, Sheffield, London, and Leicester. There have been four meetings of the Technical Committee, a meeting of the Technical Council, and about forty meetings of various Sub-Committees of the Technical Committee.

Ten members of the Council are elected by ballot for a period of two years, five retiring each year. The five who so retire at the annual general meeting on June 14 are:—Mr. A. Campion, Mr. J. W. Gardom, Mr. B. Hird, Mr. F. K. Neath and Mr. J. M. Primrose. All these gentlemen are eligible for re-election for a further period of two years, and offer themselves for re-election.

Hon. Treasurer.—Mr. W. B. Lake retired from the position of Hon. Treasurer, which he has held for four years, upon his election as Junior Vice-President, and was succeeded in the position of Hon. Treasurer by Mr. S. H. Russell, Past-President.

Mr. Lake's period of office as Treasurer has been a notable one; he has carried out several reforms in the finances of the Institute and has exercised the closest control over the general items of income and expenditure. The Council tenders to Mr. Lake its thanks for the work he has rendered in this capacity, and its congratulations upon his election to the position of Vice-President.

The thanks of the Council are also tendered to Mr. J. W. Gardom, the Convener of the Technical Committee, for his devoted work in the leadership of the various activities of this Committee and its Sub-Committees.

Revision of Bye-Laws

Some eighteen months ago, the Board of Development made certain recommendations to the Council regarding qualifications for admission to the various classes of membership. These recommendations were accepted in principle by the Council, and were referred to an Organisation Committee to work out the details. This Committee has now completed its work, and has made recommendations for the necessary alterations to the Bye-laws which will be submitted for the approval of the members at the annual general meeting on June 14.

The main purpose of these revisions is that candidates for admission to the various classes of membership of the Institute shall give evidence of possessing certain technical qualifications or of having a minimum standard foundry experience; by this means it is hoped that membership will in itself be accepted as a definite proof of qualification. This is a principle which has been adopted with success by other technical institutions and the Council recommends these proposals to the members in the confident belief that they will improve the status of the individual member and that they will improve the status and standing of the Institute generally.

The Council has for some time been anxious to give greater service to members by more frequent publication of the "Proceedings," and by extending the work of the Technical Committee. It has not, however, been able to do so for financial reasons. Very careful consideration has been given to this matter, and the Council has now approved those proposed alterations to the Bye-laws which authorise certain increases in subscriptions, in the belief that the resultant increase in the Institute's income will enable these developments to be undertaken immediately.

A number of minor alterations in the Bye-laws have been made, the general purpose of which is to facilitate smoother and more efficient working.

Staff

Owing to the increased amount of work which has to be carried out by General Office, Mr. J. Bolton was appointed Assistant Secretary at the beginning of March.

Annual Conference

The Thirty-fifth Annual Conference will be held at Bradford, from June 14 to 17. Mr. Joseph Hepworth, J.P., M.P., the Senior Vice-President, will be installed President at the opening meeting on Wednesday, June 15.

C. W. Bigg,
President.

T. Makemson,
Secretary.

Adoption of Report

The President moved the adoption of the Annual Report for the year ended April 30, 1938.

Mr. H. Winterton seconded the motion.

The Report was adopted without discussion.

Accounts

Mr. S. H. Russell (Hon. Treasurer), presenting the balance sheet and the income and expenditure account for the year ended December 31, 1937, said that the financial position was satisfactory. The excess of income over expenditure, which was carried forward, amounted to £372, but he pointed out that, if one deducted the receipts from the South African Branch—£121—and sundry receipts, which were receipts other than subscriptions—£142—the income by way of subscriptions in Great Britain was only about £9 in excess of the total expenditure.

The gift of £500 made by the directors of Messrs. Qualcast, Limited, in 1937 would in future appear in the accounts as " The Technical Development Fund." It was hoped sincerely that there would be numerous and substantial additions to the Fund within the next two or three years. He moved the adoption of the accounts as printed.

Mr. F. J. Cook (Past-President) seconded, and expressed congratulations and thanks to all who had contributed to the production of such satisfactory accounts.

The accounts were adopted without discussion.

Technical Committee's Report

MR. J. W. GARDOM (Convener of the Institute's Technical Committee) proposed the adoption of the reports of that Committee and its Sub-Committees. He commented that the work of the Committee and Sub-Committees had been difficult, in view of the many obstacles which had had to be overcome, but they were beginning to see daylight, and a few years hence the reports would be very much better than those published so far.

The resolution was seconded by MR. P. A. RUSSELL and carried unanimously.

SIXTH ANNUAL GENERAL REPORT OF THE TECHNICAL COMMITTEE

In fulfilment of the objects for which it was formed in 1931, the Technical Committee during the past year has been actively engaged in studying various technical developments in the foundry industry, and in collaborating with other scientific bodies which have been carrying out work on similar subjects.

In order to facilitate its work, the Committee is divided into eight Sub-Committees, which cover almost all phases of modern foundry practice. The reports of these Sub-Committees follow this report.

In addition to the work of the Sub-Committees, a considerable amount of work is carried out by the Technical Committee as a whole. Such activities include representation on national and international standardising and investigating bodies.

The Technical Committee's representatives, Dr. A. B. Everest, Mr. J. G. Pearce and the Secretary, attended the meeting of the International Committee on Testing Cast Iron, which was held in Paris in June, 1937. Contact with the American Foundrymen's Association has been maintained, notably through the Sands Sub-Committee, which has been studying various types of sand-testing apparatus. This Sub-Committee, together with the Steel Castings Sub-Committee, has also been co-operating with the Steel Castings Research Committee of the Iron and Steel Institute and the British Iron and Steel Federation. Amongst numerous other contacts which this Committee has maintained with kindred bodies elsewhere is that of the Cast Iron Sub-Committee with the International Committee on Testing Cast Iron. The subject in this case has been the classification of graphite.

Inquiry Bureau.—The inquiry bureau which is carried on by the Institute under the auspices of the Technical Committee has continued to provide for members a useful service which has been much appreciated.

Nomenclature.—From time to time the Technical Committee has been able to assist members in the definition of certain terms. During the past year this service has also been made use of by foreign inquirers. It is hoped that in time a comprehensive list of definitions will be made available to members of the Institute.

The Technical Committee wishes to express the thanks of the Institute to those members who have so willingly given their time both to attending meetings and to furthering the work of the Committee and its Sub-Committees by private research. The thanks of the Institute are also extended to those firms which so kindly provide facilities for members of their staffs to attend meetings; to those firms which have so readily carried out research and tests in connection with the work of the Technical Committee, and to those firms which have co-operated with the Committee by answering the questionnaires which have been circularised.

J. W. GARDOM,
Convener, Technical Committee.

REPORTS OF SUB-COMMITTEES

Sub-Committee on Cast Iron

During the past year the Cast Iron Sub-Committee has continued to co-operate with the British Standards Institution in handling specifications, directly or indirectly concerning cast iron. Early in 1938, the new Specification, No. 786, for High-Duty Cast Iron was published, the figures finally adopted being based largely on the data submitted by this Sub-Committee. At the same time the revision of Specification No. 321/1928, for Grey Cast Iron, was issued. The Sub-Committee also considered the final draft of the proposed new specification for cast-iron gears and made recommendations which have now been adopted by the British Standards Institution. The Sub-Committee has now under consideration a proposed specification for cast-iron surface plates and marking-off tables, which includes recommended compositions.

It has been agreed that the Sub-Committee should publish a Paper discussing the Sub-Committee's part in the preparation of the new specification for high-duty cast iron, and include in it references to physical and mechanical properties of grey cast iron. This Paper is now in hand and will be available to Branches for the 1938-39 session.

Further consideration has been given during the year to the possibility of issuing recommended methods of running and risering grey iron castings. This work involves many difficulties and at the present time a sheet of drawings of simple types of castings is being circulated to selected foundries who are asked to indicate the methods of running and risering they would recommend. This work should indicate how far it will be possible to proceed, with a view to drawing up final recommendations for issue to industry.

In co-operation with the International Committee for Testing Cast Iron, various suggested systems of classifying graphite form and size in grey cast iron have been under review. This work is still in hand and the Sub-Committee will co-operate with Professor Portevin in France and the Committee recently set up for the purpose of studying this question by the American Foundrymen's Association.

P. A. RUSSELL,
Convener.

Sub-Committee on Costing

Since the presentation of the Sub-Committee's report (Recommendations concerning the Establishment of Costs in a Grey Iron Foundry) at the Annual Conference at Derby, in June, 1937, no important developments have occurred in the Sub-Committee's work. It had been decided to await the reactions of the foundry industry to the Report.

Two interesting events have occurred in the meantime. Firstly, the Report was presented last January before the Birmingham Branch of the Institute of Cost and Works Accountants, at the request of that organisation. The attendance was quite large and considerable interest was shown, as proved by the discussion that followed. It is interesting to note, however, that the Report was criticised, particularly as regards the recommendation that overheads should be allocated on a labour cost basis.

The second event, of material importance to the work of the Sub-Committee, is that the Report has been recommended to its members by the Midland Iron Founders' Association. Furthermore, in the past twelve months requests have been received for copies of the Report from a number of individuals and important foundries.

It is now the hope of the members of the Sub-Committee that in the near future those foundries that have endeavoured to adopt the system, or be guided by it, will give the results of their actual experience, thereby enabling the Sub-Committee to revise the system in the light of such actual experience.

V. DELPORT,
Convener.

Sub-Committee on Malleable Cast Iron

During the past twelve months, the Malleable Cast Iron Sub-Committee has been largely engaged in surveying the investigations recently brought to a close, and in planning out the procedure regarding the revision of the B.S.I specifications.

The report on dimensional tolerances has been finalised, but the Sub-Committee feels that the time is not yet ripe for the insertion of a tolerance clause in specifications. The "Varied-Size Bar Investigation" has also been completed. In the case of whiteheart, it being found impossible to correlate tests on the standard bar with the tests obtained on the other sizes of bar. The work on this investigation now comes within the scope of the present work on specifications.

The question of the revision of the B.S.I. Specification for Malleable Cast Iron has been carefully considered by the Sub-Committee, recommendations having been finalised regarding the clauses covering machinability, and provision of test-bars. Regarding the tensile requirements, it has been decided to undertake further investigations for the whiteheart series incorporating the smaller diameter test-bar, and also the bar with a shorter gauge length.

A questionnaire has also been prepared on the current B.S.I. Specifications. This questionnaire is now in circulation, and immediately replies come to hand, this work can proceed.

A. E. PEACE,
Convener.

Sub-Committee on Melting Furnaces

As stated in the Sub-Committee's Report for 1936-37, this Sub-Committee is engaged in the preparation of a report on furnaces used in the melting of grey cast iron in order to provide data on modern melting practice. During the year a considerable amount of data has been examined and correlated in connection with various sections of the report, and further sections have been completed.

It is hoped to incorporate a section giving comparative melting costs of the various types of furnace. This work has involved a study of the average sizes of the various furnaces and average throughputs and mixtures for each typo as well as many other factors. Considerable progress has been made, and thc report is now nearing completion.

L. W. BOLTON,
Convener.

Sub-Committee on Non-Ferrous Castings

The Sub-Committee has given final consideration to the criticisms raised in the discussion on its Report: " Recommendation for Two Leaded Gunmetals." It was decided that no modification was called for in the recommendations as a consequence of the discussions held by the various Branches of the Institute, and the Secretary was therefore asked to approach the British Standards Institution with the request that they consider drawing up two new specifications for leaded gunmetals. The British Standards Institution has intimated its willingness to discuss this suggestion, and a memorandum covering the Sub-Committee's recommendations has been presented to them.

Further consideration has been given to the work on leaded phosphor-bronzes, and a number of further tests is being conducted in various foundries. In addition, an investigation has been undertaken on the effect of additions of small amounts of nickel to leaded phosphor-bronzes. Three compositions of leaded phosphor-bronzes suitable for bearings have been decided upon and are now under investigation, and it is hoped, in due course, to be able to submit recommendations for standard specifications covering these materials.

L. B. HUNT,
Convener.

Sub-Committee on Sands

Considerable progress has been made during the past year with work on sand testing. In particular the Sub-Committee has completed its recommendations for the routine testing of dry sands and loam, and approved sieve sizes for grading of foundry sands.

A draft report on " Moulding Sands used in British Foundries " has been completed and circulated to all members of the Technical Committee. This is based on information obtained from a questionnaire circulated to foundries in all parts of the country. Work now proceeding includes the consideration of core sand testing, and in particular the investigation of drying ovens. A new undertaking of the Committee is its work on casting defects.

Further co-operation between this Committee and the Moulding Materials Sub-Committee of the Iron and Steel Institute, during the past session, through the good offices of Mr. T. R. Walker, has resulted in agreement on certain common standards to be used in testing or investigatory work. Members of the Sub-Committee have also been active in making comparison between different types of sand testing apparatus, and in general, satisfactory agreement has been found between the more recent types of British and American equipment. We regret to report the resignation this year of Mr. A. Campion, one of the original members of the Committee, and welcome as a new member, Mr. G. F. Thonger.

J. J. SHEEHAN,
Convener.

Sub-Committee on Steel Castings

In order to complete and finalise the data on the heat-treatment of steel castings (which has been gradually collected since the formation of the Sub-Committee) a questionnaire has, by courtesy of the General Steel Castings Association, been circulated to all steel founders. There has been a generous response to this, and the Sub-Committee is now in possession of very complete and detailed data upon the practice of steel founders in this country for the treatment of all classes of carbon steel castings. The treatments employed show wide differences in the methods used to attain similar results. Some of the methods appear to be wasteful and show excessive expenditure of both time and fuel, with attendant difficulties in the way of scale formation and wear of refractories. It is hoped that after proper tabulation and classification it will be possible to prepare a report giving recommendations for simplified and standardised practices which may be of value to the industry.

The experimental valve castings made for test and destruction have now been sectioned, and although all the castings withstood the highest test pressures, a number of interesting defects have been revealed. The drawings showing the methods employed in manufacture, sulphur prints and macro etchings showing the internal structure of the castings, together with the test results are now being circulated for study by members of the Sub-Committee. Although the result of this research is largely negative, it is felt that the present results will form a useful starting point for future research either by this Sub-Committee or any other interested body to whom the results could be made available. The Sub-Committee wishes to express its appreciation of the help given by Mr. F. Hudson and Glenfield & Kennedy, Limited, in testing and sectioning the castings.

C. H. KAIN,
Convener.

Sub-Committee on Refractories

The Sub-Committee has met on several occasions during the past year, and has been engaged in the consideration of cupola ganister with a view to the preparation of a draft specification for a standard quality ganister. The members of the Sub-Committee have made numerous practical tests on the properties and behaviour of samples of commercial cupola ganister as delivered for foundry use, and a good deal of progress has been made. The Sub-Committee is, however, not prepared yet to put its recommendations forward for consideration by the Technical Committee. Investigations are still being carried on, and a report will be submitted as early as possible.

W. J. REES,
Convener.

Medals and Diplomas

The PRESIDENT announced that the Oliver Stubbs Medal for 1938 had been awarded to Mr. S. E. Dawson, of the East Midlands Branch;

and that the E. J. Fox Gold Medal had been awarded to Mr. J. E. Hurst.

The General Secretary announced that the Council had awarded Diplomas to the following:—

Mr. A. Tipper for a Paper on "Naturally Bonded or Synthetic Moulding Sand."

Mr. A. Phillips for a Paper on "Some Points on Non-Ferrous Foundry Practice."

Mr. Paul Fassotte (Belgium) for a Paper on "Trends of Continental Foundry Practice."

Mr. B. MacDougall for a Paper on "High-Duty Iron; Some Experiments with a Rocking Arc Electric Furnace."

Mr. J. Cameron, Jun., for a Paper on "Equipping the Fettling Shop."

The General Secretary added that certain recommendations had been made which the Council had not yet had an opportunity to examine fully, and further Diplomas might be awarded at the October meeting of the Council.

Election of Mr. E. J. Fox as Honorary Member

The President proposed that Mr. E. J. Fox (managing director of the Stanton Ironworks Company, Limited) be elected an Honorary Member of the Institute. In doing so, he said that nobody was more jealous than he in regard to election to honorary membership of the Institute; it should be a recognition only of very signal services to the industry or to the Institute, or to both, but he had no hesitation whatever in proposing the election of Mr. Fox, for all were well aware of his great work for the industry and for the Institute.

Mr. H. Bunting seconded, and emphasised the value and importance of Mr. Fox's great work in connection with education and other matters worthy of consideration.

The proposal was carried with acclamation.

Election of President

The President, proposing the election of Mr. J. Hepworth, J.P., M.P., of Bradford, as President for the year 1938-39, said that a lifetime of experience in the industry and a very great deal of public service, which had culminated during the past few years in election as a Member of the mother of Parliaments, was surely sufficient to fit a man to become a President of the Institute. Possibly the oppositions in the Council meetings were more spontaneous and the majorities not quite so dependable as in the more exalted sphere of Parliament, but he had not the least doubt that Mr. Hepworth would soon adapt himself to the new conditions. It was a source of the greatest possible pleasure to propose his election.

Mr. A. S. Worcester (President of the West Riding Branch) seconded, and said that the election would be an honour not only to Mr. Hepworth personally, but also to the West Riding Branch, which had not previously had the pleasure of organising a Conference in its district. He was certain that Mr. Hepworth would add lustre to the Presidential office.

The resolution was carried with acclamation.

Mr. Hepworth, in a brief response, expressed his appreciation of the honour conferred upon him, and said he would do his best to emulate the example of his predecessor, Mr. Bigg, though that was going to be a very difficult task.

Proposing a hearty vote of thanks to Mr. Bigg, he said it had been a pleasure to work with him during his Presidency, and if he himself could carry on his work as President in the coming year as well as Mr. Bigg had done, he would have no regrets. The Institute was deeply indebted to him for the splendid way in which he had carried out his Presidential duties.

The vote of thanks was carried with enthusiasm.

Mr. Bigg, responding, said his year of office had been a very happy one. It had meant a certain sacrifice of time, but he had been more than repaid. He repeated a remark he had made earlier, that he derived more from the Institute than he could possibly put into it. He took the opportunity also to pay tribute to his colleagues on the General Council, and also expressed his personal appreciation of the help he had received from Mr. Makemson, the General Secretary, and from all others with whom he had been associated.

Election of Vice-Presidents

Mr. V. C. Faulkner proposed the election of Mr. W. B. Lake, J.P. (Junior Vice-President), as Senior Vice-President for the ensuing year. He recalled Mr. Lake's work as a pioneer in the foundry industry and in other activities, and said that, when Mr. Lake became President of the Institute in due course, he would be the first steel foundry owner to hold that office. Therefore, in electing him, the Institute would be repairing an omission of long standing. For a full decade Mr. Lake had rendered wonderfully regular and consistent service.

Mr. J. Hepworth (President-Elect) seconded the resolution, which was carried with enthusiasm.

Mr. W. B. Lake, J.P., briefly responded.

Mr. J. E. Hurst (Past-President) proposed the election of Major R. Miles as Junior Vice-President. Major Miles held the Degree of Master of Engineering in the Faculty of Engineering at Sheffield University. He had been always a stalwart supporter of the activities of the Institute, and on numberless occasions had been glad to help the Institute and the Sheffield Branch in particular. From personal knowledge it was a pleasure to recommend him as a worthy occupant of the office of Junior Vice-President, and in due course he would maintain the traditions of the Institute as its President.

Mr. J. K. Smithson (Middlesbrough), seconding the election of Major Miles, said that the members of the Middlesbrough Branch were unanimous in their support. Major Miles, in addition to his own work for the Institute, always gave every encouragement to his staff to help by reading technical Papers and in other ways. They hoped and expected that in due course he would occupy the Presidential Chair with distinction and success.

Major Miles was unanimously elected.

Auditors

On the motion of Mr. A. Harley (Past-President), seconded by Mr. C. H. Kain, the meeting re-elected J. & A. W. Sully & Company (chartered accountants) as auditors to the Institute.

Vote of Thanks to Officers and Council

Mr. F. J. Cook (Past-President), proposing a vote of thanks to the officers and Council, said he did not think the Institute had ever been served better than it was being served at present, and had been served during the past year, by its officers and Council, and the meeting would wish to join in tendering to them a very hearty vote of thanks.

The vote of thanks was carried with acclamation, and Mr. Bigg briefly responded.

Elections to Council

It was announced that, as the result of the ballot, the following were elected to fill the five vacancies on the Council:—Mr. H. Bunting (Derby); Dr. A. B. Everest (London); Mr. J. W. Gardom (Birmingham); Mr. B. Hird (Cardiff); and Mr. F. K. Neath, B.Sc. (Leeds).

Revision of Bye-Laws

Mr. S. H. Russell put forward the proposed Bye-Laws of the Institute, as revised by the Organisation Committee which had worked out the details, following the recommendations of the Board of Development concerning qualifications for admission to the various classes of membership, which recommendations were accepted in principle by the Council.

A complete print of the proposed new Bye-Laws was in the hands of members, and Mr. Russell proposed the following resolution:—

> " That the Bye-Laws so altered and added to and as contained in the print laid before the Meeting be and the same are hereby adopted as the Bye-Laws of the Institute in lieu of the present Bye-Laws, such present Bye-Laws to cease to have effect and the

> Bye-Laws so adopted to come into force and effect when and so soon as the approval of the Privy Council to the Bye-Laws so adopted and the certificate of such approval under the hand of the Clerk of the Privy Council have been obtained."

Commenting on the new Bye-Laws and the principal changes, he drew attention to the part of Bye-Law 3 dealing with Associates, which provided that an operative engaged in the foundry industry should be entitled to remain in membership as an Associate irrespective of age, and that no other person unless elected an Associate prior to July 1, 1938, could retain membership as an Associate after attaining the age of 28 years.

Bye-Law 4 entitled Honorary Members, Members and Associate Members to use after their names the initials appropriate to their grades of membership.

In view of suggestions made from time to time that, if the revised Bye-Laws were adopted, some of those at present in membership would have to sit for an examination, he emphasised that, under Bye-Law 5, persons in membership at the date the Bye-Laws became operative could continue in the class of membership they held at that date, irrespective of their qualifications.

Another Bye-Law to which he drew attention was No. 9, providing that annual subscriptions should be £3 3s. for a Member, £1 11s. 6d. for an Associate Member, 10s. for an Associate of 21 years of age or over, and 5s. for an Associate under 21 years of age; that a Member or Associate Member who attained the age of 65 years, and had been a Member of an Associate Member for at least 25 years, and whose subscription was not in arrear, should be entitled to remain in Membership or Associate Membership without the payment of any further subscription; and that the Institute should have the right to impose entrance fees at an annual general meeting in the future—but, he added, that there was no suggestion at the moment to propose the imposition of entrance fees.

Bye-Law 16 was inserted, on the advice of the Institute's solicitor, to clarify the position regarding voting by a show of hands or by ballot at the meetings of the Council.

Bye-Law 17 gave power to elect as additional members of the Council representatives of kindred institutions and/or research associations not exceeding five in number.

Bye-Law 18 was a modification of the existing Bye-Law regarding the nomination of Vice-Presidents. It was sometimes inconvenient, he said, to invite each Branch each year to nominate a Vice-President of the Institute. Therefore, the revised Bye-Laws provided that a committee should meet and should invite a Branch to make a nomination. He emphasised that under the existing Bye-Laws it was embarrassing to invite each Branch to nominate a Vice-President, when it was not the intention to hold a convention in the district of any particular Branch during the next following two or three years.

In Bye-Law 23, the Hon. Treasurer was added to the Executive Committee.

Bye-Law 27 provided that 14 days' notice must be given of each annual general meeting; and Bye-Law 29 provided that 14 days' notice should be given of a general meeting.

Bye-Law 43 was inserted on the advice of the Institute's solicitor, who had devoted a considerable amount of time and care to the consideration of the Bye-Laws. He had suggested the Bye-Law governing the issue of notices of meetings, etc.

On Bye-Law 44, dealing with arbitration, Mr. Russell proposed a slight amendment, to delete the words, " and disposed of under the provisions contained in these Bye-Laws," and to substitute " By agreement between the parties to the question, dispute or difference."

The amendment also added the following words to Bye-Law 44:—

> "Neither party to a question dispute or difference shall require or apply to the court to direct the arbitrator or arbitrators to state a case on any question of law arising in the course of the reference or arbitration and all questions of law so arising shall be determined by the arbitrator or arbitrators, any provisions in the Arbitration Act, 1889, to the contrary notwithstanding."

Mr. Russell added that the Bye-Laws had been discussed in General Council and in the Branch Councils over a period of 18 months. Whilst he would not suggest that there was unanimity of opinion, there was a very substantial majority in favour of the Bye-Laws as proposed, and he was convinced that they would prove to be to the ultimate good of the Institute.

Mr. H. Winterton (Past-President) seconded the resolution for the adoption of the revised Bye-laws.

Mr. Bunting moved an amendment to the effect that the number of elected members of the Council should constitute half the total Council membership.

Mr. A. Harley (Past-President) said he had a certain amount of sympathy with the proposition. He complained that when the whole membership of the Institute elected a member of Council by ballot, that member remained on the Council for only two years, which was too short a period. It would be much better to have 15 elected members, of whom five should retire each year. Thus, each member would be elected for three years.

Mr. Bunting said that that was his view, and he amended his proposition to that effect, *i.e.*, that there should be 15 elected members of Council, of which five should retire each year.

Mr. Harley seconded.

Mr. T. Henry Turner opposed the motion. He pointed out that the Institute of British Foundrymen had a very much more democratic basis than other bodies, and that the representation of the Branches was exceptionally good. The representation of the ordinary members went right through to the main Council. If the proposal made by Mr. Bunting were adopted, either the Council would become excessively large (by adding another five members) or the members of the Institute generally would be asked to vote for nominees from various Branches of whom they might have no knowledge at all. He urged that the existing method was very much better than the method proposed.

The resolution proposed by Mr. Bunting and seconded by Mr. Harley was lost by a large majority.

Mr. R. Ballantine proposed, as an amendment to the resolution for the adoption of the Bye-Laws, that their adoption be delayed for a year. As a member of the Scottish Branch, he said that that Branch was in a peculiar position and had difficulty in securing new members. The endeavour should be made to secure a greater membership among the younger men in the industry; the improvement of the status of the Institute was a secondary consideration.

Mr. E. Longden seconded the amendment. In view of the position of the Scottish Branch, he felt that a little delay would be worth while.

Mr. A. Marshall (Scottish Branch) supported the amendment, and urged that an increase of subscriptions would constitute a barrier against men who were working on the foundry floor becoming members of the Institute.

Mr. D. Sharpe (a Past-President of the Scottish Branch) supported the attitude of the previous speakers in support of the amendment, and said that in Scotland it had been a struggle to introduce practical foundrymen as members of the Institute. It was also a struggle all over the country to persuade some of those men to give Papers and make comments on shop practice. Nevertheless, the Scottish Branch had succeeded in that to a certain extent. If subscriptions were increased, it would be more difficult to attract some of the practical men into the Institute, one of the primary objects of which was education, and, therefore, he urged that the adoption of the Bye-Laws be delayed for a year in order that they might be reconsidered from the point of view of the practical man in the shop.

Mr. F. Hudson (Past-President of the Scottish Branch) was also in sympathy with the practical men in Scotland.

Mr. H. Bunting (Derby) asked what advantage was to be gained by delaying the adoption of the revised Bye-Laws for a year.

Mr. T. Henry Turner suggested that the Council might with advantage explain some of the reasons for the revision of the Bye-Laws. He pointed out that the accounts for 1937 had balanced, and said that if more money were required, it must be required for some purpose.

Objects of the Proposed Changes

Mr. S. H. Russell said that the suggestion to increase income had arisen originally because it was felt desirable to render improved service to the members. It was felt that the "Proceedings" as at present issued were rather late and, having already appeared in the trade Press, were of limited value to foundrymen. It was hoped that, with increased resources, it would be possible to publish the "Proceedings" more frequently than in the past, though perhaps not quarterly to begin with. It was also intended that certain findings of the Technical Committee should be published confidentially for the information of members only. The work of the Technical Committee and its Sub-Committees was still in its infancy, but it was valuable work and could not be carried on without money; the Institute at present had not the funds with which to foster the necessary investigation and research. The work done so far had been carried on voluntarily by a limited number of well-disposed persons and firms, but the Institute could not for ever draw on those sources. Two years ago the Council had passed a resolution agreeing in principle to an increase of subscriptions in order that the work should be carried on. It would be dangerous to draw the conclusion that there was a very substantial surplus of money each year in the Institute; the actual amount of the subscriptions from members in Great Britain exceeded expenditure by a very few pounds, but a substantial sum could be spent very quickly on research or investigation with results of which the members would receive full benefit.

He could appreciate how the draft new Bye-Laws differed from the point of view of the Scottish members. It was definitely in the minds of the majority of those responsible for those revised Bye-Laws that a man should be something more than an ordinary moulder before he became an Associate Member of the Institute. That might be right or it might be wrong; but the Bye-Laws had been specifically drawn up by men with that thought at the back of their minds, and, so far as he knew, the whole Council had been quite fully aware of that. It had been emphasised by the critics that the ordinary moulder or journeyman would have difficulty in paying the increased subscription as an Associate Member; and he fully agreed. But, rightly or wrongly, the Bye-Laws were not drawn up particularly to cater for that man, except as an Associate. It was felt that a Member should be something more than a skilled operative, and rules were inserted which called for some educational qualification, or some phase of responsibility (perhaps only limited responsibility) in addition to practical knowledge, so that when a man was entitled to call himself a Member or Associate Member, it would be appreciated that he had rather more qualifications than the ordinary journeyman. It appeared that that was not clearly understood by all the members. The type of person who would pay a subscription of £1 11s. 6d. would receive back by way of service three or four or more times that value. He fully agreed that for the average journeyman working on the floor the subscription was more than he could afford; but the new Bye-Laws were not drafted to cater for that type of man except as an Associate. If such a man were already an Associate Member, he could remain an Associate Member by paying the extra money, and it would be to his advantage. But if he resigned, and wished to become a member again at a later date, he could only join as an Associate. That was the point about which the members had to make up their minds.

Mr. Bigg said that the meeting could not pretend to be able to discuss the matter fully in the time available or to discuss it to the extent that seemed to be demanded; therefore, he suggested that the meeting might be adjourned until about October next, so that everybody would have the opportunity to express their views.

Adjournment of Meeting Supported

Mr. Ben Hird (Cardiff) said that members would have to understand that a definite change was proposed, which applied to all Branches as it did to the Scottish Branch. Something more than a mere change in respect of £ s. d. was being proposed, and the members must face up to it. He favoured very much the proposal to hold a meeting to discuss the matter thoroughly.

Mr. J. W. Gardom (Birmingham) emphasised that the proposed new Bye-Laws had been under consideration for nearly two years and everybody had had an opportunity of discussing them, for they had been put to the Branches and there had been special Council meetings for their discussion. He suggested that there was really nothing in the argument about the subscription to be paid by the workman, who could become an Associate for a subscription of 10s. a year, and who would benefit by the extra money subscribed by members in other grades. One of the things it was desired to do was to be able to pay the expenses of good lecturers who would attend the Branch Meetings and would benefit workmen as much as anybody else. The Institute wanted to bring the men forward. He urged that the meeting should vote on the proposition to adopt the new Bye-Laws.

Mr. Bigg said he would be sorry to feel that, under his chairmanship, the opportunity was not afforded to ventilate the matter to the fullest extent and to consider every phase. Each individual considered that his own view was the right one, but the time available was not sufficient for a full discussion, and he did not wish to hurry it. The meeting could be adjourned until a later date for full discussion of the matter.

Mr. Lake proposed an amendment that the Annual General Meeting be adjourned until a date in October.

Mr. Stobie (Past-President) seconded that amendment, and said there was nothing to prevent giving effect to the resolutions already passed at the meeting, and adjourning the consideration of the Bye-Laws.

Mr. Hird asked definitely whether the adjournment of the Annual General Meeting would mean that the election of officers would not stand.

Mr. Bigg said it did not.

The amendment to adjourn the meeting until October was then put to the meeting and carried.

[For an account of the proceedings at the adjourned annual general meeting, see page 58.]

CIVIC RECEPTION

On Tuesday evening the members and their ladies were received at the Cartwright Memorial Hall, Bradford's Art Gallery, by the Lord Mayor and Lady Mayoress (Alderman Henry Hudson and Mrs. Hudson).

OPENING OF CONFERENCE

On Wednesday morning the members and ladies assembled in the Great Hall of the Bradford Technical College, where they were officially welcomed to Bradford by the Lord Mayor (Alderman Henry Hudson, J.P.), who extended a hearty welcome to all attending the conference, and expressed the hope that they would derive pleasure and instruction from it. He spoke of his pride in Bradford and its surroundings, of the improvement of the amenities of life in that and other cities, and urged all to help to effect such improvement in their own cities, which would make our country a far better one to live in than it had been in the past.

Presentation of Medals

The Lord Mayor presented to Mr. S. E. Dawson (East Midlands Branch) the Oliver Stubbs Medal.

Mr. Dawson, on receiving the Medal, expressed his keen appreciation of the honour, which was coveted by every member of the Institute; and he had special pride in receiving the Medal because he had known Mr. Oliver Stubbs personally. He hoped to maintain the tradition surrounding the Medal, which had been endowed by previous recipients.

Mr. E. J. Fox (managing director of the Stanton Ironworks Company, Limited), the donor of the E. J. Fox Gold Medal, which is awarded for outstanding contributions to the progress of the foundry industry, with particular reference to foundry metallurgy, presented the Medal to Mr. J. E. Hurst, a Past-President of the Institute. Mr. Hurst, he said, had devoted his whole lifetime to the analytical and metallurgical side of iron founding, and those who were deeply concerned with the industry owed him a tremendous debt of gratitude for his good work, whilst at the same time they looked forward to further good work by him in the future. It was unnecessary in such a gathering as the annual conference of the Institute to recite Mr. Hurst's qualifications, as one could do at very considerable length; but it was a pleasure and pride to present the Medal to him, and particularly gratifying to welcome him back after his recent illness. (Applause.)

Mr. Hurst, in response, expressed his great pride in the award of the Medal to him, and in the fact that it had been presented by the donor personally. During the last 25 years he had received many honours at the hands of the members of the Institute; during that period he had been concerned very closely with research work on cast iron, and the members of the Institute had honoured him by the award of Diplomas, a Branch Presidency, the Oliver Stubbs Medal, the Presidency of the Institute, and now the E. J. Fox Gold Medal. His pride on such an occasion, therefore, could be well appreciated, and he took the opportunity also to express his gratitude for the overwhelming sympathy extended to him by very many of his friends during his recent illness; the kindness extended to him at that time would remain in his memory throughout his life.

It would be fitting, he continued, to pay tribute to the encouragement and enthusiastic assistance he had received at all times from his many colleagues. Indeed, his initial interest in ironfoundry metallurgy was due entirely to the enthusiasm of two very old colleagues at Richard Hornsby's 25 years ago; they were Mr. Potts (foundry manager) and Mr. Onions (works manager), whose enthusiasm for foundry work and foundry metallurgy was transmitted to him when a young man and had remained with him ever since. There were many other colleagues also to whom he owed a great deal, for no man could work alone. He was deeply grateful to the members of the Institute for all the honours they had conferred upon him, and Mrs. Hurst and their family shared that gratitude.

Vote of Thanks

Mr. Bigg, proposing a hearty vote of thanks to the Lord Mayor of Bradford and his colleagues for the welcome extended to the visitors, and for the great help they had given to make the conference a success, said that the Institute appreciated its obligations to them in their personal capacities and as representatives of the great City of Bradford. All attending the Conference had a lively interest in Bradford; they knew that their first West Riding Conference would be a success, and they had already had very tangible evidence from the Lord Mayor and his civic colleagues that Bradford wished them well.

Mr. Hepworth seconded, and said it was indeed a pleasure to him to second the expression of thanks to the Lord Mayor and the City Fathers—with some of whom he had been apprenticed many years ago in the engineering industry—for their very genuine support of the Conference.

The vote of thanks was accorded with acclamation.

The Lord Mayor briefly responded.

Investitures and Votes of Thanks

Mr. Bigg invested Mr. Hepworth with the Presidential Badge, which was an earnest of the co-operation of every officer and member of the Institute, and, inviting him formally to occupy the chair, wished him a very happy and successful year of office.

Mr. Hepworth occupied the chair, amid applause, and he presented to Mr. Bigg a Past-President's badge, with the best wishes of the Institute as a whole, and the hope that he would wear it for many years to come.

Mr. Bigg, returning his thanks, said there was a sadness in all finality; he had surrendered an office in which he had been perfectly happy and of which he was thoroughly proud. He expressed his appreciation of the friendship and the kindly co-operation which had been extended to him from every quarter.

Mrs. Bigg then invested Mrs. Hepworth with the badge worn by the wife of the Institute's President.

Mrs. Hepworth replied.

The badges worn by the Senior and Junior Vice-Presidents were then presented to Mr. W. B. Lake and Major R. Miles.

Greetings from Overseas

Telegrams conveying good wishes for the success of the conference were received from Mr. Steinbach, the International Chairman of the American Foundrymen's Association, and from Mr. Sandre, the President of the Association Technique de Fonderie.

Welcome to Overseas Members and Visitors

The President extended a hearty welcome to Herr G. Gürtler, of Frankfurt-on-Main, Germany; Mr. W. Mason (a Member, from Bombay); Mr. Simpson (a Member, from Hong Kong); Mr. Schofield (from India); Mr. F. G. Williams (from India) and Mr. D. A. H. Spring (from Australia). The West Yorkshire Branch, he said, would do all it possibly could to extend to them real Yorkshire hospitality, and he hoped their visit to Bradford would prove to be both profitable and pleasurable.

Mr. Hepworth then delivered his Presidential Address.

PRESIDENTIAL ADDRESS

Mr. Bigg and Gentlemen:—

The Presidential Address given to an Institute of this kind frequently makes reference to the last occasion upon which a Conference was held in the same area. No such reference can be made on this occasion, because this is the first time that the West Riding of Yorkshire Branch has had the pleasure of entertaining the Annual Conference. It is a pleasure which has been anticipated by the members of the Branch for a long time; they have put much thought and energy into the preparations, and on their behalf I extend to you all a sincere welcome to the West Riding of Yorkshire, and to the City of Bradford in particular.

Industrially, Bradford is associated in the minds of most people with wool, and quite rightly so, for it is the centre of the largest woollen manufacturing area in the world, and makes the finest material in the world. It is, however, an important engineering centre, and historically it has played an important part in the development of engineering and in the development of iron manufacture.

The changes and developments in the iron industry and in engineering in Bradford are, to some extent, typical of those which have taken place throughout the industrial world. Additionally, Bradford has made an individual contribution of its own to the manufacture of certain classes of iron; I feel that it would be of some interest to review briefly these changes and developments.

Monastic records show that monks were engaged in the extraction and manufacture of iron in and around Bradford from very early times, the monks of Rievaulx Abbey having been granted mineral rights, in districts now part of the city, in the year 1150. From that time onwards the ancient chronicles make frequent references to forges in the locality. Developments on a large scale, however, may be said to date from the close of the eighteenth century.

Early Metallurgical Developments

Although Bradford can hardly be classed as an iron-making district with such districts as, say, South Staffordshire and Cleveland, it has the distinction of being the birthplace of the highest grade of iron in the world. A village, now within the city boundary, has given its name to this class of iron, which is known as "Low Moor iron." In addition to the Low Moor Iron Company, other firms in the district, namely, the Bowling Ironworks at Bradford and the Farnley Company, Cooper Brothers, and the Monkbridge Company at Leeds, embarked upon the manufacture of this class of material under the name of "Best Yorkshire Iron."

No account of the iron industry of the district would be complete without some description of the two famous works already mentioned, namely, the Low Moor Iron Company and the Bowling Ironworks, for they undoubtedly influenced the local engineering industry to a considerable degree, inasmuch as many of the founders of other firms in Bradford served their apprenticeship at one or other of the works.

The Low Moor Company had its inception in 1789, when the Lord of the Manors of Royds

Hall and Wibsey was forced to dispose of his estates, which passed into the hands of three gentlemen, Messrs. Hird, Dawson and Hardy. These gentlemen built up the Low Moor Works, which was carried on for one hundred years under their name before it became the Low Moor Iron Company, Limited. The foundation stone of the first blast furnace was laid in 1790. The furnace was built of stone and was 50 ft. high. It was, of course, hand fed, but as early as 1800 a mechanical charging system was introduced, the tubs of raw material being hauled up an inclined plane and automatically tipped. The blast was provided by a beam engine, designed by the company's engineer, Mr. John Smalley, and was built locally by Emmets, of Birkenshaw. It was of the Boulton & Watt type, with a single-acting open-topped steam cylinder, 5 ft. diameter, at one end of the beam, and a single-acting blowing cylinder, 8 ft. 5 in. in diameter, at the other, the stroke being 9 ft. 6 in. in each case. This engine did duty until the erection of new furnaces in 1892, and was preserved in perfect condition at the works for several years after. The new furnaces had capacities of 340 and 240 tons per week, and produced the famous Low Moor cold-blast pig-iron known to all foundrymen.

Coincident with the erection of the first blast furnace, a foundry was opened by Messrs. Hird, Dawson & Hardy. The output during the first few years was mainly colliery tub wheels for the company's collieries, cast-iron rails, pillars and general hardware, but attention was then devoted to the manufacture of cannon and shot, and in 1854 the weekly output of ordnance amounted to several hundred tons. During this period the company also turned its attention to the manufacture of engines, pumps and heavy machine tools, which were made for firms all over the country. It was, however, in the manufacture of the famous Low Moor wrought iron that the company was supreme; the plate mill was the largest in the country, whilst it is interesting to note that the piston rods, crankshafts, crank pins, etc., for the "Great Eastern" were forged here.

A few years ago the works was dismantled; one small portion remains, however, where Best Yorkshire Iron is still made. At the height of its fame the company's collieries covered an area of 8,000 acres, the ironstone mines had 73 miles of underground roads, all laid with cast-iron rails, and the works also occupied a vast acreage.

The Bowling Ironworks

The Bowling Ironworks was established a few years prior to that at Low Moor. The valuable nature of the local mineral deposits was first recognised by several business men, amongst whom were Mr. John Sturgess, of Wakefield, an ironmaster of some repute, and a Mr. John Paley, of Leeds. In 1784, they, with others, set up the first foundry at Bowling for doing foundry and smiths' work, and a brisk trade was done in flat irons, posnets, ovens, boilers, sash and clock weights. It was not until the year 1788, however, that works was established at Bowling for the smelting of iron ore, three years before the sister works at Low Moor. The works was very small during the first few years, but in addition to the domestic products, heavy guns, carronades, howitzers, as well as shot and shell were made. The Bowling cast-iron guns, shot and shell did splendid service at the battles of Trafalgar, Waterloo, the bombardment of Algiers, and at other historic battles on land and sea. Cast-iron guns were made at Bowling up to the time of Sir William Armstrong's invention of the improved wrought-iron guns, and it is interesting to note that some of the first coils to be used by Sir William for the latter were made of Bowling wrought iron.

The commercial enterprise following upon more peaceful times involved equal enterprise on the part of the Bowling Company, which at a later period turned out from their rolling mills large quantities of rods and bars, as well as boiler plates, sheet iron, angle and tee iron, weldless tyres and weldless hoops for steam boilers; from the forges, all kinds of heavy and light forgings, axles, shafts, piston rods, cranks, etc., and from the engineering shops, boiler shops and foundries, the largest classes of factory engines, pumping engines, rolling-mill engines, steam presses, etc. Old hands used to refer with pride to a pair of oscillating cylinders each over 30 tons in weight, and each made in one piece; also to flywheels of ponderous size which were made for various firms. During the late nineteenth century the manufacture of steel was also undertaken, and the steel foundry attained a reputation for steel castings of the largest size. The company's mineral resources were, however, rapidly becoming exhausted, and in 1896 the works was dismantled. Luckily for the local workers the engine shops were taken over by a Dewsbury firm, Bever, Dorling & Company, Limited, who transferred their business to Bradford in 1902. This firm had a world-wide trade in sugar-refining plant, and were also famous for mining plant, their products being found in practically every well-known colliery in the North of England.

Textile Engineering

Normally, the name of Bradford is associated with the textile industry, and the large engineering trade which was carried on in the city in the early part of the century is unknown to the majority of people. About 1900, Thornton & Crebbin were supplying marine-engine cylinders to all the leading shipbuilders in the country in sizes up to 108 in. diameter and 25 tons in weight. It is interesting to note that H.M.S. "Invincible," which was Admiral Sturdee's flagship at the battle of the Falklands; H.M.S. "Thunderer," which fought at Jutland, and the ill-fated "Hampshire," which was lost when carrying Lord Kitchener to Russia, were all engined by the firms to whom Thornton & Crebbin supplied the necessary cylinder castings. It is a lasting testimony to this firm that situated as they were, many miles from the sea, with heavy carriage costs, they were able to compete successfully in such a market. Unfortunately, this concern has passed on, the business being taken over by Cole, Marchent & Morley, which was founded in 1848 by John Cole and James Marchent, both of whom were employees of the Bowling Ironworks. The business was acquired in 1890 by Herbert Morley, who received his training in the Bradford Technical College, being one of the first of the day students. He was instrumental in introducing the manufacture of the Diesel engine in 1911, and his firm also played a large part in the introduction of the "Uniflow" or "central exhaust engine" in this country. In this connection, another local firm, Newton, Bean & Mitchell, shared the honours.

Another famous firm of a few years ago, and one whose name will be familiar to the majority of foundrymen, was Thwaites Brothers, who were identified with the manufacture of steam hammers, forge and smithy plant, Roots' blowers, cupolas, steel converters, ladles and foundry and metallurgical equipment in general. During the war, this firm laid down a large steel foundry for the production of steel castings from the electric furnace, in particular steel wheels for lorries and buses, but the falling-off in demand, consequent upon the post-war depression, brought this venture to an end.

Existing Conditions

At the present time, heavy castings of the type required by the old engine builders are not being produced in the city, but there is, nevertheless, quite a considerable foundry industry, mainly of a jobbing nature, as well as foundries associated with some of the larger engineering firms. There are also several firms which have built up successful businesses in the manufacture of specialities, and although it is difficult to forecast the future development of the foundry industry of the city, prosperity possibly lies in the extension of such specialised manufacture.

It is a curious fact that, with the exception of looms, the machinery in the Bradford trade is obtained almost entirely from sources outside the city, and it is a fact that many advantages would accrue from the encouragement of the machine making branch of local engineering. The success, however, depends on a prosperous textile industry, which is itself a matter of conjecture as regards the future.

The Work of the Institute

The story of ironfounding in Bradford is one which shows many changes—changes which have been made necessary both by developments in the industry itself and by other outside factors. Furthermore, it is probably only representative of the changes which have taken place in the whole foundry industry throughout the country during the last fifty or sixty years. It is to be expected that this Institute, which in a little over thirty years has developed from but a small group of inquiring foundrymen to a strong national body, should reflect the progress of the industry which it serves. Such progress is indicated by the Incorporation by Royal Charter in 1921; the formation of the Technical Committee in 1931, and the foundation of the many medals and prizes which foundrymen have so generously given for the benefit of the Institute and the honouring of its members.

The changes which have taken place in the industry, in its technique and in its methods during the last twenty years, and increasingly so during the past five years, have had their effect upon the personnel. Positions which at the end of the war were considered to be of little importance have developed to-day into posts where a considerable amount of executive ability is required. The growth of specialisation, the application of technical knowledge to the various foundry processes, and the increasing use of mechanical appliances, have created new posts in the industry, and in addition to the foundryman of long practical experience, the industry to-day contains many men who combine experience with technical knowledge.

Since the granting of the Royal Charter in 1921, the Institute has definitely increased its usefulness to its members. For example, the Technical Committee has been in existence for some seven years, and in that time it has been of considerable help to the industry as a whole, and to many individual members. International relations have been established and extended, our own membership has increased overseas, and we have now a flourishing Branch in South Africa. Relations with other scientific associations have been closely cemented, and the Institute has carried out a great deal of work in connection with the development of foundry technical education.

The Annual Reports of the past few years contain particulars of many other developments, some national in character, some comparatively small, but all of them of importance to the industry and the members of the Institute. The immediate value to the individual members of some of the developments to which reference has been made is not always apparent, but the possibilities are not by any means exhausted, and the Council and various committees are at present engaged in investigating various lines of further development with a view to giving increased services to the individual member.

Thus I have entered upon my year of office at a time when, I believe, much of the work which has been carried on during the past few years will be completed, and will be passed on to the members of the Institute and to the industry which it serves. I feel. too. that the various developments which are at present being formulated, and the new programme of work under consideration, will, when the time comes for me to vacate this chair, have formed some definite step upon which we can safely tread, with the assurance that we have made yet further progress.

In conclusion, I would like to say a word or two about our export trade, realising as I do that it is of vital importance to our existence as a nation. For a moment I will confine my remarks to Empire trade. The Empire possesses as a buying power a population of 500 million people, and I think that every business man and industrialist will agree that a market of that magnitude, bound to us in many ways, such as common policies, tradition and language, is a market that ought to be well worth striving for.

The Empire overseas to-day bought more goods than all the rest of the world, in addition to buying 209 million pounds worth of foreign goods. Some of you may ask what these figures and Empire trade mean to the foundry trade; it means this—if our export trade is strong and healthy, our foundry industry is bound to be in a healthy condition. Therefore, let us try to do all we can to develop mutual confidence and sympathy, so far as is practicable with our Empire overseas; the world is by no means a saturated market, especially within the Empire, and if we here at home do not seek this increasing trade, other countries will.

The main conditions of industrial welfare and expansion are security and the confidence which flowed with it, and these must be based upon peace amongst the nations of the world, and all factors operating against peace must be removed and overcome if our industry or any other industry is to go forward.

Mr. Bigg proposed a hearty vote of thanks to the President for his address, which included a most interesting historical survey of the founding industry in Yorkshire and some thoughts on the outlook for the future.

The vote of thanks was carried with acclamation, and the President briefly responded.

The Conference then divided into two sessions. Session A was devoted to more general Papers, and was under the chairmanship of the President, whilst all Papers dealing with non-ferrous metals were presented and discussed in Session B, over which Mr. W. B. Lake, J.P., Senior Vice-President, presided. Papers presented and discussed in Session A were:—" The Randupson Process of Cement Moulding," by F. W. Rowe, B.Sc.; " Relief of Internal Stress in Castings," by L. E. Benson, M.Sc., and H. Allison, B.Sc.: and " English and American Steelfoundry Practice," by C. J. Dadswell, Ph.D., B.Sc.(Eng.), Ing.E.S.F. Papers presented and discussed in Session B were as follows:—" Heat-Treatable Aluminium-Silicon Alloys," by Monsieur Gauthier (presented on behalf of the Association Technique de Fonderie); " Aluminium Casting Alloys," by Dipl.-Ing. G. Gürtler; and " Some Physical Factors in Casting High-Strength Brasses," by J. E. Newsom, M.Met.

After luncheon, which was taken at the Connaught Rooms, Manningham Lane, the following works were visited by members:—Wm. Asquith, Limited, and Modern Foundries, Limited; Fairbairn Lawson Combe Barbour, Limited; John Fowler & Company (Leeds), Limited; and Prince-Smith & Stells, Limited.

The ladies inspected the factories of John Foster & Son, Limited, and Price's Tailors, Limited.

THE ANNUAL BANQUET

In the evening of Wednesday the annual banquet was held at the Connaught Rooms, Manningham Lane. The President and Mrs. Hepworth, with the Lord Mayor and Lady Mayoress, received the members and guests, who enjoyed a very happy evening.

The guests included Sir Anthony Gadie; Alderman J. W. Longley, J.P.; Mr. H. Holdsworth (M.P. for Bradford South) and Mrs. Holdsworth; Alderman S. Horsfall, J.P., and Miss Horsfall; Captain L. J. Sarjeant, O.B.E., and Mrs. Sarjeant; Principal H. Richardson (Bradford Technical College).

The Toasts

The Loyal Toast having been honoured, the President proposed " Our Guests," and said that they were distinguished in many walks of life. In the first place, he mentioned the visitors from overseas. There were also distinguished representatives of the City of Bradford, whom the members of the Institute were delighted to welcome. In a tribute to the Lord Mayor and his colleagues on the City Council, he said he had wondered what was the main reason for their spontaneous generosity on the occasion of the Bradford Conference, and had concluded that it was the fact that the Institute was intent upon developing the practical and scientific sides of the industry, for the Bradford City Council had always been pioneers in matters of education. He paid tribute to Alderman Horsfall as a stalwart of the City Council; and to Alderman Longley, the Chairman of the Technical Education Department, and to his Committee, who had placed the Technical College at the disposal of the Institute for the purpose of its meetings, and would entertain them the following evening.

The **Lord Mayor**, in his response, said that he and his colleagues on the City Council were happy to be present and to wish the Institute well. In a reference to industrial affairs in Bradford, he said they had been under the impression that when the iron and steel trade was busy, prices in the wool trade were good. But at present, for the first time in 50 years, he was told, although the iron and steel trades had been busy making money, the soft goods trades had been losing money.

However, he and his colleagues and fellow guests were grateful for the manner in which they had been entertained, and were enjoying a happy evening in good company.

The Engineer and the Foundry

Capt. L. J. Sarjeant, O.B.E., proposing "The Institute of British Foundrymen," made a brilliant speech, in which he said that when he was asked to propose the toast, his first reaction was to refuse, on the ground that there were others more competent than he; but after a little thought it had appealed to him as a pleasure, for he occupied a very interesting position, inasmuch as he was closely in touch with the foundry, though definitely he was not of the foundry. Therefore, he had delved into the archives of the Institute and had read a number of its Papers.

The foundry, he continued, was one of the most important, if not *the* most important part, of the works which he controlled, and his contact with it was of intense interest. Its products were needed in every portion of the things which his organisation produced, and they were needed at a very early stage.

He was intensely interested in the art of the foundryman, because when difficulties arose it was found that there had been some change, though perhaps only a very small change, in the production of the castings. For that reason he could see clearly the part which the Institute must play in the development of a great industry. To him, although an outsider, successful founding was clearly a matter of extreme accuracy and intense precision, and he did not see how it was possible for the industry to progress as it must and would do without the help of the Institute, which was controlling, centralising and distributing knowledge. The foundry was the beginning, and it remained the foundation, of the engineering industry, and he visualised that the part it played would be woven more and more deeply into the structure of the nation and of industry as a whole in the future.

The part played by the engineering industry in the future would be similar to that of the doctors of the medical profession. When discoveries were made and difficulties were overcome by doctors, the results were made known immediately to the whole profession, to be used for the benefit of suffering humanity. Similarly, when difficulties were overcome in the future in the engineering world, the information derived would be made free to all engineers, for the benefit of suffering industry; and, as the result of delving into the archives of the Institute and reading Papers presented to its members, he felt that the founding industry was perhaps further along that road than was the rest of the engineering calling.

Mr. C. W. Bigg (immediate Past-President) said he was honoured to be asked to respond to the toast, proposed so ably, wittily and gracefully by Capt. Sarjeant.

Expressing appreciation of the kind references made to the activities of the Institute, he said that when he was installed as President, a year ago, he had had a very great affection and respect for the Institute, and as the result of his year of office his respect and affection for it had become greater than ever. That a large number of men, who were already very busy, should devote time and effort, and to a considerable extent their money, not only to increasing their knowledge of their own particular jobs, but also to passing on their knowledge to others, was an ideal state of affairs, worthy of the admiration of everybody.

The Institute had achieved a great deal. But one of the factors in its working which he had noted was the existence of what might be called a form of divine discontent, which expressed itself in an urge on the part of its members not to allow themselves to be satisfied with their accomplishments, but to strive all the time for new and greater achievements. They could not stand still; the conditions and circumstances by which they were surrounded were continually moving, and unless they as an Institute kept pace with progress they would go back. They could claim to have taken a very large share in the developments which undoubtedly had taken place in the industry during the last two or three decades. Whatever the opinions they held with regard to any one particular problem which faced the Institute, the members were unanimous in their ambition to ensure that the Institute should continue to be among the leaders—and he had every confidence that that ambition would be realised.

Presentation to Mr. Wise

After the formal speeches, a presentation was made by Mr. A. S. Worcester (President of the West Riding Branch) to Mr. S. W. Wise (Hon. Conference Secretary) in recognition of his hard work in connection with the organisation of the conference. Mr. Worcester said he was particularly happy to have the opportunity to make the presentation, for he had been a colleague of Mr. Wise 30 years ago in Messrs. Willans & Robinson, of Rugby, and it was a pleasure to be associated with him also in the West Riding Branch. The organisation of the conference had entailed an enormous amount of work, the three outstanding personalities in connection with which were Mr. H. Forrest (Chairman of the Conference Committee), Mr. Thornton (Hon Conference Treasurer), and Mr. Wise, who was the ideal Secretary of the West Riding Branch.

In making the presentation, which took the form of a tankard and a cheque, Mr. Worcester wished Mr. Wise good health, and " strength to his elbow."

Mr. Wise, in expressing his thanks, said he had been a member of the Institute for many years, and had always enjoyed contact with his fellow members; never had he worked with colleagues with such unanimity as had been in evidence throughout the organisation of the conference. He could not have carried on without the active support of all of them.

Presentation to Mrs. Bigg

A second presentation was made by the President to Mrs. Bigg for the part she had played in making Mr. Bigg's year of office so successful as it had been. It took the form of a pair of silver candlesticks and an ashtray.

Mrs. Bigg, in response, made another of the happy speeches for which she is becoming noted.

Following the banquet, the members and their ladies enjoyed dancing until a late hour.

THURSDAY, June 6

The Conference resumed at the Technical College at 9.30 a.m., when a technical session was held in the Great Hall. The following Papers were presented and discussed:—"Chemical Changes of Cast Iron in Cupola Melting," by Dr. J. T. MacKenzie; "Copper in Cast Iron," by A. J. Nicol Smith, B.Sc. (arranged by the British Cast Iron Research Association); "Modern Manufacture of Machine-Tool Castings," by J. Blakiston, A.I.Mech.E.; and "Sand Blasting as Applied to the Vitreous Enamelling Process" by H. Whitaker, M.Sc. (arranged by the Institute of Vitreous Enamellers).

The Conference was adjourned at 12.30 p.m., and luncheon was taken at the Connaught Rooms. In the afternoon members visited the works of Hepworth & Grandage, Limited; J. Blakeborough & Sons, Limited; Thos. Broadbent & Sons, Limited; and Hopkinsons, Limited.

Parties of ladies were able to visit the factory of John Mackintosh & Sons, Limited, and that of Patons & Baldwins, Limited.

Conversazione

In the evening members and ladies, together with a number of distinguished citizens of Bradford, were entertained to a conversazione at the Technical College, at the invitation of Alderman J. W. Longley, J.P., Chairman of the Technical Education Sub-Committee, and of other members of the Committee. Guests were received in the main hall of the College by Alderman Longley, and by the President and Mrs. Hepworth.

The various departments of the College were then inspected under the guidance of students, and demonstrations were arranged in each department by the members of the staff and senior students.

The evening's programme included dancing in the College Hall, which was beautifully decorated by the Bradford Corporation Parks Department. and the company were entertained to refreshments by their hosts. At an interval in the proceedings, **Mr. J. Hepworth**, the President of the Institute, expressed to Alderman Longley, and his colleagues on the Technical Education Sub-Committee, his thanks for their hospitality. **Alderman Longley** responded and expressed the pleasure of himself and his colleagues at the opportunity of entertaining the Institute.

EXCURSION THROUGH THE DALES

As is customary, the last day of the Conference was given over to an excursion, and this took place on Friday, June 17, enabling the party to see some of the most beautiful scenery in the Yorkshire Dales.

The party left either Bradford or Leeds by motor coach, the first halt being made at Harrogate, where coffee was served in the Valley Gardens. The journey was continued to Ripon, where luncheon was taken at the Spa Hotel, which is beautifully situated in extensive grounds on the outskirts of the city. After luncheon the opportunity was taken to tender the thanks of the members and ladies to the officials of the West Riding of Yorkshire Branch for their hospitality, for the work which they had carried out in connection with the Conference, and to congratulate them upon the success of their efforts.

Mr. C. W. Bigg (immediate Past-President) voiced the thanks of the Institute, and assured the West Riding of Yorkshire members that all those visiting the Conference had enjoyed it, and appreciated fully all that had been done for them. Mr. Bigg's remarks were supported by

Mr. H. Winterton (Past-President), who stressed particularly the work of Mr. S. W. Wise, the Secretary, and Mr. H. Forrest, the Chairman of the Conference Committee.

Mr. S. W. Wise, in replying, said that he was glad that Mr. Forrest had been particularly associated with the remarks, and paid his own personal tribute to the valuable co-operation which he had had from Mr. Forrest.

The journey was continued during the afternoon by way of Masham and Leyburn and along Wensleydale. A halt was made at Aysgarth, and opportunity was taken to lay in stores of Wensleydale cheese. The party then proceeded along Bishopdale and entered the upper end of Wharfedale, passing through Buckden to Burnsall, where tea was served at the invitation of the President and Mrs. Hepworth.

Mr. and Mrs. Hepworth were thanked for their hospitality, on the motion of Mr. V. Stobie, seconded by Mr. D. Sharpe. Mr. Hepworth replied on behalf of Mrs. Hepworth and himself.

The journey continued along Wharfedale, another halt being made at Bolton Abbey, and terminated at Bradford, one coach calling at Leeds *en route*.

ADJOURNED ANNUAL GENERAL MEETING

The annual general meeting of the Institute of British Foundrymen, which was adjourned from June 14, 1938, was resumed at the Engineers' Club, Albert Square, Manchester, on Saturday, October 15, Mr. C. W. Bigg presiding.

Consideration was given to the following items on the agenda of the meeting of June 14, namely:—

To propose:—

(12) "That the Bye-Laws so altered and added to and as contained in the print laid before the Meeting be and the same are hereby adopted as the Bye-Laws of the Institute in lieu of the present Bye-Laws such present Bye-Laws to cease to have effect and the Bye-Laws so adopted to come into force and effect when and so soon as the approval of the Privy Council to the Bye-Laws so adopted and the certificate of approval under the hand of the Clerk of the Privy Council have been obtained."

(13) In the event of the Bye-Laws being adopted it will be proposed:—

"That the Council be and it is hereby authorised to take all necessary steps to obtain the approval of the Privy Council to the newly adopted Bye-Laws and for such purpose if necessary to seek the granting to the Institute of a Supplementary Charter."

(14) Any other business.

The **President** explained that the meeting had been adjourned from June 14 in order to continue a discussion on a resolution which was proposed by Mr. S. H. Russell, and seconded, he believed, by Mr. Winterton. At that meeting there was some discussion as to the legality, first of all, of an adjournment. In order to make the position quite clear he was going to ask Mr. Makemson to read the legal opinion upon the point.

Mr. Makemson (Secretary of the Institute) stated that the solicitors who had been giving advice with regard to the bye-laws had stated it was perfectly clear that a body, constituted as was the Institute, had the power to adjourn a meeting to a convenient date, and a resolution passed at such an adjourned meeting would be just as valid as if passed on the first date of the meeting. Indeed, the two meetings together were the annual general meeting.

The Chairman then called upon Mr. S. H. Russell to open the discussion by recounting the procedure to date.

Mr. Russell thought it would not serve any useful purpose if he spent some considerable time going over the history of the changes in the bye-laws. At Bradford there were two outstanding things in the discussion which arose. First, some members made a point quite clear. They were particularly members who were not definitely or conveniently attached to any Branch. As they all knew, many members could not conveniently attend Branch meetings. It was found that such members were, to a great extent, unfamiliar with the proposals which were before the annual meeting. For that reason, the Organisation Committee decided to circularise the memorandum to all classes of members, which was received about a month ago. It was a four-page leaflet, and really contained everything as regarded the history and the reasons for the suggested alterations to the bye-laws.

A second objection, and perhaps a more important objection, which was raised at Bradford was to the increase in subscriptions. That point, of course, would be further discussed that afternoon. Nothing in the previous discussion at Bradford could be said to have altered the unanimous recommendation of the Organisation Committee that the bye-laws should be adopted. Supposing the subscriptions were increased, he did not think it would serve any useful purpose if he elaborated the point for the moment, as to the particular reason why they should be increased. The matter had been gone over before. The Organisation Committee were fully convinced it was necessary for the well-being of the Institute that the subscription income should be increased.

The **Chairman** then announced that the Secretary had received a number of letters with reference to the resolution to increase subscriptions. He asked him to read them.

Mr. T. Makemson accordingly read the letters protesting against an increased subscription, and also a number of letters in support of the proposals.

The **Chairman** said he had no desire to restrict in any way the opportunity of any member to express his views on the matter under discussion. He was anxious that there should be a thorough expression of opinion, and he was sure that all present would appreciate the desirability of every speaker keeping to the point and coming to a finish as quickly as was reasonably possible.

The Position in Scotland

Mr. Daniel Sharpe (Scottish Branch) regretted that Mr. Ballantine was unable to be present, as he officially represented the Scottish Branch. He hoped that the attitude of the Scottish Branch would not be misunderstood. He thought that Mr. F. J. Cook, in his letter, had clearly set out the position of the Scottish Branch, although he had tried to state the negative case. It would appear almost as though the Scottish Branch had a peculiar membership in so far as they had a very large number of operatives. When compared with, say, the London Branch, who had a minimum of workshop members, it was well that they should appreciate the point of view expressed by the Scottish Council. He would like to assure them all that at the last meeting of the Scottish Branch appreciation was expressed for the work done by the Committee, and the Scottish Branch were very sincere in believing that that Committee were acting for the very best interests in their own view, and according to the information they had before them. In the Scottish Branch they had a large number of members who were operatives and also members in junior executive positions. The view which had been expressed at Bradford on their behalf was much the same as the view which was held that day, namely, it was feared that by increasing the subscription the original intentions of the association would be hampered.

Mr. R. A. Miles (Manchester): In what way will it do that?

Mr. Sharpe replied that in Scotland they believed in giving good value for money as well as expecting value for money. They did not want to give less than what a man was paying for. From the point of view of the man on the floor he thought that they ought to be careful and see that they were not going to put the man in the position of saying: "Well, it is not worth while," and dropping out. He just raised the point that they should be quite conscious there was no desire on the part of the Scottish Branch to belittle the work of the Committee who had been to a great deal of trouble and had done their work so well. Nevertheless, they ought to keep in view the original intention of the association to bring the operatives into touch with them all. Perhaps they were unfortunate in Scotland from the point of view of having such a number of their active members who were men working on the floor. He did not wish to enlarge on the situation from the point of view of the increase of subscription. His personal point of view, and he thought also that of his colleagues who were present upon that occasion, was that the increase mattered very little. They did want to know whether the man on the floor was going to get value for his money. It was quite appreciated that the medium-class man was not going to suffer very badly, while the actual junior was going to be better off to the extent of sixpence. It was not a case of bargaining as to whether they were going to pay a pound more or a pound less. It was necessary to consider whether they were likely to sacrifice a type of member whom it was desirable to have in the association.

Pessimism at Newcastle

Mr. C. Lashly (Newcastle Branch) felt that Newcastle must associate themselves with the Scottish Branch. Mr. Gresty, who was their President last year, had already expressed himself on the point, he thought. The membership of the Newcastle Branch was made up of about 65 per cent. of men who were operatives. There was not the slightest doubt that when the new terms of the subscription were mentioned to them those men would leave. Newcastle felt very strongly that it would mean the breaking up of the Newcastle Branch.

London's Approval

Mr. C. C. Booth (London Branch) could not understand what the Scottish people really had to complain of. He thought they all appreciated that they opposed the proposition, and this was to some extent an advantage, because it had enabled all the members to obtain a fuller grasp of what the Organisation Committee were doing. He could not understand why anyone should think they were trying to exclude the operatives; as a matter of fact, they were trying to do more for them. Their subscription was not more; he believed it was less. In some cases they could get in for 5s. If the Institute became a more powerful body surely they could do more for their members. At the present time he did not think the Branches did a great deal for them. A certain number of lectures was provided for, though they were not all published.

In London they were not able to get all the operatives to attend meetings, because they covered such a large area. The meetings had to be held in a central place in the West End, which involved the men having to travel long distances, as the foundries were very widely scattered. They were unanimous in their support of the proposition at the meeting in London.

Mr. T. Makemson then read the details respecting the proportion of the different grades of membership in each Branch of the Institute.

Fifteen Per Cent. Operatives

Mr. V. Delport (London Branch) said that it seemed apparent the objections to the scheme had been made on behalf of a particular class of membership, namely, the operative or the man who worked by manual labour. It was apparent also that that class of membership constituted about 15 per cent. of the total membership of the Institute. He was, of course, open to correction on that point; but he thought it was also the fact that 15 per cent., or the large majority of such operatives, were associates.

He could not help referring to a statement made at the previous meeting, on behalf of some of these men, to the effect that they were not interested in an increase of status of the Institute, and they did not want it. Speaking from the floor himself, and not as a member of the Committee, this seemed to be an indefensible attitude. In his opinion, any man who belonged to an organisation, whether it be an Institute, a business, a club, or a church who was not interested in the development, the prestige and the increase of influence of such organisation was not much use to his organisation, nor was he much use to the other members of his organisation. The best thing to do with that type of argument was to dismiss it from consideration. He would now come to what he termed the solid objections. They seem to come under two headings; namely, (1) increase of subscription, and (2) qualification. It should be remembered that they were dealing, in fact, with a number of men the majority of whom at the present moment either were or would be eventually Associates of the Institute. As regarded the new rules, they were going to be asked to pay a subscription of 10s. as against the 10s. 6d. they were paying at the present time. Therefore, far from there being an increase in their subscription, there would be a slight decrease.

Qualifications

A new provision was being made in the rules for young men under 21 years of age only to pay 5s. Therefore, there was no financial hardship in the new rules as they applied to the particular class of men on whose behalf the objection had been made.

Were they getting less for their subscriptions? No! They were going to get exactly the same advantages they were receiving at the present time. In addition, if the scheme went through it would put the Institute into such a position that in future it would be able to do more for their particular class as well as for the other members of the Institute.

With regard to qualification, at the present time any operative could join the Institute without qualification, if they were of the age of 21. In his opinion, the objections put forward on behalf of the men referred to fell to the ground, and he could not see any reason why Resolution No. 12 should not be passed unanimously.

Improved Finances

Mr. J. Gardom (Birmingham Branch) spoke in favour of the resolution being passed. He thought the objections of the operative had been suitably dealt with by previous speakers. He considered that, if the resolutions were passed, in a few years the Institute would be £1,000 per year better off. Assuming that the increase of revenue was only £500 it would enable them to do a great deal more for the operative. He had almost made himself unwelcome on the Technical Committee by forcing men who were doing a job every day to do some work at home at nights for the benefit of the operative. He would not recapitulate all the work done in that respect, but they had published three major reports of interest to the operative. First, there were the "Typical Microstructures of Cast Iron and Malleable Iron," secondly there was the Malleable Cast Iron Sub-Committee's report on "Dimensional Tolerances," and thirdly there was the Cast Iron Sub-Committee's report on the "Properties of Grey Cast Iron." Could anyone say that those three publications were of no advantage to the operative? He thought not. It was in the province of the Institute to bring the operatives into the organisation and to improve the standing of those men. It was only fair to assume that more could be done for their benefit if there was more money applied to that purpose.

West Riding Approval

Mr. A. S. Worcester (West Riding of Yorks. Branch) thought there was one point which must not be lost sight of. Many Associate Members were actually operatives or worked in the capacity of minor foremen. They had become Associate Members chiefly in order to get the Proceedings, and he thought they were the largest number of members to be affected by the proposed alterations. Actually they were better off under the new bye-laws. According to the circular which was sent out, under the new bye-laws they could be Associates and purchase the Proceedings for 8s. In the West Riding Branch, he claimed that they had perhaps more members in actual contact with moulding or on the floor or as minor foremen than any other Branch in England. In his Branch, the proposed alterations of bye-laws were certainly not viewed with alarm.

Mr. F. A. Harper (Lancashire Branch) said that Mr. Worcester rather seemed to infer that an Associate member, wanting to economise, would immediately spend 8s. instead of 30s. There were something like 1,000 Associate Members.

A Question of Grading

Mr. J. Cameron, junr. (Scottish Branch), speaking from the point of view of the Scottish Council, said they had very few Associates. He thought six was the total number. Their operatives were Associate Members. It was a much greater thing for a practical man on the floor to pay his extra 10s. 6d. than it would be for people such as himself. Such a man would probably have to revert to being an Associate as opposed to continuing as an Associate Member. Should they not include provision to enable the man on the floor, who was an Associate Member, to be an Associate and still derive the benefits of the Institute by attending meetings and taking part in discussions. He could buy the Proceedings if he desired. It was a point upon which he would like to be quite clear—the transference from Associate Membership to Associateship.

Mr. Makemson said it was implied that any member of the Institute could transfer to any other grade if he was qualified for that grade. In other words, a man who was an Associate Member at present, but who fulfilled the qualification for Associateship as detailed in the rules, could transfer to Associateship.

Mr. J. Cameron, junr., read the following paragraph:—

> "An operative engaged in the founding industry shall be entitled to remain in membership as an Associate irrespective of age. No other person, unless elected an Associate prior to June 1, 1938, can retain membership as an Associate after attaining the age of 28 years."

He submitted there was a definite number of minor foremen who could not be classed as operatives and on whom Associate Membership was a burden.

Mr. Makemson said it would not apply to minor foremen.

A Student Member said there was a small number of students in the Institute, and they were always hearing foundrymen deploring the fact that there were very few young people who took an interest in foundry work. Very few young men actually wanted to go into the foundry, whereas they would go into other trades. If the status of the Institute were raised, there would probably be many more students joining, and working their way up to responsible positions in the foundry world.

Falkirk Section

Mr. T. Shanks (Scottish Branch) said that a considerable number of members in the Falkirk district felt that the difficulty could be overcome by forming another grade of membership, who wished for some technical qualification. This had evidently been done before in the Institute, and the subscription had been raised from 10s. 6d. to a guinea. The Falkirk Section felt very strongly about the point, and he believed there would be a big change in that district, unless something of the sort was done. Another point was that all Associate Members were proud of being members of the Institute, and hoped to continue to be members. The new bye-laws were not generally acceptable by the Associate Members. He felt that the meeting should give opportunity to those members who were unable to attend to voice their opinions.

Graduation of Increase Suggested

Mr. J. J. McClelland (Wales and Monmouth Branch) was of opinion that the Associate Member was not the most difficult member from whom to collect subscriptions. He did not think the Institute would be so much penalised from that side as they would be from the full Membership. As a matter of fact, he was recently told by a full Member that he did not get very much for his money. The meeting knew his opinion about the matter. He still held the view that if the move was made by a graduated method it would be much more successful. There would be much less dissatisfaction, and he did not see any reason as yet for altering his opinion. If the meeting was not going to accept his suggestion, it left him no alternative but to vote against the resolution.

A Representative Meeting

Mr. Ben Hird (Wales and Monmouth Branch) remarked that the present meeting was called because it was felt that there was not sufficient time to discuss the subject at Bradford, and that there should be a chance afforded for the operative member to give his opinion. It would have been thought that the operative member would have made an effort to attend from some of the Branches. Even if it cost something to do so one would have thought the Branches could have subscribed to send one representative. Looking round the room it was evident that the operative member was lacking in attendance. The members who had to carry on the work. and were carrying on the work, were present again settling the point. The trouble, as he saw it, with the operative member was that that member felt if the rules became law he would lose a certain status. Personally, the speaker thought that was the position which the operative member envisaged for himself. Really, the operative member was going to be better off, and, personally, after being very much against the proposal, he had been converted in its favour. He thought it was going to be the best thing for the operative in the future.

Mr. J. Bayne (Lancashire Branch) felt that while there had been a strong plea made for Associate Members, two guineas was as much as many good men could afford to pay. To increase the subscription to £3 per year meant that many men could not really afford to pay it.

Lancashire's Approval

Mr. J. E. Cooke (Lancashire Branch) said the Lancashire Branch Council took the attitude some months ago of definitely agreeing with the majority of the proposals suggested. They recently thought it desirable to reconsider the position in the light of what subsequently happened at Bradford. They had again affirmed their decision to support the proposals of the Organisation Committee. In addition to that, at the October meeting of the Branch, a point was raised that the Lancashire Branch members should make it convenient to attend the present meeting in large numbers. Those of them who were familiar with the faces which were usually to be seen at the Lancashire Branch meetings would realise that the remark of Mr. Ben Hird was quite correct; that the people who carried out the business of the Institute were present but the grades of members it was desired should attend were absent.

Branch Secretaries, as Mr. McClelland had said, knew fairly well what the members' viewpoint was. He was rather surprised to learn from the Scottish and Newcastle Branches that their members were definitely opposed to the alteration. Personally, he felt he was as much in touch as anyone else with large bodies of men in the industry, and he had heard no serious objections put forward to the proposals from any considerable body of opinion. There were, naturally, persons who possibly would be adversely affected and wish nothing to come of it. The general opinion of the Lancashire Branch was in support of the proposals, and he thought all its representatives would vote in their favour.

Previous Increases

Mr. H. Winterton (Past-President) thought they were not all looking at the matter from the same point of view. He had been a member of the Institute since 1906, and there had been several increases of subscription. He had also seen considerable advances in the status of the Institute. Upon each occasion, when increases of subscriptions were proposed, the same objections were raised. It was stated upon each occasion that they would lose their membership. They had heard to-day that at the first rise from 7s. 6d. to 10s. 6d. it was stated they would lose members, and instead they had increased their membership and were able to give a little more to the members of all grades than ever before. Upon the occasion of the second increase, similar objections were raised, but the finances improved and the membership increased. Now they were dealing with another suggested increase and the same objections were again brought before them. Candidly, he was bound to say that he did not think there would be any decrease in membership or subscriptions. He believed that the Institute would gain in status, membership and finance. It would most definitely be raised in the estimation of all other Institutions of the same character, which were operating throughout the country.

He would like to say in connection with the Scottish Branch, of which he had had the honour of being President on one occasion, that they all appreciated the enormous amount of work which had been put into the preparation of the proposals by the Committee of the Institute. He attended a meeting on the previous Saturday afternoon in Glasgow, and his hearers, if they had also been present, would have been astonished to observe the enthusiasm with which the younger operatives attended that meeting. The best feature of the afternoon was a Paper read by one of the younger members of the Institute who had been awarded a Gold Medal for its excellence. He was a thoroughly practical young man, who understood everything he was speaking about. He thought some of his Scottish friends were fearing something which was not going to happen. He believed that the finances of the Institute would increase and that its status would be most definitely enhanced.

The circumstances in respect to the Newcastle Branch were somewhat different as they had had a particularly bad time lately. They were in process of re-building their organisation, and in their particular case it might be more difficult to prevent some of the corner stones of their structure from becoming dislodged. Nevertheless, he felt that the Newcastle Branch would do their best to help the Institute and to help the Organisation Committee which had been working so hard upon the subject. He was convinced that eventually not only in Newcastle, not only in Scotland, but throughout the British Empire, membership of the Institute of British Foundrymen would become synonymous with excellence in every respect in the foundry trade.

East Midlands Approval

Mr. R. Spriggs (East Midlands Branch) said that as an indication of the feelings of the East Midlands Branch members, he came with a very strong contingent of over 20. The East Midlands Branch did not share the fears and forebodings of their northern friends. He thought the matter had now been discussed quite sufficiently and the resolution should be put.

Mr. Dunleavy (East Midlands Branch) said that a point had been made concerning the increased subscriptions being a hardship. An increase of 10s. 6d. represented slightly over an outlay of 1d. per day. He could not conceive that there was any hardship in that.

Mr. C. Lashly (Newcastle Branch) thanked Mr. Winterton for the very kind things he had said, and would like the members generally to appreciate that 8 per cent. unemployed in a district was apt to make members think somewhat on the lines of the Newcastle Branch.

Mr. J. Roxburgh (Sheffield) said that Sheffield Branch Council unanimously supported the new bye-laws.

Mr. Blythe (Birmingham) said that the members of the Birmingham Branch were not anxious to pay more money than they had done previously; nevertheless, if the subscriptions were raised, he was quite sure the Birmingham Branch would not by any means let down the Institute on that account. He did not think the membership would be substantially altered.

The **Chairman** thought that, as President of the Institute during the time that the matter was brought to a head, and as chairman of the meeting, he need have no qualms with regard to the possibility of any accusation that the discussion had been in any way stifled. He had not the slightest hesitation in putting the resolution to the meeting.

Upon resolution No. 12 being put to the meeting, there were 58 in favour and 5 against. It was therefore carried by a majority of 53.

Mr. Daniel Sharpe wished to assure the meeting that the Scottish Branch would be very happy to work in full collaboration with the findings of the meeting.

Resolution No. 13 was then put to the meeting on the motion of **Mr. R. A. Miles**, seconded by **Mr. C. H. Kain.** It was carried unanimously.

Mr. Makemson said there was a small point to be settled. On page 3, paragraph 4, of the suggested new bye-laws, there appeared :—" No other person unless elected an Associate prior to July 1, 1938, can retain membership as an Associate after attaining the age of 28 years." July 1 was inserted because it was thought that the proposed new rules were going to be passed at the Annual General Meeting in June, and that date would have to be altered.

Mr. S. H. Russell moved that the date be July 1, 1939, as it was necessary that the bye-laws should be presented to the Privy Council, who would require that a specific date should be inserted.

The motion was seconded and carried unanimously.

There being no other business, the proceedings concluded.

PAPERS PRESENTED AT THE BRADFORD CONFERENCE

THE RANDUPSON PROCESS OF CEMENT MOULDING

Paper No. 631

By F. W. ROWE, B.Sc. (Associate Member)

The Randupson process of cement moulding is the invention of a French engineer, Mr. Durand, of the Cie Randupson, of Marseilles, and has been developed, particularly with regard to the special technique necessary, by the Société d'Electro Chimie d'Electro-Metallurgie et des Aciéries Electriques d'Ugine (who own the world rights) at Ugine in the South of France, during the past seven years.

It consists, briefly, of the use of silica sands bonded with ordinary Portland cement and water in place of the more usual moulding sands. This sand-cement-water mixture is rammed round patterns mounted in wooden box parts or in coreboxes or strickled in the manner usual with loam sands. The sand is reinforced at various points with straight irons, and staples are embedded where necessary for lifting. The resulting moulds or cores are set aside to harden, for periods varying from 24 to 48 hrs., blacked if necessary, then the various parts clamped together and cast without any surrounding box parts.

The moulds or cores after they are set have great mechanical strength and very high permeability. After casting the moulds are stripped in the usual manner and the sand crushed, desilted and stored for use over again.

Sand bonded with cement for foundry use appears to have been tried as early as 1897, and Moldenke makes mention, in his well-known text book, of cores made from a cement-bonded sand, but the use of such sands for cores appears to have been abandoned after an experimental period. This is understandable, since no study of the fundamentals appears to have been made and the sole object of the addition of the cement was to provide a bond.

Mr. Durand, however, in his researches discovered that it is essential to preserve a certain well-defined ratio between the amount of water used and the quantity of cement, to ensure the high permeability which is the outstanding feature of the process. Normal recognised methods of permeability testing are of little value for Randupson mixtures, since the permeability is much higher than that obtained with other types of moulding sands.

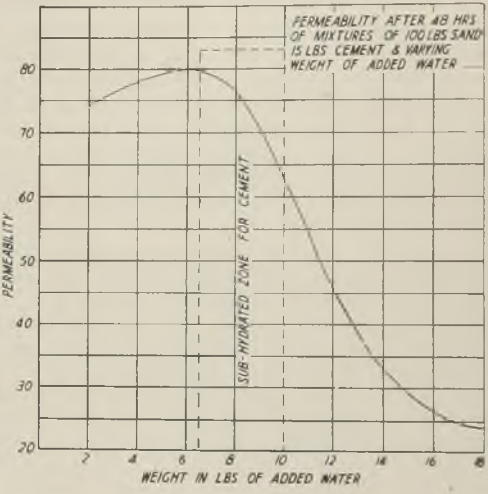

FIG. 1.—PERMEABILITY CURVE FOR 15 PER CENT. CEMENT.

Rôle of Water Additions to Cement

In order to ensure this high and essential permeability, the proportion of water added to the cement sand mixture must be such that the cement is subhydrated only. Given an unlimited amount of water, Portland cement absorbs water in two stages. The first absorption takes place usually inside 24 hrs., and is called the first set, whilst the second absorption proceeds more slowly and is not complete for a period approaching 28 days.

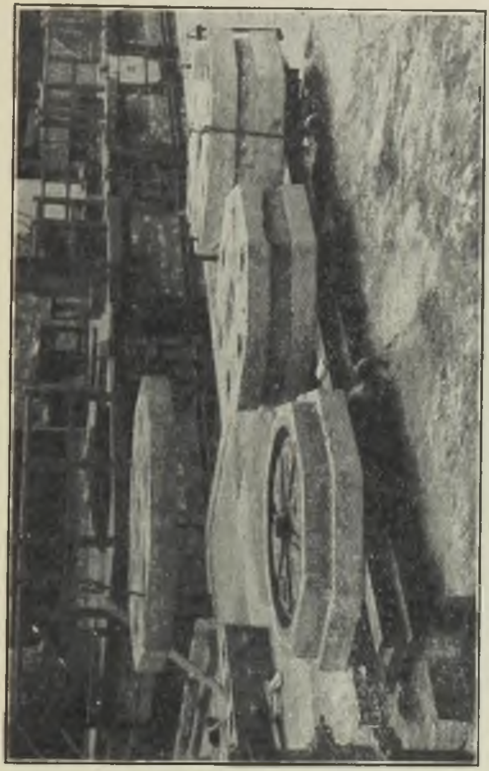

FIG. 3.—SHOWING METHOD OF CLAMPING ONE TYPE OF MOULD.

It is the first set only with which the Randupson process is concerned, and provided the essential conditions of the specifications are observed, the permeability of the mixture when set and fully hardened is extremely high. Fig. 1 shows a typical permeability curve for a mixture containing 15 per cent. of cement with varying proportions of added water, and illustrates the importance of subhydration only. It will be seen that once the correct proportion of water is exceeded, the permeability drops with extreme rapidity, and such material would be useless for foundry work.

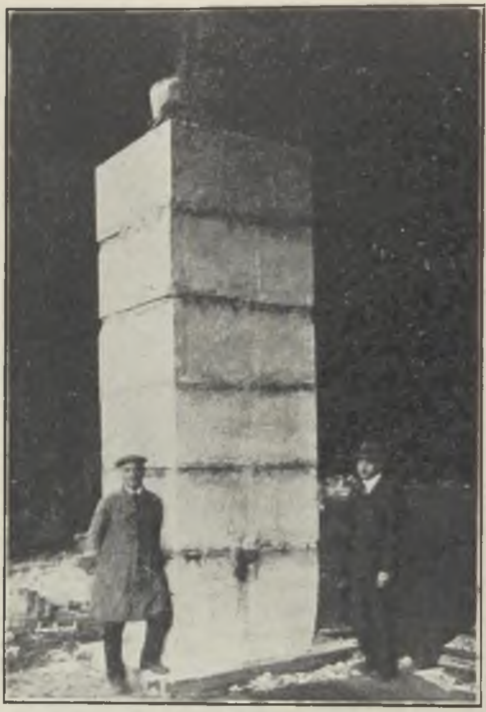

FIG. 4.—LARGE ROLL CASTING MOULD AFTER BEING CAST.

In practice the actual proportion of cement and water used depends very largely on the type of casting being cast. At the present time large tonnages of carbon and alloy steels, cast iron, gunmetal, phosphor bronze and manganese bronze, aluminium alloys and magnesium alloys are being cast by this process and in weights varying from a few pounds up to 30 or 40 tons, and so experience has shown what variations are needed to get the best out of the process for varying conditions.

FIG. 5.—SAME MOULD AS SHOWN IN FIG. 4 PARTLY STRIPPED.

Sand Considerations

The type of sand used is dependent on commercial considerations and local deposits, but the most suitable is a fairly pure silica sand of rather coarse grain size—for instance, one in which 70 per cent. of the grains remain on a 60's sieve. Reasonable freedom from clay and fine silt is an advantage for the Randupson

Fig. 6.—Casting Stripped from Mould.

process, and where refractoriness is important, as in the case of steel castings, a 98.5 per cent. pure silica should be aimed for. For cast iron and lower melting-point alloys this is not so important, and a less degree of purity can be allowed providing the correct grain size and low clay content are secured.

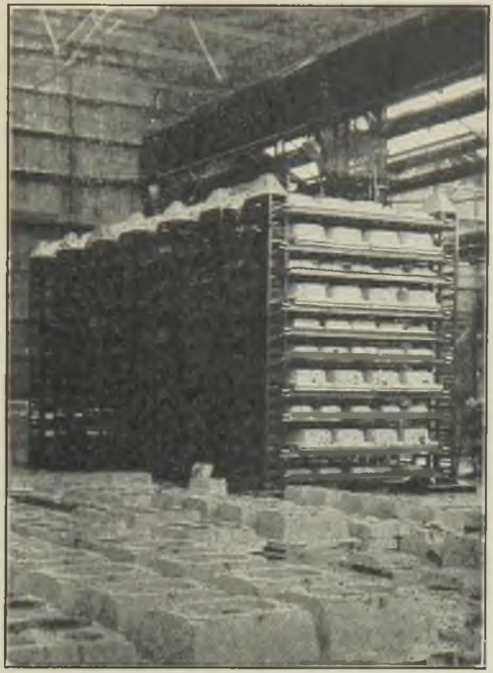

FIG. 7.—RACK STORAGE OF MOULDS.

Cement proportions most suitable for various conditions vary from 3 to 15 per cent. with a total water content in the mixture from 2 to 9 per cent The actual mixing is usually done in a mill where no milling occurs, and most

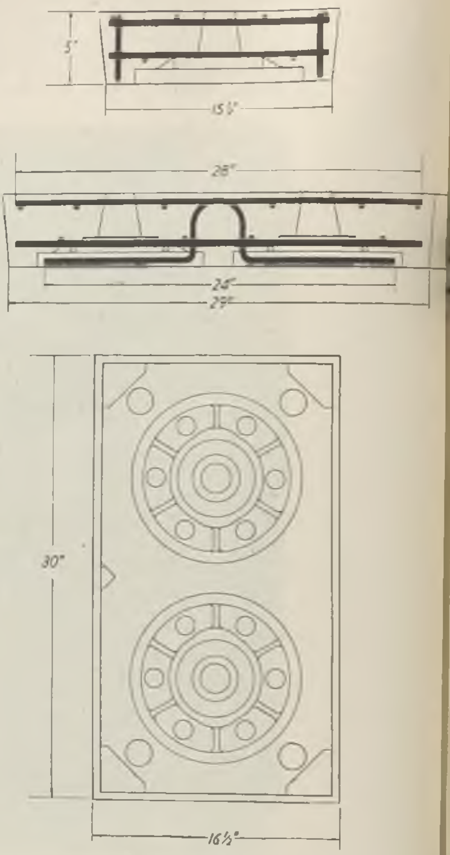

Fig. 2.—Typical Instruction
8-in. Wor

The uppermost diagrams show the position of
are ten irons in each mould. The cent
(4½ in. by 24 in. by ⅜ in. round, two in
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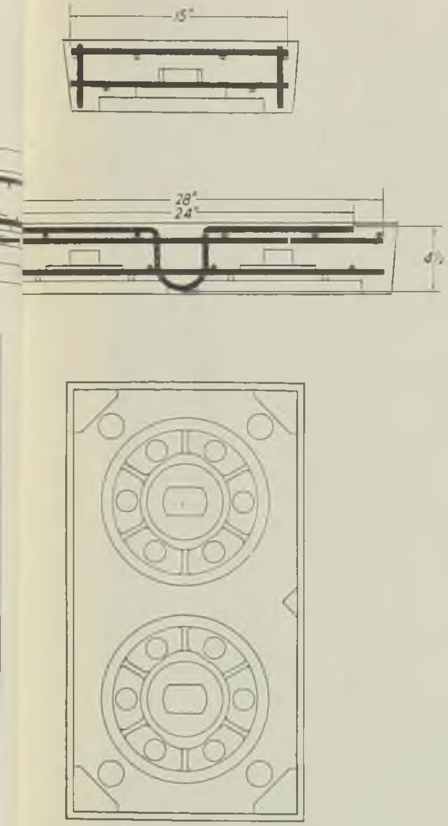

OR RANDUPSON MOULDING (FOR
CENTRE).

(15 in. by $\frac{3}{8}$ in. round) and patterns. There
ams show the position of the irons and staples
ld; irons 28 in. by $\frac{3}{8}$ in. round, six in each
the patterns and the two runners and risers

of the more modern types of mills are suitable for Randupson sands. The mixing time is very short—the total cycle is usually between $1\frac{1}{2}$ and $2\frac{1}{2}$ min. The sand must be used within three to five hours of being mixed, and any sand remaining unused has to be returned to the mixing plant for reconditioning.

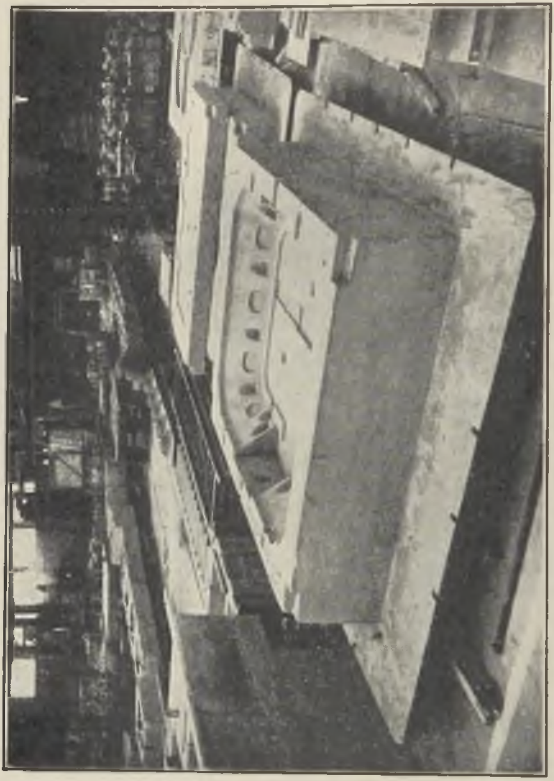

FIG. 8.—TYPICAL SECTION OF LARGE MOULD FOR CAST IRON TURNED OUT ON STEEL PLATE.

Steel Foundry Conditions

For iron and non-ferrous founding it is usual to use nothing but old sand, but for steel

FIG. 9.—MOULDING SMALL AND MEDIUM STEEL CASTINGS ON CONVEYORS.

founding a facing of all-new sand is essential to secure the highest refractory properties. In the green state the sand has very little bond and in this respect is comparable to sea sand bonded

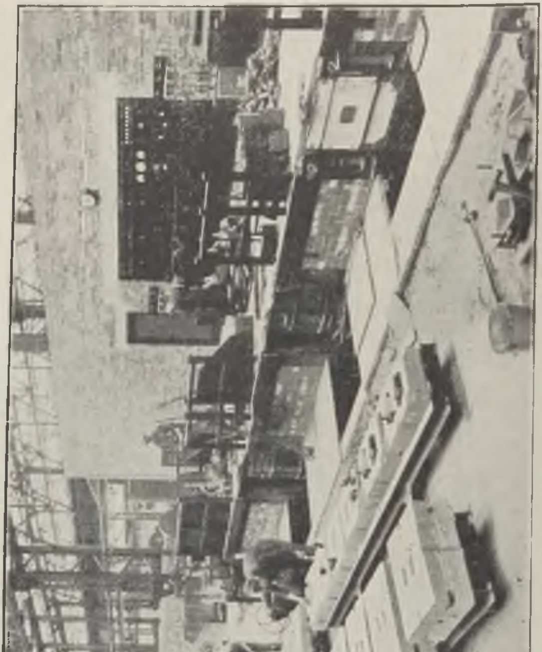

Fig. 10.—Setting Small and Medium Steel Castings in Casting Bay.

with oil. The sand, therefore, will not "lift" and suitable arrangements to cater for this are necessary in setting out a job for moulding. Split patterns are the ideal or the "all core" method, but with very little ingenuity most existing patterns or methods for moulding can be adapted with very little expense.

Mould Making

Ramming is very easy and needs little skill; in fact, this is the main advantage of the process. The sand flows readily and needs little compression and it is remarkable with what speed the wooden core or moulding boxes are rammed. The sand can also be jolted or vibrated with equally successful results. It is

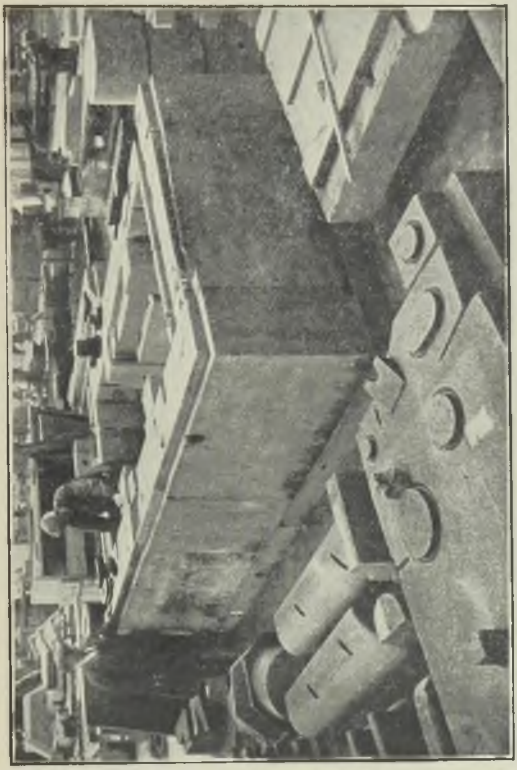

FIG. 11.—MOULD FOR LARGE MARINE GEAR-CASE CASTING—ALL-CORE METHOD.

necessary in all but the smallest cores and moulds to reinforce the sand with straight rods of iron. Suitable stocks are kept of straight irons of varying diameter and length, and these are embedded in the mould during the process of ramming. If it is necessary for the mould or core afterwards to be lifted by the crane, suitable staples are embedded also. The mould is usually turned over on to a wooden board and the pattern and wooden frame removed.

Fig. 12.—Setting Mould for Manganese-Steel Pelton Wheel Casting.

In the case of large moulds, *i.e.*, those above 4 ft. square, a steel plate of welded construction is used, since large boards have not sufficient stiffness to remain flat when being slung by the crane. The mould (or core), after the necessary finishing, is put on one side for the chemical reaction of setting and hardening to take place. How long this takes depends entirely on the composition of the mixture, the temperature conditions of the shop and the size of the mould.

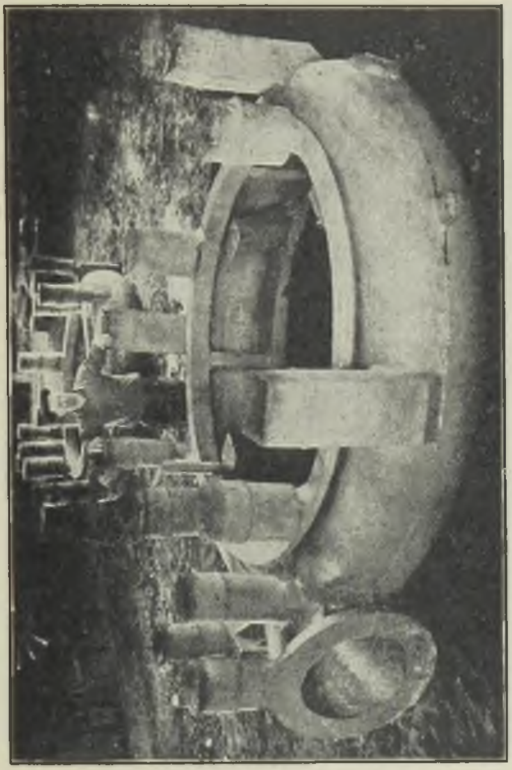

FIG. 13.—LARGE WATER-TURBINE CASING IN CAST STEEL.

In most cases it is advisable to allow 48 hrs. for this to take place, especially if the average temperature of the foundry is between 45 and 55 deg. Fah., but if the shop temperature averages 60 deg. Fah., small and medium-size moulds are sufficiently set to be safe to cast or to black in 36 hrs. In most cases, however, even the largest moulds and cores are sufficiently strong to lift in 24 hrs.

FIG. 14.—CORING CEMENT MOULD FOR CAST STEEL HAWSER PIPE.

In the case of steel moulds no coating of the moulds is necessary or even desirable, and the same applies to non-ferrous alloys (including aluminium alloys) except those containing phosphorus or those of which the casting temperature exceeds 1,150 deg. C. For cast iron, owing to the fluidity of the metal, a coating of blacking is necessary, and this is best done when the mould or core is set. Sufficient time is allowed for this blacking to air-dry, usually six to twelve

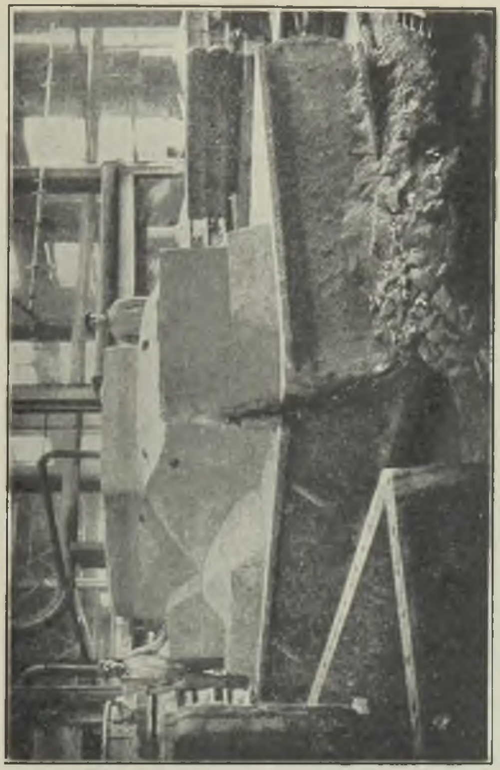

FIG. 15.—MOULD READY FOR CLAMPING BEFORE CASTING.

hours, or the blacking can be dried with a blow-lamp or hot-air dryer in a few minutes.

The moulds are clamped together in the manner shown in the various illustrations and cast in the normal way. It is a little frightening to foundrymen to see large moulds being cast without enclosure of any kind, but experience soon breeds confidence, and after one has seen a few 20-ton rolls, 15 ft. long, cast in an open pit one

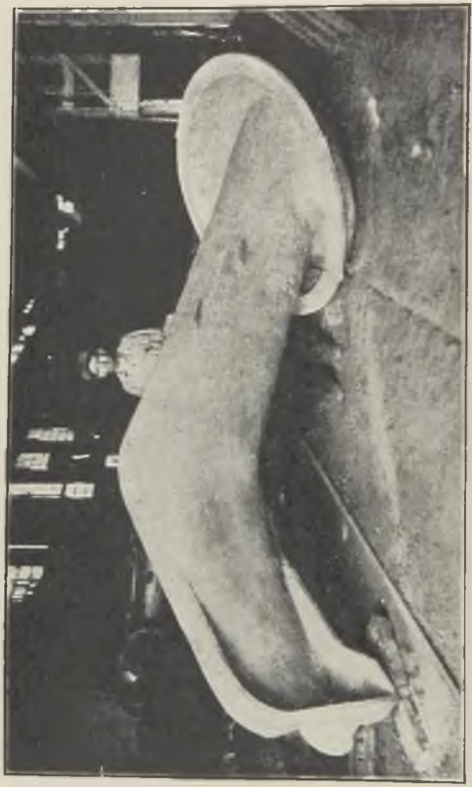

FIG. 16.—FINISHED CASTING FROM THE MOULD SHOWN IN FIG. 15.

soon begins to appreciate the extraordinary mechanical strength of the Randupson mould.

After the moulds have been cast, they are knocked out either on a grid or in proximity to a crusher. The used sand passes through a crusher and is elevated to screens or other type of desilting plant which removes the larger portion of the spent cement and any silt, and stores the reconditioned sand in hoppers over or

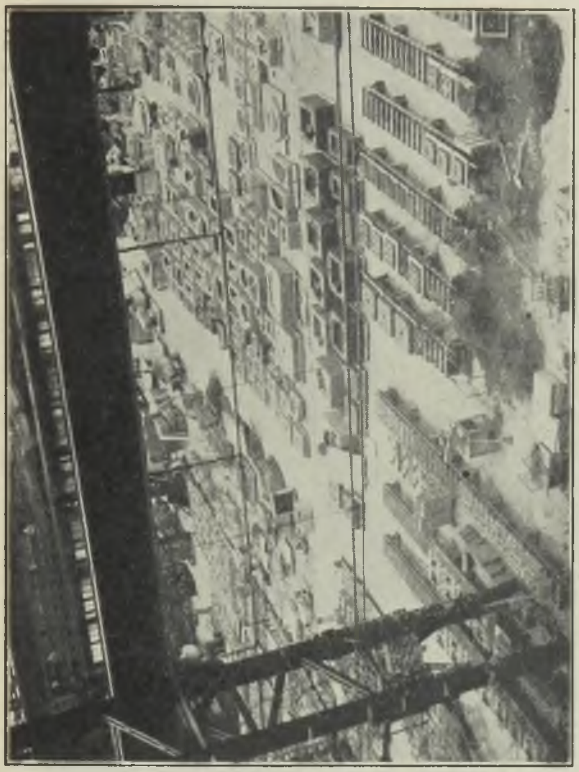

Fig. 17.—View of Foundry showing Typical Small and Medium Moulds.

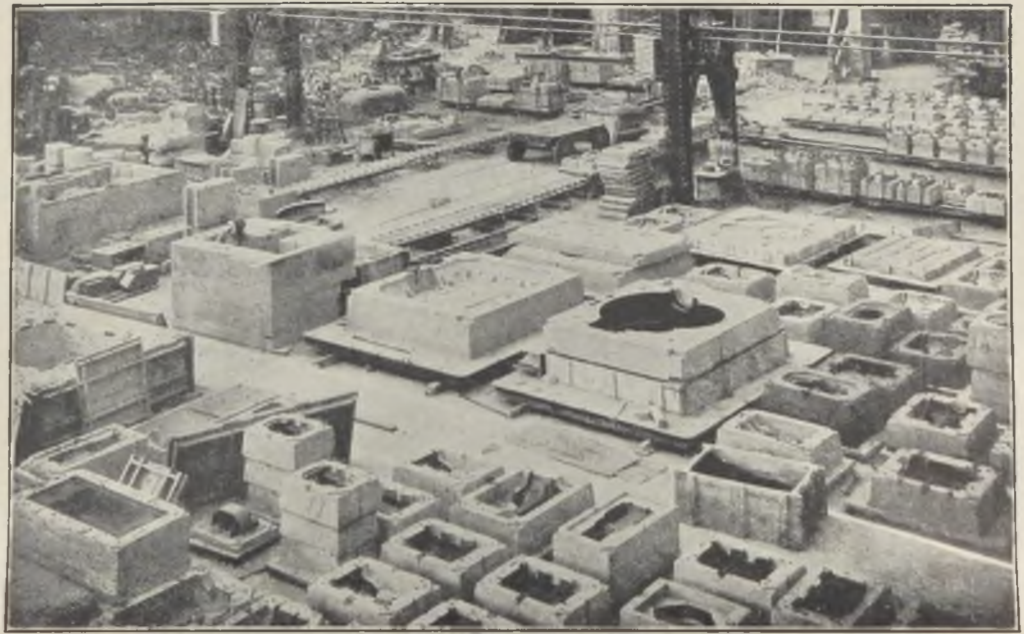

FIG. 18.—VIEW OF FOUNDRY SHOWING LARGER MOULDS FOR CAST IRON.

adjacent to the sand mixer. This reconditioned sand is mixed with the correct proportion of cement and water, and used over and over again. In iron and bronze founding no new sand is needed except to replace that lost by inevitable wastage, but, as mentioned previously, a layer of all-new sand should surround the pattern or form the outside of the core in steel founding. To economise in sand it is usual in large moulds and cores to form the greater portion of these from lumps of old broken moulds. These replace the usual coke filling in large cores also.

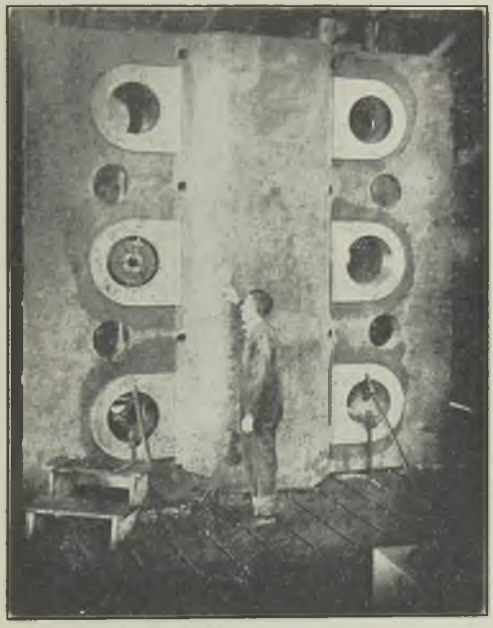

Fig. 19.—Machining a 60-ton Steel Casting made by Randupson.

Core construction is exactly similar to that employed in ordinary moulding, except that in no circumstances are cast grids necessary, and the vent wire is never used (nor is this ever used in moulding). On acount of the high strength

FIG. 20.—PUTTING TOGETHER PARTIALLY-STRUCK-UP RANDUPSON CASTING.

of cores it might be thought that with thin castings contraction troubles might be experienced, but provided the sand wall does not exceed 2 to 3 in., such do not occur. The reason for this is obvious on studying the mechanism of the casting. Cement, like any other hydraulically-bonded material, breaks down under the application of heat, and thus the ¼ or ½ or 1 in. of sand adjacent to the casting (dependent on the

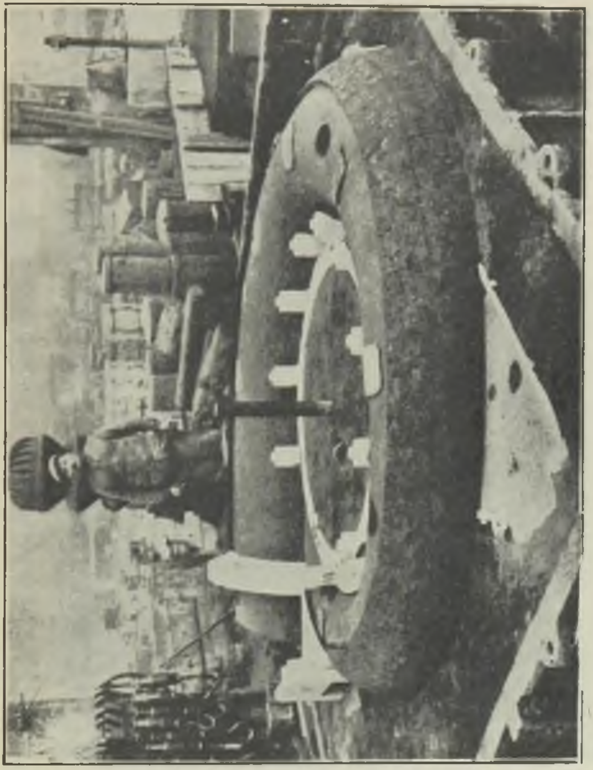

Fig. 21.—Strickle-Moulding a Water-Turbine Casing.

mass) is rotted under the action of the heat of the metal, allowing the casting to contract and rendering dressing operations easy. Fettling or dressing costs on castings made by the Randupson process are no different from, and certainly no more expensive than, normal methods.

Disadvantages of the Process

It is not irrelevant at this stage to review the disadvantages, obvious or otherwise, of the Randupson process. First of all there is the disadvantage of the time needed for setting and the space occupied by the moulds during this setting time. In practice it can be said that no mould is cast until two days after moulding, *i.e.*, moulds made on Monday are not cast until

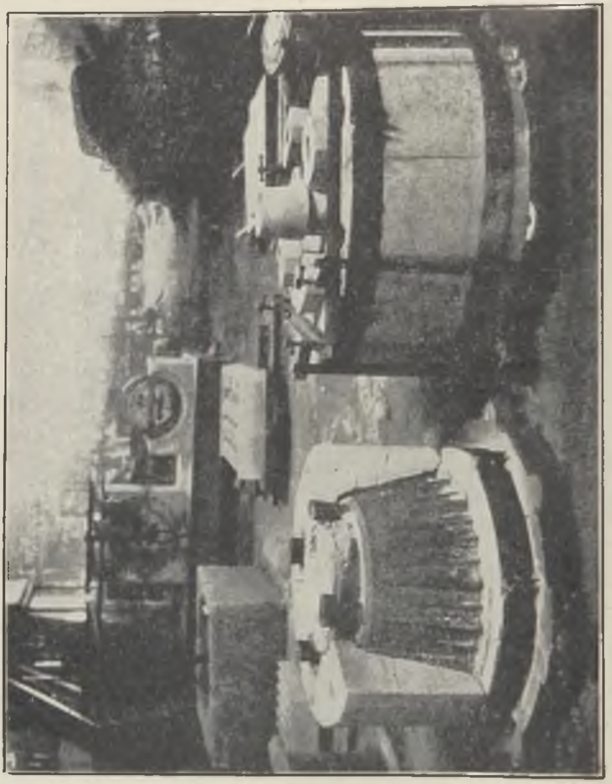

FIG. 22.—MANGANESE-STEEL CRUSHER MOULD READY FOR CASTING AND PARTIALLY STRIPPED.

Wednesday. This excepts special cases and rush jobs which can be stove-set ready for casting in six hours if stoves are available, or moulds otherwise dried where the setting time is artificially aided by heat.

FIG. 23.—MOULD FOR LARGE STERN TUBE BRACKET IN CAST STEEL.

Secondly, there is the room occupied during the setting time. In most foundries the mould made on Monday is stoved on Monday night and cast on Tuesday, but with Randupson extra storage space has to be provided to store two days' moulding instead of one.

Thirdly, all sand used has to be put through the mixing plant, and all old sand has to be regenerated with fresh cement.

FIG. 24.—STERN TUBE BRACKET IN CAST STEEL, PARTIALLY STRIPPED.

Fourthly, the sand will not last for more than three to five hours (dependent on shop temperature conditions and the exact mixture).

Fifthly, the cost of the sand due to all having to go through the mill and to have new cement additions each time, is more expensive than normal sands used in iron or bronze founding practice. In steel founding the sand costs on Randupson are about the same as with the old methods, or in some cases cheaper.

Sixthly, the sand will not lift and has little or no bond in the green state.

Having recited these disadvantages, the author will go into the practical significance of these as they appear in everyday practice.

FIG. 25.—35-CWT. VALVE BODY IN CAST STEEL, PARTIALLY STRIPPED.

Process Analysed

This first disadvantage, that of setting time, is a big one on small moulds usually cast in green sand, and, in the author's opinion, considerably lessens the appeal of the process where the large majority of the work is cast green sand. In medium-sized work normally dried, the disadvantage is not so marked, since only an extra day is required and suitable racks or storage stands can be made (as shown in Fig. 7) to hold the moulds or cores during the setting period.

In large moulds the advantage is very definitely on the side of the Randupson process for the following reasons. Due to the extraordinarily speedy moulding possible with Randupson, the extra time needed before casting is more than compensated for by the saving in moulding time. This remark refers to time only, quite apart from cost considerations. As a typical example, the author will quote a casting which repeats itself in the foundries with which he is connected with

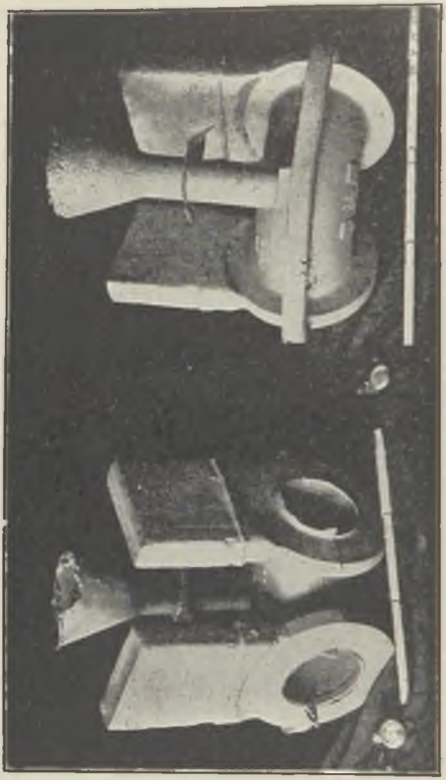

FIG. 26.—CAST-STEEL ELBOWS SHOT-BLASTED ONLY FROM MOULD.

fair frequency, so that they have recorded numerous time studies both in clay-bonded and Randupson sand. In skin-dried clay-bonded sand the piecework time was 120 hrs., and two skilled moulders usually make and case one of these castings in one week. With Randupson, the piecework time is 45 hrs., and one skilled man and three helpers make the mould in one day. Thus, in the old method a mould started on Monday is cast last thing on Friday, whereas a mould in Randupson is started on Monday and finished that day and cast on Wednesday, a saving of two days.

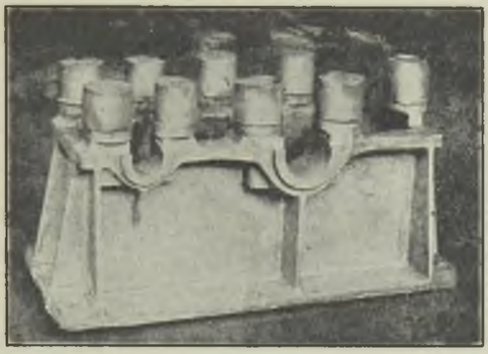

Fig 27.—Cast-Steel Gear Case in Randupson.

If a number off a large mould is required from the same pattern, the saving in time is much more remarkable. For instance, if the same pattern came in for six off, in the ordinary methods six weeks would be required, whereas in Randupson six castings could be made in nine days.

In brief, it may be said that in large complicated castings, where the normal moulding time is three days or above, a casting can be produced by the Randupson process in less time, and if two or more are required from the same pattern, in very much less time.

In medium castings (*i.e.*, 5 to 15 cwts.) one casting can be delivered in Randupson in about the same time, but, if a number of castings is required from the same pattern, in much less time.

For small castings normally cast green sand, one casting will take two days longer in Randupson, though a number can be produced in the same time.

Fig. 28.—Mould for Locomotive Wheel-Centre

Of the second disadvantage, *i.e.*, room required for storage, there is no question but that, taken on the whole, a jobbing foundry requires 10 per cent. more floor space when using the Randupson process. To some extent this extra floor space may be minimised by storing moulds in racks, and foundries producing nothing but heavy castings can produce more castings per square foot of floor area than with ordinary methods. In steel founding or jobbing work where most moulds are dried, little or no extra space is required.

The third disadvantage, that of all sand having to go through the mills, necessitates a modern sand plant to operate the process. It is not uncommon to-day with many foundries to recondition and desilt *all* sand, and any such foundries need only the addition of a crusher to their plant to enable them to work the Randupson process. Provision of a crusher and desilter is essential to work the Randupson process economically.

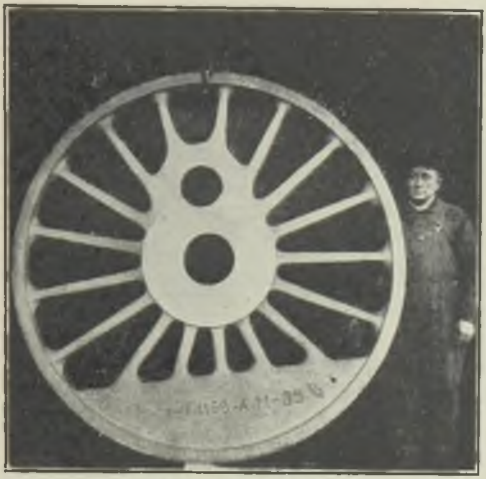

FIG. 29.—LOCOMOTIVE DRIVING-WHEEL CASTING FROM MOULD SHOWN IN FIG. 28.

The fourth disadvantage needs no comment, and is not difficult to cater for.

The fifth disadvantage, *i.e.*, higher cost of sand in iron founding, has to be offset against savings made in other directions.

The sixth disadvantage is catered for in setting out the pattern or moulding methods, and is mentioned to warn foundrymen that universal applicability of ordinary methods is not possible.

Advantages Shown

Having dealt with the various disadvantages of Randupson, the foundryman unacquainted with this unique method of moulding may well ask where the appeal lies against traditional methods.

First of all the author will outline the advantages in ascending order as they appear in practice.

FIG. 30.—SMALL AUTOMOBILE CASTINGS MADE BY THE RANDUPSON PROCESS.

(1) No drying stoves needed and no fuel. No comment is needed on this.

(2) No box parts or no storage space for box parts. Every foundryman can correctly assess the value of this without any further dilation.

(3) The castings, either iron, steel or bronze, are *much* truer to pattern—no swells and much less warpage due to greater rigidity and strength of moulds.

(4) No scabbing due to greater strength of moulds.

(5) With suitable sand and working of the process no blowholes due to much higher permeability.

In discussing the advantages, the one which counts the most in practice has been left to the last. That is the speed with which Randupson moulds can be produced in practice. The author gave previously an example which probably sounded incredible to readers, but such is the daily experience of those working this process. Actual moulding times, and by that the author wishes to be very clear that he means moulding times alone—not putting together, coring up, etc., which are the same as in ordinary practice—are reduced from 50 to 300 per cent., and overall labour times from 30 to 75 per cent.; and—also important—much less skill is required—no sprigging, no venting, no careful ramming. In those two facts one has the success of the Randupson process in the field for which it is applicable. The process is in practice quite different from ordinary founding methods and a very great deal of one's preconceived ideas and experi-

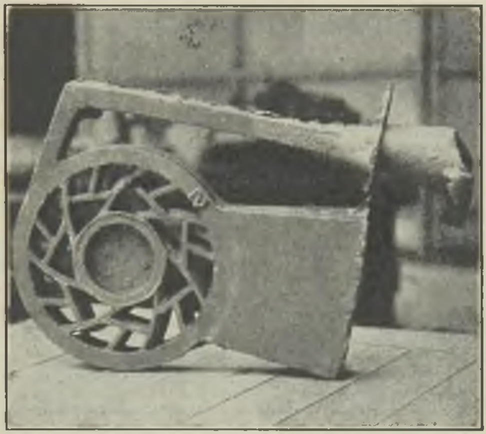

FIG. 31.—SMALL ALLOY STEEL CASTING MADE BY RANDUPSON.

ence has to be discarded, but in the author's opinion the process is bound to spread rapidly not only on account of the quality of casting produced, but on account of the ease and cost with which such castings—either in iron, steel or non-ferrous alloys—are produced.

In conclusion, the author would like to express his thanks to Mr. David Brown, the managing director of David Brown & Sons (Hudd.), Limited, not only for permission to publish this Paper, but for his continued interest and assistance in the development of the Randupson process in the Penistone Works of his company. Thanks also are due to the Société d'Electro Chimie d'Electro-Metallurgie et des Aciéries d'Ugine, for much of the technical information contained in this Paper, and without whose help the successful exploitation of this revolutionary process in the foundries with which the author is connected would not have been possible.

The author acknowledges the help in information and photographs from other licensees of the process, including Mr. Marshall Post, Vice-President of the Birdsboro Foundry & Machine Company, Birdsboro, U.S.A., Dr. Guido Vanzetti, Mr. Lewis, of the Manganese Brass & Bronze Company, and the Société des Forges d'Ales of Alais, France.

DISCUSSION

Mr. E. Longden, who, after paying tribute to Mr. Rowe and his firm for having taken on so wholeheartedly a moulding system which was described as revolutionary, pointed out that in the foundry industry nothing so far disclosed could be described as revolutionary. Most executives who had been in the industry for the last ten to twenty years would have tried almost everything, including the cement process, which he would not go as far as to say had been found useless; perhaps, through lack of perseverance foundrymen had not reached such a high state of efficiency as claimed for the process in Mr. Rowe's Paper.

A Practical Reaction

He thought it was due to the foundry trade generally that there should be a thorough airing of this very special phase of foundry practice. It touched very keenly the practical side of foundry work. When the Paper was published foundry executives throughout Britain might be receiving requests to look into their supposedly out-of-date moulding practice and go ahead. Some individuals connected with foundries would try anything once, whatever it might be, but it could prove very dangerous and expensive. His criticism must not be misconstrued that he was against change. The hazards of the trade necessarily made one cautious of claims to revolutionary changes in the foundry. The first illustration in the Paper, Fig. 2, showed the arrangement for reinforcing a cement mould for a very small gear centre casting. Was there any foundryman who valued the appearance of a small casting, or who operated moulding machines, or ran a continuous casting plant, who would for a moment look twice at the cement process? Was it possible to secure equally good-looking castings in cement? Was it possible to obtain the smooth running of the elastic system which obtained with sand in the normal moulding practice?

A Steel Gear Casting

After ascertaining from Mr. Rowe that the mould described in Fig. 2 was for a steel casting, Mr. Longden agreed that there might be some small justification for making the mould in cement, if one considered from the Paper as a whole that steel came out favourably in this process. But later in the Paper reference was made to the elimination of moulding boxes. What, then, was the use of trying to save the use of moulding boxes if from six to twelve loose irons must be introduced into the very small cement mould to hold it together? To his mind, that was not going forward, but in circles. Mr. Rowe admitted that he was not too happy with the economy of cement-bonded sand for small castings.

Time Cycle

Then there was the question of the cycle of operations which called for a setting time of from one to two days, which was rather alarming when compared with the steady running of normal sand moulding with its continuous sequence of operations. The fact that so wide a range of setting times as from 24 to 48 hours was needed was a set-back to the foundry. After all, unit production per unit area of the foundry floor reflected on the on-cost charges. It influenced the cost of castings where the floor area was large and there was a small *pro rata* output.

Roll Castings

Referring to Fig. 5 showing a cement mould for a roll casting, for which much was claimed as having been cast on end without moulding boxes, Mr. Longden said that one could nearly count the numerous wrought-iron or steel rods embedded in the cement sand. It was not thought to be an improvement to abandon the use of moulding boxes (which were normally available). One could identify, from the illustration, 40 circular irons, and there might be as many vertical ones, many of which could be also seen. To bend irons and bed them in a mould and handle them from point to point was time-absorbing. What about the cost of the irons?

Moulding Box Costs

There was also expense for the wooden boxes to make the mould. After the cement had been knocked off the outside the irons were disclosed, showing that very considerable reinforcements were necessary to withstand ferro-static pressure. With ordinary moulding boxes the same mould could be made without a single iron. The clamping of moulding boxes was also less costly than clamping cement sand moulds.

The amount of tackle that the system demanded quickly cancelled out any possible saving in moulding boxes.

The precision with which ordinary moulding boxes went together and the accuracy of the joints of the mould were very important. The moulding costs would be increased by the time of setting the cement parts together and that was a considerable item. Again, dressing charges might be increased due to the irregular joints on the casting made by putting cement blocks together.

Auxiliary Labour

With the cement process there was a serious cost in sand mixing and ancillary labour, whilst the cement itself was not cheap. Mr. Rowe had himself outlined the many disadvantages as well as the advantages of the process. The advantages which the speaker appreciated were concerned with the possibility of reducing swelling of the casting if of large dimensions and elimination of drying by artificial means, although this last advantage was doubtful in view of the long setting time. But was the cement mould free from the usual hazards which surrounded normal sand practice?

The Time Element

It had been pointed out that danger arose if too much water was introduced into the cement sand mixture. The proper setting time was between 24 and 48 hrs., depending upon the class of mould, and the cement sand took on a secondary and more permanent and stronger hardness after about 24 days. This would exclude the production of the very large class of casting taking more than about three weeks to make.

Hardness and Surface

The mould would be so hard that it would have to be broken up by a tup. The hard set of the mould was against a fine surface finish and easy repair to the face of the mould. A serious repair to a mould, which was not uncommon, would require the setting time over again.

Were moulding boxes eliminated, as claimed? On most of the illustrations one could see, more or less, moulding boxes employed for cement moulds.

It was stated that cores did not need cast core grids. But was this time-saving? Was there not more time taken in arranging loose irons and their wiring than in stamping out a simple grid on the foundry floor. The speaker suggested that the hawser-pipe core shown in Fig. 14 would be more cheaply and safely made by using a cast grid. The hawser-pipe mould was enclosed in a moulding box, it would be noted—it was not cast without the ordinary moulding box as stated in the Paper.

Largest Weight and Section

The manganese steel mould was made with section cores, otherwise it would be too long to let the mould stand, perhaps reaching the secondary hardening. Would Mr. Rowe be kind enough to give more information about the large casing casting he referred to? Could Mr. Rowe state the weight and section thickness of the largest casting he had made, but not included in the illustrations? The casting was a piecework job for which, under normal sand practice, 120 hrs. was given to two skilled men.

Mr. Rowe said the casting was 4½ tons weight and had a general section of $\frac{7}{8}$ in.

Labour Costs

Mr. Longden said the question was involved by the introduction of "helpers." A piecework time of 45 hrs. was given in the cement process to one skilled moulder and three helpers. It was often difficult to find out the cost of castings made under new systems. There was a tendency when a new process or article was introduced to prove its worth by giving every help and facility not yielded to the normal method.

The three helpers should really be included in the prime or first cost, and this was in relation to the 120 hours given to two skilled moulders on the normal practice.

Mr. Rowe said that the 45 hours was the total time spent by one skilled man and three labourers making a mould.

Mr. Longden: Roughly, the men would make time and a-half?

Mr. Rowe: Yes.

Mr. Longden: Would they make time and one-half on both classes of moulds?

Mr. Rowe: Yes.

Mr. Longden: How much time was spent by the core maker on the job?

Mr. Rowe: Probably a day.

Mr. Longden observed that the saving in time at the best was in the shortened ramming time. All other operation times could not be cut. Information had been given of the acceleration of delivery time in the cement process if more than one casting was required of the same pattern. Surely that was a question, really, of sufficient moulding tackle. If one could go on making one cement mould after another, one could do the same in the ordinary practice. He thought the real intention was to infer that delivery time was accelerated apart from the saving in ramming time.

Again, it was all a question of the reasonable provision of foundry tackle. After all, there could be no saving in ramming against a mould rammed mechanically. In the cement process there was the disadvantage of weakness in the green state compelling more extensive use of rodding. Might he ask why, with an iron casting, a mould was coated with refractory and no coating was required on a steel mould which was poured with a much higher melting point metal? It was stated that, if blacked, a mould would air dry in six hours. Thus, a mould would occupy the foundry floor 24 to 48 hours for setting and 6 hours for blacking, unless hastened by artificial drying processes. Finally, Mr.

Longden asked Mr. Rowe whether the cost of the castings was lower with the cement process than by the previous ordinary and standard practice.

A Well-Established Process

Mr. Rowe suggested that Mr. Longden had not read the Paper—short as it was—with the care he would have liked him to do. The proof of the pudding was in the eating. There were no less than 4,000 tons of castings per week being made by cement moulding up to the present time. There were some 37 different companies operating the process, and, of course, some of them might be fools, but it was hardly likely that all of them were. He (Mr. Rowe) did state very clearly that, in his own personal opinion, and he was only voicing his own personal opinion, the process was not suitable to compete with green-sand moulds.

Reduction in Ramming Time

Mr. Longden had stressed the disadvantage of the long setting time, but that was one of the points he (the speaker) had emphasised in the Paper, yet there were hundreds of types of pattern which neither the speaker nor Mr. Longden nor anyone else could ram up in a week, which one could ram up in cement in a day, and that was very definite. How far that was favourable to one's own work was a matter of individual taste, or individual requirements of the very different foundries. Personally, he would be the last to put the process forward as the be-all and end-all of foundry work, but in considering the question of the long setting time, one had to take into account the saving of ramming up the ordinary mould; it was the saving on the ramming up in the quantity order which reduced the time taken to make a multiplicity of moulds.

Ironing *versus* Cast Grids

As regards the question of ironing, and the amount of ironing required, it was something for the individual foundryman to decide for himself as to whether the time required for ironing outweighed the advantages of the system. He was sorry that Mr. Longden thought fit to query the core for the hawser-pipe as having core grids in, because he did not think Mr. Longden had any evidence there to go on at all, and he could assure Mr. Longden that cores much more difficult were regularly being made without cast core grids with loose irons and no wiring. Moreover, it suited the speaker's conditions better to make them with irons rather than cast core grids. The largest castings made by this process were 50 to 60 tons in weight, though his had not exceeded 15 tons.

As regards blacking moulds, it was stated quite clearly in the Paper that moulds for cast iron had to be blacked, because the fluidity of the cast iron, or phosphor-bronze, was so great that with this highly permeable sand one did not otherwise get a smooth skin.

Mould Breaking Costs

Mr. R. Spriggs said he had had the privilege of seeing the Randupson foundry, and it was surprising to him that more foundrymen had not tried the process. There was no doubt that Mr. Rowe had made a success of it, and that he made good castings was well known. The author had very frankly given a list of disadvantages, and the speaker was aware that Mr. Rowe had taken very effective steps to deal with these disadvantages by organisation and mechanical means. One point which he had not enumerated was the cost of breaking up the moulds. That appeared from a very casual personal observation to be quite an item, and definitely a disadvantage to this class of work. Then the previous speaker had said it was a question of economics. He believed that Mr. Rowe did claim that there were savings in the process, quite apart from other advantages, such as unskilled labour and so on. He employed a quantity of mechanical means; in fact, from the illustrations it could be seen that his foundry was at any rate partially mechanised, and it would be interesting to learn whether he based his savings on floor moulding—the floor where the sand was made up—without mechanical means, or whether he would get the savings if he compared with another foundry having an equal amount of mechanisation to his own plant.

Floor Moulding Jobs

Mr. Rowe said he regretted that he did not mention in the Paper the disadvantage of breaking up the moulds, which certainly one had to take into account. He had tried as far as possible to be fair and unbiased and unprejudiced about the process, and he had named the disadvantages, and the breaking up of the moulds was one that at the present time he was overcoming by mechanical means. The whole of the moulds could be crushed, and the sand recovered, without any serious cost.

In regard to the comparison of costs and the effect of mechanisation, as far as possible in the illustrations he had chosen jobs made on the floor, by ordinary methods, and jobs which were still made on the floor. He was afraid he could not do more than reiterate that the greatest advantage was the extremely rapid moulding times on jobs and the rapidity with which numbers of castings from medium and large sized patterns were made where only one pattern existed, and the fact that less care needed to be exercised in making the moulds than in the normal processes.

Skill Retention

Mr. J. H. Cooper asked whether it was the policy of the Institute to reduce to an absolute minimum the amount of skill required. He did not think that it was. He thought the object was to retain the skill of the moulder and the people connected with the foundry at the highest possible level of efficiency, so that when a difficult casting was to be made, there were the skilled men available. He would like to ask Mr. Rowe whether, if he went to another foundry, he would have confidence in applying the same process. He knew that at his present foundry there had been adaptation exclusively for this, and it had ample space. Would he have the confidence to apply the process to another foundry which was successfully making steel castings at the present time?

Mr. Rowe, in reply, asked if he would be wrong in saying that Mr. Cooper's object was to keep foundry work as difficult as possible?

Mr. Cooper explained that he meant that skilled men were essential. He did not mean to make it difficult at all, but experience was necessary.

The "Normandie" Castings

Mr. Rowe said that, so far as introducing the process to another factory, of course his firm was only one of many licensees of the process, and it was interesting to note that stern and stem posts for the "Normandie" were cast by this process. Steel castings up to 70 tons in weight were being cast by the process every day and many of them were most difficult and intricate castings. He had not had the advantage of personal acquaintance of making very large steel castings of that type, but those were merely shown to illustrate that the field was not restricted by the size or intricacy of the castings concerned.

Ingot Mould Making

Mr. Robert Ballantine said that the Randupson process for ingot mould production had particularly interested him over a period, and more so since the Valley Mould Company in America had adopted the system. In the firm with which he was connected (the Fullwood Company) they cast as much as 200 tons per day, but, he understood, the American concern reached 500 tons per day. In view of this huge total cast, it would appear that the process was highly successful, but on the question of costs he was sceptical as to whether the introduction would effect economies as compared with the existing dry-sand system.

Was it essential for the roll shown in Fig. 4 that the mould should be built up in sections; further, could it be jolted and dried successfully as a unit?

Jolt-Ramming Cement Sand

Mr. Rowe, referring to the large roll casting, Figs. 4, 5, 6, *et seq*, said that it was quite possible to jolt-ram with cement sand. At the foundry in question quite large moulds up to 15 or 20 tons in weight were being jolt-rammed in cement sand. He had not the advantage of knowing just how the Valley Company made their moulds, but he did know that they were producing somewhere between 2,500 and 3,000 tons of ingot moulds and the like per month, exclusively by the cement sand process.

Mould Permeability

A Member asked what effect the cement sand would have on the hands of the moulders, and whether, in Fig. 1, the curve could be taken in conjunction with Dr. Dadswell's Paper in regard to maximum permeability.

Effect on Skin

Mr. Rowe said that people who had not been used to working with cement sand certainly, for the first few days, found that it did cause some irritation of the finger-tips; but when they had been working for probably two or three weeks, the trouble disappeared. His foundry had something like 200 men working in it all day long, and there was no difficulty at all on that score.

With regard to permeability figures, the ordinary tests were not suitable for the Randupson process, since the permeability, as far as one could see, was something like three to four times as high as the best permeability figures recorded with ordinary moulding sand. That, of course, was one of the great features of the process, that the permeability was so high. As a matter of fact, one of the demonstrations that the original licensees had been doing to show the high permeability was to take an ordinary steel mould about 2 ft. sq. and pour a quart of water into it, and to cast within five minutes to demonstrate that, in spite of the large amount of steam generated, the permeability was such that the steam found exit without any trouble.

Contraction Strains

Replying to Mr. Hird, who asked if there had been any trouble with contraction strains, Mr. Rowe said that that question raised a point which immediately came into people's minds when they saw those hard cores and a very hard mould. The core-making practice was exactly the same as one would adopt with ordinary sand, inasmuch as the centre, as far as possible, was either filled with coke or with portions of broken mould, and it was necessary to keep the thickness of the cement sand in the core to a reasonable maximum, something like 2 to 2½ inches.

Everybody was aware of the difficulties of contraction tears in steel castings, which were much higher than those in iron. People who had seen the author's foundries had always commented on the fact that the system demanded very much less bracketing on steel castings than was normally the case. With valve castings in particular there was no bracketing at all. The foundry was making quite a number of very light steel castings where again no brackets were used, and there was no trouble with contraction tears.

Moisture Control

A Member asked Mr. Rowe where he recruited his labour. Were the men skilled in dry-sand work, or were they just people who came in new to the job? Was the control of moisture very much more difficult when working this process than in ordinary green or dry sand?

Mr. Rowe said he had a number of skilled moulders, and, of course, with difficult and intricate castings the skill of the moulder in finishing and knowing where to place his runners and where to iron the job and set in cores, and that sort of thing, was as much needed as ever, whether the cores and moulds were made of green sand or oil sand or any other type. The skill and experience of the moulder were required to put such castings together.

The moisture in the sand was controlled by frequent tests throughout the day to see that the moisture content of the sand was within the specified limits. Actually, the control of moisture was not so critical in cement sand, and variations of ½ per cent. up or down were admissible without any noticeable difference in the hardness or permeability of the finished mould. Working very largely, as he did, with recovered sand, it was dry and moisture free. It was quite easy working with new sand, using the ordinary type of water meter, to control the weight or volume of water entering.

Application under Abnormal Humidity Conditions

Mr. P. Barry Parks said his company was in Hong Kong, and possessed a foundry where he was operating a battery of small electric furnaces. It was, unfortunately, situated in a very humid belt in which for a considerable portion of the year there was the abnormal humidity of sometimes 90 or even 100 per cent. He noticed one of the chief claims for this process was the advantage of natural drying, and he asked Mr. Rowe if he could give an opinion as to how the operation of the Randupson process would be affected under such conditions of abnormal humidity. He was chiefly concerned in steel castings, stern frames and rudder frames, and propeller brackets of about 5 tons. He had not had time to study the new process very carefully, having only been in this country a very short time; but it occurred to him that these abnormal conditions might seriously interfere with the effectiveness of the process. By a strange coincidence, one of his friends, Mr. Simpson, was also present from Hong Kong, and he thought he would verify the statements about the trouble occurring in foundry operations on account of this abnormal humidity.

Atmospheric Conditions

Mr. Rowe said the process was far more influenced by temperature than by humidity. This had been fairly well studied, and humidity readings in various foundries of various licensees had been taken over fairly long periods to see how this affected the process. As a matter of fact, the foundry of the original licensees was situated in a very damp corner of the Alps, and the humidity there ranged from 85 to 95 quite frequently. As to whether a rather greater humidity, as was experienced in the visitor's foundry, would affect the process, it was somewhat difficult to be dogmatic; but he imagined with the greater temperature that they had there that the drying time would not be seriously affected by the increased humidity. Those who knew the mechanics of cement knew it was quite possible for this cement to harden in very damp atmospheres.

COMMUNICATIONS

Mr. H. J. Miller wrote: As pointed out in the early part of Mr. Rowe's Paper, the application of cement-bonded sand is not by any means a new development, although most of the earlier attempts to use such mixtures were a failure. However, one example of outstanding success in the use of cement-sand mixtures, which dates back for a considerable period—apparently prior to the commercial application of the Randupson process—is provided in connection with certain copper castings employed in the copper refining industry.

From information provided by the courtesy of Mr. C. H. Aldrich, technical manager of the United States Metals Refining Company, it is possible for me to say that in 1928 a technique for producing copper castings with cement-sand cores was developed in the Carteret works of that Company. It is believed, however, that cement-sand mixtures were also being used somewhat earlier in certain other copper refineries, but it is difficult to state just when the practice was first developed. Since about 1930, however, the use of cement sand cores for certain copper castings has become general practice throughout the industry. The cement-sand mixtures have also been used for moulds in addition to cores, and it would seem that the practice as developed by the United States Metals Refining Company and others, has not been protected by patents.

The most important application of cement-sand mixtures in copper refineries is for the cores used in manufacture of water-cooled copper castings required for the producion of the solid copper moulds in which wire bars are cast. These castings are of approximately the same external shape and dimensions as a copper wire bar, and they are hollow with only two or three small holes at the top, which are provided for pipe connections. These holes serve to carry suspension hooks for the core, which must eventually be removed through these holes. The difficulty of core removal was responsible in the first place for the experiments on core materials; other factors which it was necessary to observe were: (*a*) The avoidance of volatile constituents which could liberate gases, a matter which is of more than ordinary importance with tough pitch copper; (*b*) the possession of sufficient strength in the cores to maintain the necessary shape during casting, and (*c*) the use of a comparatively weak and fragile mixture so as to avoid shrinkage cracks in the copper castings.

After many experiments with a wide range of core materials, used under different conditions, the core material which was developed was a mixture of ten parts of silica sand and one part of Portland cement, dampened with water to such a consistency that it can be packed into a wooden core box. After standing in the boxes for 24 hrs., the cores are removed and painted with bone ash emulsion, and are then dried in a steam heated oven for 48 hrs. at 110 deg. C.

Castings made with cores prepared in this manner are allowed to cool to a temperature somewhat below red heat, and they are then quenched in a tank of water. The penetration of water into the hot core gives rise to steam generation with more or less explosive violence, and this results in a complete disintegration of the core, which is entirely blown out, leaving the casting quite clean.

In addition to the advantage which the cement sand mixture offers in respect of its "disintegration" features, it is found to be stronger than ordinary sand and gives far less "blowing."

The above procedure is, of course, a very special development, but the cement sand mixture has also been used for moulds. The similarity in practice, especially in regard to the proportions of cement and water, with the Randupson process is very striking, and indeed the only difference seems to be in the adoption of stove heating in the one case.

Mr. A. Marshall, in a written contribution, asked if the Randupson process was applicable to the manufacture of large cast-iron marine cylinders, cast on end, and with a head above the bore. Mr. Marshall pointed out that the best runner system was a combination of drop and bottom pouring. The ingate at the bottom was placed so that the metal entered the mould tangentially, whilst the drop runners were spaced 8 or 9 in. apart, being kept clear in the regions of the ports.

Mr. Marshall said that when making cast-iron liners up to 24 ft. in length, these were cast on end. The first metal down from the basin entered the mould at the bottom and when about 15 cwts. to 1 ton had been poured, plugs were released and the casting completed by top and bottom pouring. He asked if the Randupson process would be applicable to these castings.

He would also welcome some further information on the application of the process in replacing large cores which were at present swept up in loam, and remarked that a mould and core of cement would appear to prevent contraction taking place. If this were the case he would like to know whether any difficulties were experienced from hot tears, distortion, etc.

Author's Reply

In answer to Mr. Marshall's questions, Mr. Rowe replied that the Randupson process was quite applicable both to the manufacture of large marine cylinders and to liners up to 24 ft. long. The casting shown in Fig. A, although not actually a marine cylinder, is a similar casting, and this was cast with a suitable head above the bore.

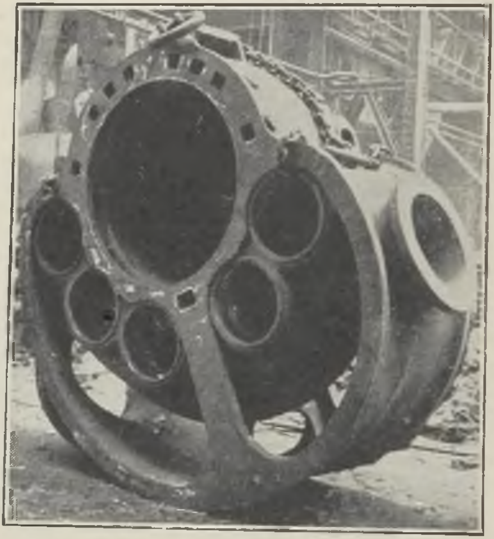

Fig. A.—Casting Similar to a Large Marine Cylinder.

In answer to the further queries, the author stated that any casting normally swept up in loam could be made without the necessity of brick reinforcement or drying. The large gear-wheel centre illustrated in Fig. B was swept up in loam. Despite the great strength of cement sand when set, the cores are made in the usual manner with a coke or rubble centre, and no difficulty is experienced due to contraction. Mr. Rowe explained that the reason for this was that under the application of hot metal, the first ½ in. or 1 in. of the surface was rotted due to the heat, and this allowed of contraction taking place. The method of core construction in the Randupson process was exactly the same as for ordinary sand.

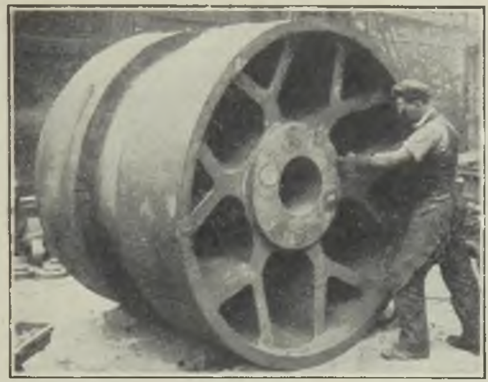

Fig. B.—Gear-Wheel Centre Weighing 12½ tons. Swept up in Loam.

Paper No. 632

RELIEF OF INTERNAL STRESS IN CASTINGS

By L. E. BENSON, M.Sc., and H. ALLISON, B.Sc.

Whilst some of the harmful results of internal stresses in castings have been known for a long time, little attempt has been made to find out what annealing conditions are necessary for the removal of internal stresses. Internal stresses can result in cracks which may or may not be detected before the castings are finished and go into service. Apart from actual cracking, internal stresses may lead to distortion during machining or in service under easy service conditions.

In the authors' experience distortion of castings and forgings during machining is in the main not due to "machining stresses" (*i.e.*, stresses set up during machining), as frequently stated, but is due to internal stresses initially. These are only revealed when the removal of metal on machining disturbs the balance of the internal stresses, thus allowing distortion to occur until a balance is restored. With proper annealing beforehand, such distortion on machining can be avoided except, perhaps, for special work demanding very close limits.

Another fallacy which it is hoped this Paper will explode is that, in steel castings and forgings, at any rate, objectionable internal stresses revealed by machining are due to casting or forging conditions. The relief of stresses on annealing is essentially a creep phenomenon, but as the bulk of existing data on the creep of steel is concerned with steady loads and temperatures over long periods, the data are not readily applicable to practical annealing conditions where the time is comparatively short and the stress is progressively reduced as annealing proceeds and relief occurs. Furthermore, little creep data exist on materials other than steel.

Procedure

To obtain some information regarding the degree of stress relief to be obtained from different annealing treatments, experiments have been made on cast iron, carbon steel, Admiralty gunmetal and a high-tensile bronze. With each material, test-pieces were carefully machined and ground to size, and pairs of test-pieces were fitted together with a stirrup in the middle, the ends being separated by small distance pieces, as shown in Fig. 1. The size of the stirrup and thickness of distance pieces were chosen to give the required maximum bending stresses at the middle of the span. Each assembly was then annealed in an automatically-controlled furnace, and, after cooling down, the residual stress was calculated from the amount of straightening which occurred when the test-pieces were released from the stirrup.

The maximum fibre stresses in the bars were calculated from the following approximate expression based on the elastic theory.

$$f = \frac{\delta E t}{0.17 l^2}.$$

when f = maximum fibre stress.
δ = deflection of bar measured at mid-length.
l = effective length of bar between supports.
t = thickness of test strip.
E = Young's modulus taken as
13,000 tons per sq. in. for steel;
6,250 tons per sq. in. for cast iron;
7,000 tons per sq. in. for gunmetal and bronze.

It was realised that the method employed is not strictly accurate, and that the stress calculations are based on the assumption that stress distribution in the bars is linear both before and after annealing, which is not necessarily true. The method is sufficiently accurate for practical purposes, however, and, with steel specimens, test results obtained by a less convenient but more direct method have given good agreement with results obtained by the method described here.[1]

CAST IRON

Stress Relief in Annealing

The test-bars were machined from a cast block of grey iron approximately 3 in. square section, so as to represent the conditions existing in a large casting.

An analysis of the material gave the following results:—G.C, 3.03; C.C, 0.40; Si, 2.02; Mn, 0.38; S, 0.096 and P, 0.64 per cent. The results of the experiments are given in Table I.

An annealing period of 6 hrs. was chosen first as representing commercial practice with large furnaces, when a fairly lengthy soaking period has to be allowed. Tests A, A_1, B and C (Table I) show the effect of annealing at temperatures varying from 350 to 600 deg. C. with an initial stress of about 5 tons per sq. in., and the results are shown graphically in the left-hand curve in Fig. 2.* This curve shows that the percentage stress relief increased progressively with temperature, the curve falling steeply in the region of 500 deg. C. At 550 deg. C. the curve is flattening out and the initial stress has been relieved by 90 per cent.

The influence of time of soaking for annealing temperatures of 500 and 600 deg. C. is shown by a comparison of tests D and E with tests A_1 and C.

Test.	Annealing treatment.	Stress relief. Per cent.
D	Heated to 500 deg. C. No soaking	51.5
A_1	Heated to 500 deg. C. 6 hours' soaking	60.0
E	Heated to 600 deg. C. No soaking	80.0
C	Heated to 600 deg. C. 6 hours' soaking	97.5

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* Stress-relief temperature curves for cast iron and steel similar to those shown in Fig. 2 were shown in the discussion of a Paper by Machin and Oldham at a meeting of the Lancashire Branch on February 16, 1935. As they were not printed in the report on the discussion, they are included in this Paper.

It will be noted that a considerable measure of stress relief is obtained merely by heating to the annealing temperature without soaking (the heating time in all cases was about 1 hr.), and with slower rates of heating such as would obtain in ordinary foundry practice the degree of stress relief on merely heating would be greater still.

Growth on Annealing

Whilst it appeared from the above that annealing at temperatures above 550 deg. C. would give substantial freedom from internal stress, it was desirable to know at what temperature growth of iron on annealing would occur. Existing information did not provide the information required, as growth was measured after repeated or lengthy annealing, and the measurements were generally too coarse to be of value after a single treatment. Accordingly tests were made on $1\frac{1}{4}$ in. round sand-cast bars of cylinder iron $13\frac{1}{2}$ in. long.

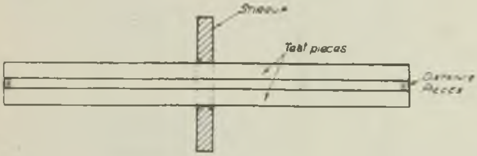

Fig. 1.—Assembly for Tests to Determine Effect of Annealing Period on Stress Relief.

The nominal composition of the iron was as follows:—T.C, 3.3; C.C, 0.7; Si, 1.4; Mn, 0.7; S, 0.10, and P, 0.5 per cent.

Tests taken on one bar gave a tensile strength of 13.6 tons per sq. in. and 217 Brinell. Microexamination showed a satisfactory pearlitic type of structure.

Each bar was cut in two and the pieces machined at the ends in line with Fig. 3. The "pips" at the extreme ends were subsequently

Table I.—*Stress Relief of Cast Iron on Annealing.*

Speci-men.	Treatment.	Thick-ness. Ins.	Effective length. Ins.	Deflection. Ins.		Stress. Tons per sq. in.		Stress relief. Tons per sq. in.	Stress relief. Per cent.
				Initial.	Final.	Initial.	Residual.		
A	6 hrs. at 350 deg. C.	0.489	11.5	0.039	0.008	5.3	4.21	1.09	20.6
A_1	A re-heated 6 hrs. at 500 deg. C. ..	0.489	11.5	0.031	0.018	4.21	1.69	2.52	60.0
B	6 hrs. at 550 deg. C.	0.511	11.25	0.036	0.032	5.3	0.5	4.8	90.0
C	6 hrs. at 600 deg. C.	0.511	11.5	0.039	0.038	5.54	0.14	5.4	97.5
D	Heated to 500 deg.C.	0.511	11.5	0.039	0.020	5.54	2.7	2.84	51.5
E	Heated to 600 deg.C.	0.511	11.5	0.039	0.031	5.54	1.14	4.4	80.0

used for overall length measurements, the shoulders being provided in order that end caps could be shrunk on so as to protect the " pips " from oxidation during annealing. One test-piece from each bar was machined all over the length, reducing the diameter to 1 in., the other test-piece being unmachined except for the ends.

Machined and unmachined bars were annealed at various temperatures in an electric furnace for 6 hrs., overall length measurements being made on each bar before and after annealing.

The measurements made are given in Table II and are shown plotted on the right-hand side of Fig. 2. After annealing at the highest temperature, only the slightest discoloration of the measuring pips was found, so that no loss of accuracy occurred through oxidation. The measurements were made to an accuracy of 0.00001 in. per in. length of specimen. It will be seen that virtually no growth occurred at 500 deg. C., and at 550 deg. the extension was only 0.0002 in. per in. Above 550 deg. C., however, a very rapid increase in the rate of growth occurs. It is important to note that machined and unmachined specimens behaved similarly.

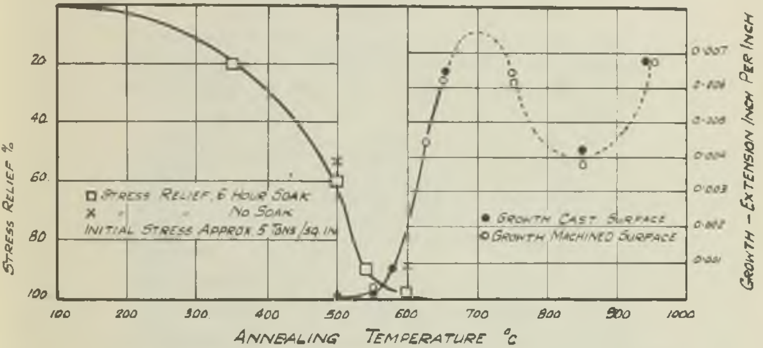

FIG. 2.—EFFECT OF ANNEALING TEMPERATURE ON THE STRESS RELIEF AND GROWTH OF CAST IRON.

The irregularity in the growth curve in the region of 850 deg. C. was not expected, and has not been investigated further. It may be due to changes associated with the critical range, in which case it would probably be swamped by the growth extension on repeated heating, or on heating for very much longer periods. Considering the stress relief and growth curves together it appears that annealing at a temperature of 550 deg. C. is suitable for cast iron. At lower temperatures substantial stress relief cannot be relied on, and at higher temperatures there is a risk of appreciable growth occurring.

STEEL

The behaviour of steel has been considered as regards the shape of the stress relief curve with annealing temperature and also as regards the effect of the annealing period. The results are included in detail in Table III. The results obtained on wrought material as well as on cast material are given, but no apology for doing so is made since such good agreement has been found that the results can be considered together as a whole with advantage.

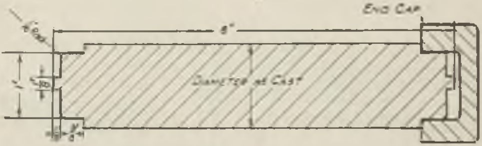

Fig. 3.—Specimen Used to Determine Growth of Cast Iron on Annealing.

Analyses of the steels are as follow:—

Wrought Steel.—C, 0.13; Si, 0.28; Mn, 0.38; S, 0.036; and P, 0.019 per cent.

Cast Steel.—C, 0.30; Si, 0.24; Mn, 0.71; S, 0.046; and P, 0.034 per cent.

The physical properties of the cast steel, which was obtained in the form of a coupon attached directly to a steel cylinder, were as follow:—Ultimate tensile strength, 34 tons per sq. in.; yield point, 16.8 tons per sq. in.; elongation, 28.0 per cent.; reduction of area, 33.6 per cent.; and bend, 127 deg.

The wrought-steel bars were annealed in a laboratory furnace at 880 deg. C. and slow-cooled. The cast material had been annealed for 23 hrs. at 900 deg C. in a large foundry furnace with a load of castings, and after rough machining of the castings it had been further annealed for 4 hrs. at 650 deg. C. and cooled in the closed furnace to 100 deg. C. in 14 hrs.

The stress relief: temperature curve of an annealing period of 6 hrs., which approximates to practical conditions, is shown in Fig. 4. The curve is generally similar to that for cast iron, and falls steeply in the region 500 to 550 deg. C., flattening out to a low residual stress figure at about 600 deg. C. It will be noted that annealing for 6 hrs. at 600 deg. C. has reduced the initial stress in both cast and wrought steel to 5 to 10 per cent.

TABLE II.—*Growth of Cast-Iron Bars.*

Annealing temperature. Deg. C.	Cast surface.		Machined surface.	
	Total extension. Ins.	Extension. Per in.	Total extension. Ins.	Extension. Per in.
500	≯0.00005	0.00000	—	—
550	0.00065	0.00013	0.0012	0.0002
575	0.00435	0.0008	—	—
625	0.0222	0.0044	—	—
650	0.03145	0.0063	0.0304	0.0061
750	0.0318	0.0064	0.0307	0.0061
850	0.0208	0.0042	0.0185	0.0037
950	0.034	0.0068	0.03425	0.0068

The effect of the length of the annealing period is illustrated by Fig. 5. Although points are plotted for both wrought and cast material, it is found, allowing for reasonable experimental error, that the points must fall on some such family of curves as is shown. A relatively considerable measure of stress relief has occurred with no soaking period at all, *i.e.*, just heating

TABLE III.—*Stress Relief of Steel on Annealing.*

Specimen.	Annealing treatment.	Effective length. Ins.	Thick-ness. Ins.	Deflection. Ins.		Stress. Tons per sq. in.		Stress relief. Per cent.
				Initial.	Final.	Initial.	Final.	
Cast steel :								
A	400 deg. C. for 3 hrs.	11.5	0.483	0.020	0.0025	5.6	4.9	12.5
A_1	400 ,, ,, 6 ,,	11.5	0.483	—	0.00375	5.6	4.55	19
A_2	400 ,, ,, 12 ,,	11.5	0.483	—	0.004	5.6	4.5	20
B	500 ,, ,, 3 ,,	11.5	0.500	0.019	0.0085	5.5	3.05	44.5
C	600 ,, ,, 3 ,,	11.5	0.463	0.0175	0.0155	4.7	0.5	88.5
C_1	600 ,, ,, 6 ,,	11.5	0.463	—	0.0165	4.7	0.25	94.5
C_2	600 ,, ,, 12 ,,	11.5	0.463	—	0.017	4.7	0.1	97.5
D	650 ,, ,, 3 ,,	11.5	0.483	0.0215	0.020	6.0	0.4	93
Wrought steel								
3 & 9	500 deg. C. for 0 hrs.	12.0	0.490	0.022	0.009	5.8	3.42	41.0
7 & 8	500 ,, ,, 3 ,,	12.0	0.490	0.022	0.010	5.8	3.16	45.5
1 & 5	500 ,, ,, 6 ,,	12.0	0.490	0.0205	0.0105	5.4	2.7	50.0
11 & 10	500 ,, ,, 12 ,,	12.0	0.490	0.021	0.011	5.55	2.65	52.5
12*a* & 22	550 ,, ,, 0 ,,	12.0	0.486	0.024	0.0125	6.2	2.96	52.5
17 & 20	550 ,, ,, 3 ,,	12.0	0.486	0.0225	0.0145	5.82	2.07	64.5
15 & 16	550 ,, ,, 6 ,,	12.0	0.486	0.022	0.015	5.7	1.82	68.0
14 & 19	550 ,, ,, 12 ,,	12.0	0.486	0.026	0.0205	6.6	1.3	80.5
26 & 27	600 ,, ,, 0 ,,	12.0	0.486	0.025	0.0175	6.45	1.9	70.5
24 & 25	600 ,, ,, 3 ,,	12.0	0.486	0.025	0.0235	6.45	0.37	94.5
30 & 28	600 ,, ,, 6 ,,	12.0	0.486	0.025	0.0225	6.45	0.63	90.0
35 & 36	600 ,, ,, 12 ,,	12.0	0.486	0.025	0.0235	6.45	0.37	94.5
21 & 37	650 ,, ,, 0 ,,	12.0	0.486	0.0195	0.0162	5.0	0.8	85
29 & 32	650 ,, ,, 1 hr.	12.0	0.486	0.022	0.0215	5.7	0.15	97.5

up to the annealing temperature. In view of this and of the way the curves tend to flatten out, it is clear that within practical limitations the length of the soaking period is of secondary importance to the temperature itself.

ADMIRALTY GUNMETAL AND HIGH-TENSILE BRONZE

It is not usual to anneal non-ferrous castings, but for some purposes where permanence of dimensions is important and where absence of internal stresses must be assured annealing may be desirable. To obtain some idea of the behaviour of such alloys, stress relief curves have been constructed for Admiralty gunmetal and a high-tensile bronze, these alloys being chosen deliberately as being important representatives of the Cu : Sn and Cu : Zn types of alloy.

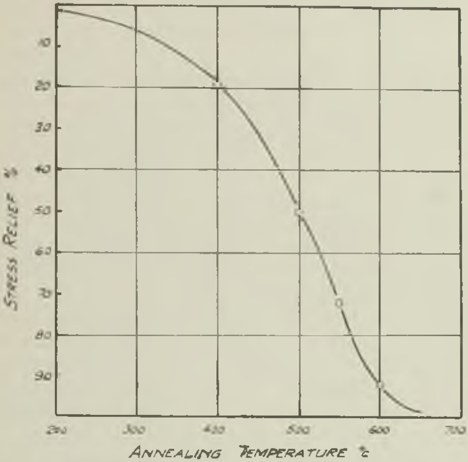

Fig. 4.—Effect of Annealing Temperature on Stress Relief of Steel. (Annealing Period 6 hrs. Initial Stress approx. 5 tons per sq. in.)

To simulate conditions that would be likely to occur in actual castings, material for the tests was obtained as sand-cast slabs 9 in. by 9 in. by ⅝ in. thick, these being machined into strips of the desired dimensions. Particulars of the materials are as follow, the test figures being obtained on pieces machined from sand-cast bars:—

Admiralty Gunmetal.—Cu, 88.0; Sn, 10.0; and Zn, 2.0 per cent.

H.-T. Bronze.—Cu, 55.93; Fe, 1.49; Mn, 3.74; and Zn, 35.03 per cent.

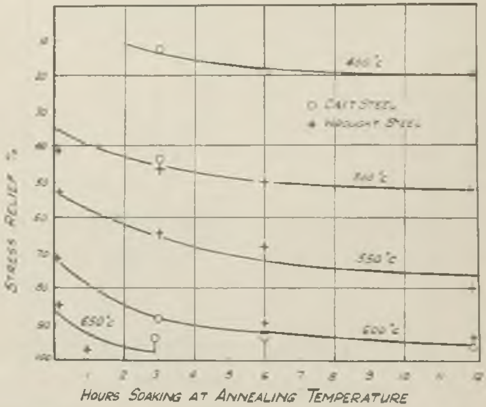

Fig. 5.—Effect of Annealing Period on Stress Relief of Steel at Different Annealing Temperatures.

Admiralty Gunmetal.—Yield point, 9.7 tons per sq. in.; ultimate tensile strength, 17.4 tons per sq. in.; and elongation, 16.0 per cent.

H.-T. Bronze.—Yield point, 21.8 tons per sq. in.; ultimate tensile strength, 42.3 tons per sq. in.; and elongation, 28.0 per cent.

Particulars of the annealing experiments are given in Table IV, and the stress relief : temperature curves for an annealing period of 3 hrs. are shown plotted in Fig. 6.

The curves in Fig. 6 show that in these non-ferrous alloys the initial stresses are dissipated at a much lower temperature than with steel or cast iron, substantial freedom from stress being obtained after annealing at 400 deg. C. for high-tensile bronze and 500 deg. C. for gunmetal. The curves are also of a somewhat different form, the steepest part occurring at an earlier stage.

It is also important to note that although the copper-zinc alloy has a tensile strength in the cold more than twice as great as the copper-tin alloy, the temperature necessary to bring about an important degree of stress relief is approximately 100 deg. C. lower. Whilst such a result might not be expected, it is not altogether surprising since, as has been pointed out, stress relief is really a creep phenomenon and the study of creep has shown that the behaviour of materials under stress at atmospheric temperature can be altogether misleading as regards their behaviour under stress at elevated temperatures. Indeed, Dickenson in his pioneer Paper of 1922[2] gives data regarding a nickel-chrome steel which had a tensile strength in the cold of 52.8 tons per sq. in., as against 43.2 tons per sq. in. for a carbon steel, but which, nevertheless, broke in one-tenth the time for the latter steel when tested at 550 to 600 deg. C.

CONCLUSIONS

(1) *Effect of Annealing Temperature and Duration.*—Under the conditions of the experiments, which were chosen to represent practical conditions as far as possible, it has been shown that substantial stress relief can be obtained by annealing at approximately the following minimum temperatures.

Admiralty gunmetal	500 deg. C.
High-tensile bronze	400 deg. C.
Cast iron	550 deg. C.
Carbon steel	600 deg. C.

It has been shown that annealing grey cast iron appreciably in excess of 550 deg. C. will produce measurable growth.

It may also be pointed out that annealing certain steel castings, notably molybdenum steel castings, much in excess of 650 deg. C., but below the critical range, will bring about spheroidisation of the carbide constituent, possibly with very detrimental results as regards the creep strength of the material, *i.e.*, the property for which these steels are particularly valuable.[5]

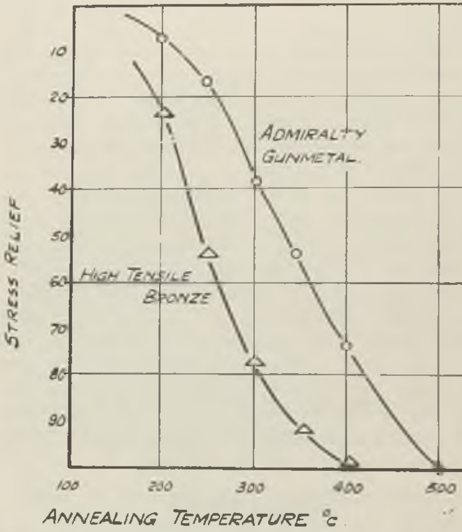

FIG. 6.—EFFECT OF ANNEALING TEMPERATURE ON STRESS RELIEF OF ADMIRALTY GUNMETAL AND HIGH-TENSILE BRONZE.

The effect of the length of the annealing period is of secondary importance at any rate within ordinary commercial foundry practice. The temperature : stress relief curves are steep, however, and for this reason it is essential that sufficient soaking should be allowed for the castings to attain the annealing temperature throughout. Under ordinary shop conditions there is generally a very big lag in temperature between the job and the control thermocouples unless a practice is made of deliberately placing thermocouples in suitable holes in the castings themselves, or, if not convenient, in holes drilled in blocks of metal of representative dimensions compared with the charge.

The experiments made show that it is quite erroneous to suppose that in iron or steel castings any large measure of stress relief can be obtained by ageing at atmospheric temperature or by annealing at temperatures such as 150 or 350 deg. C. The impression conveyed by some specifications in this respect is unfortunate.

(2) *Effect of Rate of Cooling after Annealing.*—The annealing treatments considered above will produce effective stress relief at the annealing temperature, but the parts when cold will not necessarily be still stress-free. Internal stresses are generally the result of uneven temperature distribution during cooling down, particularly whilst cooling through the temperature at which the material changes in character from plastic to elastic—say 600 to 350 deg. C. for steel and cast iron. Cooling from the stress-relieving temperature may, set up a system of internal stresses therefore, as well as cooling after casting or after a high-temperature annealing treatment.

To avoid this possibility, furnace-cooling is recommended, and the authors' experience indicates that cooling in a closed furnace to 100 deg. C. is satisfactory even for such important steel castings as turbine cylinders and large steam-chests. Small parts of even section may be air-cooled without serious detriment, but it is difficult to draw the line in practice, since castings are not generally of even section and large temperature differences would be likely on cooling in air.

TABLE IV.—*Stress Relief of Gunmetal and Bronze on Annealing.*

Specimen.	Annealing treatment.	Effective length. Ins.	Thickness. Ins.	Deflection. Ins.		Stress. Tons per sq. in.		Stress relief. Per cent.
				Initial.	Final.	Initial.	Final.	
Admiralty gunmetal.								
16 & 17	300 deg. C. for 3 hrs.	8.5	0.345	0.023	0.009	4.5	2.75	39
14 & 15	350 ,, 3 ,,	8.5	0.356	0.0215	0.0115	4.35	2.0	53.5
18 & 19	250 ,, 3 ,,	8.5	0.347	0.024	0.004	4.75	3.95	16.5
12 & 13	200 ,, 3 ,,	8.5	0.378	0.0265	0.002	5.7	5.3	7.5
20 & 21	400 ,, 3 ,,	8.5	0.375	0.0205	0.015	4.4	1.2	73
25 & 26	500 ,, 3 ,,	8.5	0.375	0.0225	0.0225	4.8	0.0	100
High-tensile bronze.								
1 & 2	300 deg. C. for 3 hrs.	8.5	0.376	0.022	0.017	4.7	1.05	77.5
8 & 9	350 ,, 3 ,,	8.5	0.338	0.0245	0.0225	4.7	0.4	92.5
3 & 4	250 ,, 3 ,,	8.5	0.377	0.023	0.0125	4.9	2.3	54.5
5 & 6	200 ,, 3 ,,	8.5	0.376	0.0235	0.0055	5.0	3.85	23.5
5*a* & 6*a*	400 ,, 3 ,,	8.5	0.376	0.019	0.019	4.1	0.0	100

(3) *Generation of Internal Stresses.*—Steel castings are almost always annealed at a temperature in the region of 900 deg. C. and are frequently given a second treatment at 600 to 650 deg. C. after rough machining. In view of the fact that internal stresses become dissipated at about 600 deg. C., it is clear that the internal stresses to which the engineer objects are not the result of cooling down after casting or forging as sometimes supposed, but have been developed by uneven cooling after annealing. It may even happen, through lack of appreciation of how internal stresses are developed and relieved, that the second annealing treatment is more detrimental than beneficial. For example, castings annealed at 900 deg. C. and slowly cooled may be internally stress-free and actually in better condition than after a second treatment followed by comparatively rapid cooling. It is the last treatment that counts, and in the authors' opinion one properly controlled heat-treatment is thoroughly satisfactory unless exceptionally heavy machining is done subsequently. In any case, one properly controlled annealing is preferable to repeated annealing treatments if due regard is not paid to the final cooling conditions.

As regards annealing stresses in steel parts, it is only fair to say that the authors' experience is that the foundry is less culpable than the forge. Whether iron foundries are in such a strong position is a debatable point, since many iron castings are not annealed at all. The need for annealing will depend, of course, on the degree of internal stress that can be tolerated and the uniformity of temperature that can be maintained as the castings cool down, particularly through the range 550 to 350 deg. C.

(4) *Magnitude of Internal Stresses.*—The stresses applied to the test-bars experimentally were chosen arbitrarily for convenience and to represent the magnitude of stress which the authors believe may exist. It is quite clear that much higher stresses can exist in castings

since cracking does occur, but it is to be expected that such stresses would be dissipated at substantially the same temperatures as indicated by this investigation. This view is supported by the fact that stress relief curves obtained on steel using initial stresses of different magnitude tended to come together as the annealing temperature approached 600 to 650 deg. C.[1]

The authors are indebted to Dr. A. P. M. Fleming, C.B.E., director and manager of the research and education departments of Metropolitan-Vickers Electrical Company, Limited, for permission to publish the information contained in this Paper.

REFERENCES.

1 Benson and Allison. "The Low-Temperature Annealing of Welded Mild Steel Structures to Relieve Internal Stresses." Welding Symposium, Iron and Steel Institute May, 1935.

2 Dickenson. "Some Experiments on the Flow of Steels at a Low Red Heat, with a Note on the Scaling of Heated Steels." Journal, Iron and Steel Institute, 1922, Vol. CVI, p. 103.

3 Bailey and Roberts. "The Testing of Materials for Service in High-Temperature Steam Plant." Proc. I. Mech. E., 1932, Vol. 122, p. 209.

DISCUSSION

Mr. Benson, introducing his Paper, said that at the time the experiments were carried out, he and his colleague could not find any work useful for correlation or any real guidance regarding the conditions which were necessary to give effective stress relief in castings, and for this reason they would welcome particularly any criticism or constructive remarks.

Further Correlation of Results Suggested

Dr. A. B. Everest suggested that one should accept the authors' results with caution. There was, on the one hand, plenty of evidence that castings may be stressed locally, even up to breaking point, and such stress resulted in distortion and sometimes fracture long after the casting had cooled. For the elimination of such stress many of the British specifications advised annealing at a temperature of 450 deg. C., but apart from this there was a general impression among engineers that even lower temperatures could be effective, and in fact weathering at normal temperatures was regarded as of use in equalising the stresses in question. Now the authors quoted a figure of 550 deg. C. as the minimum temperature necessary to give stress relief, and this figure was clearly a great deal higher than most foundrymen would be prepared to accept. He asked whether this difficulty had perhaps crept in because the authors were dealing with test specimens where the stress was uniform, whereas the troubles which normally arose in a casting were clearly of a more intense and localised nature. Again, it was obvious that stress relief was achieved by means of creep. Work carried out at the N.P.L. had shown that the creep stress of cast iron at temperatures below 450 deg. C. was relatively low, and certainly far lower than the intense localised stresses referred to above. It would not seem, therefore, necessary to go to a temperature as high as 550 deg. C. in order at least to reduce these stresses to harmless values. It did not perhaps matter a great deal if the stresses left in the casting were low, provided they were well distributed and balanced.

Another point noticed in the authors' Paper was that the work has been carried out on irons of fairly high phosphorus content. It was suggested that this might have had an important bearing, and he asked what the authors would consider the relationship between phosphorus content and the temperature necessary for effective stress annealing.

Stress-Free Castings Non-Existent

Mr. Benson, in reply, said the point raised by Dr. Everest regarding the amount of stress which might safely lie in castings and the annealing temperature which was necessary was a question of degree. It was common knowledge there were many castings in service behaving perfectly satisfactorily which were not stress free. It was probably true to say that there were no castings which were really stress free, and very few which were even effectively stress free. Whilst for some purposes moderate stress could exist without being seriously harmful, there were cases where substantial freedom from stress was desirable and where the slightest distortion would be serious. To obtain a substantially stress free condition, he believed, and all the evidence he had seen supported the view, that that could only be obtained by annealing at about 550 deg. C., followed by sufficiently slow cooling, not to generate a new system of internal stresses.

He thought Dr. Everest meant, when he referred to " uniformity of stress," internal stress of a moderate magnitude.

Specificational Difficulties

There was, of course, no such thing as a casting containing uniformity of internal stress; if the stresses were internal, there must be some stress in tension and some stress in compression. With regard to the specification temperatures, he was glad that point had been raised. The wording of some specifications was misleading. It was stated in some specifications that castings must be annealed at a temperature such as, in one case, 150 deg. C., in another case 350 deg. C., and in some specifications 450 deg. C., for a sufficient time to produce relief of all internal stresses. That, of course, was impossible, unless one annealed at a temperature of 550 deg. C., but at lower temperatures for many types of work satisfactory castings were produced, containing moderate stresses. Referring to Fig. 2, it was obvious that in the region of 400 to 450 deg. C., the rate of stress relief increased very rapidly. He did not think it was possible to obtain any stress relief worth considering by means of ageing. He did not consider that phosphorus had any substantial effect on the annealing temperature, although he had not tried it out experimentally. The relief of stress was really a kind of rapid " creep," and phosphorus was not one of the elements generally recognised as having an appreciable effect on the " creep " behaviour of ferrous metals.

Rigidity of High-P Irons at High Temperatures

Mr. R. C. Tucker pointed out, in reference to the last statement, that the work done by the British Cast Iron Research Association had shown that even at a temperature of 850 deg. C. phosphoric irons were generally more rigid than low phosphorus irons.

Mr. Benson said he did not wish to challenge that statement. He was very glad to have the information.

Ameliorative Effect of Vibration

Mr. E. Longden, after congratulating Mr. Allison and Mr. Benson on tackling another phase of foundry practice which was so very important to those who were making delicate and large castings, said so far as the statement was concerned that ageing did not relieve stress, the practical foundryman felt that this did obtain. They put certain classes of castings that could be conveniently handled into ovens for annealing, and found that at a temperature of 250 deg. C. they obtained a considerable change in the dimensional stability of the metal. Castings were usually rough-machined, and then put in the oven for this very slight annealing. He considered that the ageing was in a measure effected by the vibration of the surroundings, rather than just the passage of time. He thought that if one considered the shaking of the casting, the disturbance of it, just by earth tremors due to the operation of a workshop, and temperature changes, that might have a bearing on the question. It was the practice of some foundries to age a casting, and they would not use a casting unless it was twelve months old. Annealing at temperatures round about 500 deg. C. would not injure the hardness, and any serious changes in shape would be cured in 99 per cent. of the cases. But, so far as large castings were concerned, that, of course, was impossible, since such large ovens could not be made available.

Mr. Benson said he was glad to hear that somebody else had found that a temperature as high as 500 deg. C. was advantageous. With regard to ageing, he could not agree that ageing for even a year was going to be beneficial. Yet even if it was, it seemed to be much more satisfactory to produce the effect in a furnace under controlled conditions, and with certainty in a few hours.

Improvement by Rumbling

Mr. T. H. Turner (Doncaster) asked whether the authors had considered the action of rumbling the castings. Some foundries had castings shaken and banged together in a rotating barrel. He had heard that that resulted in a reduction in the residual internal stresses.

Mr. Benson said he doubted whether rumbling would have an appreciably beneficial effect, but he could understand that with small castings containing extremely high internal stresses rumbling might be sufficiently severe to produce local yielding in places. This might occur with steel, but in the case of cast iron such severe treatment would be likely to produce cracking rather than plastic distortion.

Vibration Theory Substantiated

Mr. Ben Hird, speaking with reference to internal stresses in cast iron, said he had definite proof that vibration removed these stresses and improved the strength of the casting. This effect was very pronounced with cast iron railway chairs cast on to steel sleepers. The chairs, when cast on the sleeper, were subjected to a transverse test within a few days of casting. Later a number of these sleepers were taken out of the railway track, after twelve months' service, and tested in the same way. The results showed a 100 per cent. increase in strength. As cast, the average was 20 to 25 tons transverse—after twelve months' service, 40 to 50 tons.

A number of years ago, Moldenke, writing on this subject of vibrations, suggested that large castings which could not be tumbled in a barrel would have their stresses removed and strength improved by subjecting them to vibrations on a plain jolt machine table.

Mr. J. H. Cooper said there was a quantity of published data with regard to this vibration of castings, particularly in America, and it was shown definitely that even the tapping of the end of the machine made an increase in the test results which was quite appreciable. It was published in the American Foundrymen's Association's Proceedings, and subsequently they incorporated in their specification that this should be done.

Cooling Rate Important

Mr. Kain thought members ought to be particularly grateful to the authors for putting this question of stress relief on a quantitative basis at last. There had been much discussion about these matters from time to time, but it had never been previously put on a quantitative basis. He hoped that any further work that they did, they would publish and make available for the steel foundry industry. He asked if the authors could give a definite maximum figure for the cooling rate. He noted that furnace cooling was recommended, but founders were very apt in these days, when pushed for output, to open the doors to hasten the cooling of the castings; shutting the doors to steady-up the cooling, then to re-open them again. He would like to know if they could give a definite maximum figure beyond which they consider it was not safe to go.

Controlling Factors

Mr. Benson, in reply, said that was a very difficult question to answer precisely. He had had experience in the measurement of internal stresses in some castings as delivered to his firm. Also, it was known from general principles that the risk of internal stress was greater with large masses; the greater the dimensions the greater the risk, so that the rate of cooling to be preferred depended not only on the shape of the casting, but on its mass, which complicated matters very profoundly. There was no doubt that many small castings, particularly when uniform in shape, were in a perfectly safe condition if air-cooled from the annealed temperature. At the other extreme, very large castings developed internal stresses so easily that people who had had experience of these knew of castings cracking spontaneously on cooling down freely in air. For example, rigid barrel-shape castings must be cooled very slowly in the furnace. The largest castings of which he had had personal experience, such as flywheels of 20 to 50 tons weight as rough-machined, must be cooled down in the furnace for a period of days, say for a week, if they were to be substantially stress free. With the intermediate size of castings he feared one had to be guided by experience. At Trafford Park steel castings for turbine work were all cooled slowly in the furnace, particularly on the second anneal which was at 600 to 650 deg. C. The most dangerous range of temperature was the range during which the castings changed from a plastic condition to a rigid elastic state. That range was known for carbon steel, and it was also substantially the same, he thought, for cast iron. That range of temperature was from about 600 to 350 deg. C.

Mr. Makemson, in closing the discussion, said that further contributions to the discussion in writing would be welcomed, and would be published.

Communication

Mr. A. Marshall wrote that he had made some cast-iron gears ranging in section at the rim from 1 in. to 4 in., and that he had given these castings a heat-treatment which was carried out as a continuous process in a three-chamber furnace. The first chamber was used to preheat the castings, the second for soaking, and the third for cooling off. All castings were of the same composition. He would like to know if any harm would be done by giving all the castings the same treatment, and if the time fixed for those of 1-in. section would be adequate for those of 4-in. section.

Authors' Reply

In reply, the authors stated that the treatment to ensure that internal stresses are reduced to a minimum is the same for cast-iron gear castings as for other cast-iron parts, and we recommend that they should be heated to a temperature of 550 deg. C.

The soaking period should be adjusted so that the whole furnace charge, including the thickest section, reaches this temperature uniformly. Soaking beyond this point is unnecessary and conditions which are suitable for the heaviest castings will be suitable for lighter work also. Conditions suitable for 1-in. section castings might be insufficient for the 4-in. thick castings.

Within ordinary foundry limits the treatment at 550 deg. C. will be satisfactory for different compositions of iron.

Continuous annealing in a three-chamber furnace should be satisfactory, but if the castings have to be taken from the furnace before they have cooled to about 150 deg. C. they should then be allowed to finish off cooling gently in an empty furnace, pit or other enclosed space, so as to avoid unequal cooling of different sections.

Paper No 633

ENGLISH AND AMERICAN STEEL-FOUNDRY PRACTICE

By C. J. DADSWELL, Ph.D., B.Sc.(Eng.), Ingenieur E.S.F.

The steel-foundry industry in Great Britain is esentially of a jobbing nature, the existing foundries being of all sizes, with outputs varying from a few tons per week up to several hundred tons per week. There have been few British steel foundries laid out for specialised production of a limited variety of castings excepting in cases such as mine tub wheels, railway wagon components and wheels, some manganese steel specialities, some gear wheels and valve castings, and it is only recently that more elaborate methods of production have been introduced. In no case does the output of these specialities compare with the output obtained in the largest American foundries* devoted to the production of vast quantities of the same or similar castings.

The American steel-foundry industry is very much specialised, not only for the mass-production of machine-moulded castings but for types of castings of all sizes, and it is this specialisation that strikes one so forcibly during a visit to the steel foundries of that country. The cause and effect of this line of development make an interesting study. The cause was partly the size and geographical position of the markets and partly the cost and quality of labour available, particularly in the earlier days of the industry, whilst the effect has been a higher standard of quality and a decrease in the cost of production, which has been marked enough to be an important factor in the trend that appears to exist in America towards the greater use of steel cast-

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* The term "American" throughout this Paper refers either to the country or the people of the U.S.A.

ings at the expense of fabrication and other methods of manufacture. There are grounds for believing that an opposite trend exists in this country to-day, particularly in some branches of the electrical industry, which would seem to suggest that a co-operative effort is needed towards a higher degree of specialisation in production and a more active and organised propaganda amongst designers to meet the competition from outside the steel casting industry, a far more serious matter for the trade as a whole than rivalry within itself.

For the mass-production of steel castings the British industry has no plant really comparable to the larger ones in America, but latterly British steel foundries have tended to specialise in a modest way, and although the quantities involved, either for mass-production or for what one might term "specialised production in small quantities," are nothing like those obtained in the States, better production methods have been developed. They have usually been somewhat hampered in that quantities have not warranted special foundries or even full mechanisation, so that suitable compromises have been introduced as a development of the special lines already established.

There is in fact a tendency amongst all the larger British producers of steel castings to have one or more specialist lines with which to form a nucleus of production, to help them with their output of jobbing work, a policy which seems to offer the best prospects of success under our conditions, and which has some advantages over American methods by making our average outputs less variable with the fluctuations that can occur in specialised products. The principle is satisfactory if properly applied, but can lead to trouble with both types of product due to the antipathy that exists between the improvisation of the real craftsmen and the mechanical discipline so essential to specialist production methods. There is no doubt that the organisation of a large jobbing foundry is very much more difficult than that of a foundry devoted entirely to mass-production work.

It will be admitted that the British steel foundries have been slower in adapting their organisation for the " modest " or " semi-mass " production type of work, and in this respect were behind the British iron founding industry, which commenced on higher production bases somewhat earlier owing to its association with the motor-car industry which quickly learnt its lessons from American motor vehicle manufacturers.

The method of recruitment for executives in British foundries has probably had some influence on the slow development of production methods. In America there was no doubt at one time a lack of skilled foundry artisans, and the executive positions were filled by a combination of foundrymen and engineers. In our country the recruitment of executives has in the past been almost exclusively from the ranks of moulders and patternmakers, who, whilst capable of producing the highest quality castings, are not always so receptive of the latest developments in science, engineering and management as the less specialised general engineer.

There is no doubt that in foundry management both an engineering and a metallurgical training are always an advantage, and the former is almost essential where mechanisation has been seriously developed. The lack of skilled artisans had also no doubt a direct influence on the earlier application of production methods and specialisation in America, in that means had to be found to make the product as far as possible independent of the skill of the workmen. Further, the tremendous rate of development of a great virgin country by a race that was progressive and enterprising almost to a fault, naturally led to intensive production beyond anything that had been heard of in the old world.

In certain cases a great improvement has recently been made in the rational organisation of British jobbing and semi-production work. This has been assisted by the introduction of planning sections, which are more or less elementary as compared with those in large mass-production factories but which do, to some extent, take the laying-out of the work and so on from the shop floor and place them more under considered office control. In the case of jobbing work and with keen and intelligent foremen it is neither desirable nor feasible to make the planning of production entirely office-controlled, but careful guidance on the part of those in charge enables the foremen to work out the final details to advantage and is a most useful educational force for them.

The technical aspect of the steel-foundry industries shows differences between the American and British methods, due to the factors which have already been mentioned as affecting the question of specialisation, and also due to variations in raw materials and the mechanical appliances which it is possible to use on jobbing and special production work. Other important factors are the psychology and traditions of the people and the standard of finish of the products required. The impression in this country is that buyers demand a better finish from British than from American steel foundries, but the author is of the opinion that present-day American castings are becoming generally equal in finish to our own, and in the case of some of the best specialised firms even better.

This improvement is largely due to the effect of the last depression, during which the American foundries sought to improve their products to gain customers and increased their expenditure on research, with a consequent improvement in their technique. Similarly, although less money has been spent in this country on steel-foundry research during the same period, the recent depression in our foundries has encouraged investigations to develop materials and methods which will cheapen production, whilst maintaining the standard in finish. Incidentally, this same depressed period in this country has diminished the number of skilled artisans available, by reduction in recruitment and by drift to the better paid and more secure sheltered trades, making it necessary for us to develop methods of production and organisation that can function with less dependence on the standard of labour.

Distribution and Organisation of the Industries

The remarkable amount of specialisation in the American steel foundries has already been mentioned. It does not follow that one parent company operates foundries throughout the country which in every case make the same products, but one finds the same castings being made in different parts of the country by different concerns. Their methods, however, are often very similar, even in detail, though the works may be far apart. This is partly due to the interchange of information, which in recent years has become more common, between manufacturers of similar castings. They realise that everyone benefits by such interchange, and that they have little to fear from distant competitors as transport costs safeguard their market. The spread of ideas is also fostered by the tendency for American executives generally to move about from one employer to another more than is usual in this country, and, their experience being specialised, they naturally move principally among the firms making the same types of castings. An example is the cast mill-roll, which is a highly successful specialised product made in just the same way in Pittsburg or Chicago, two centres for this class of casting where the demand is large. Fortunately, the interchange of ideas among British steel founders is far more frequent than it was only ten years ago and is bound to benefit everyone concerned.

In America one finds specialisation even in large castings, one example being that of rolling-mill equipment, the manufacturers of which plant operate their own foundries and produce perhaps several roll housings of over 50 tons weight per week. Fig. 1 shows two such housings which were cast and machined in England. The operation of their own foundries by firms of engineers is more marked in America than in England,

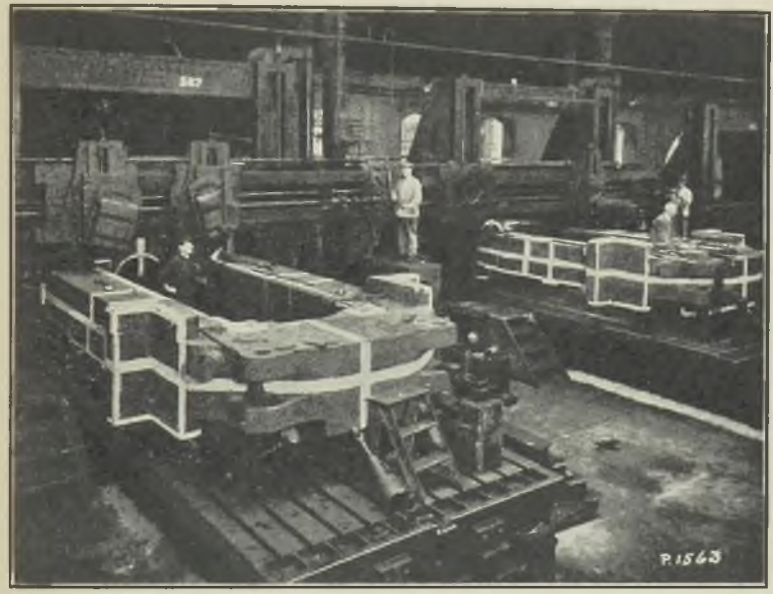

Fig. 1.—Two Roll Housings of English Manufacture.

particularly in the heavy industries. In this country, the demand for large castings for any one firm could not warrant a special foundry, and, in fact, no foundry could exist on an output of large castings only, so that in England it is found that large castings are made by foundries run in conjunction with steelworks, where the surplus output of the large open-hearth melting furnaces can be absorbed by the production of ingots for forging or rolling.

Moulding Technique and Materials

There is a marked difference in America and England regarding the categories of size and weight into which castings are divided for making in green sand, skin-dried or dry sand.

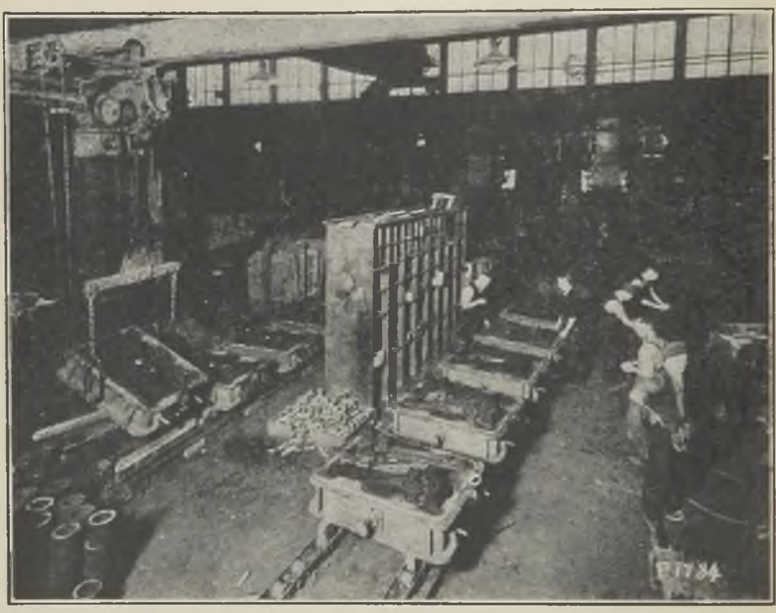

Fig. 2.—English Moulding Unit for Green-Sand Castings.

There is also considerable difference in the kind of moulding mixtures employed for these different sands, the difference in material being most marked in the case of American dry sand, which with very few exceptions is of the synthetic type for all sizes of castings. Moulders' "composition" as used almost generally in this country for heavier castings is practically unknown, and there are fewer than half-a-dozen American concerns using chamotte "compo," a process which has recently been learnt in America from the Continent, but which is not likely to extend very much, owing to its higher cost compared with synthetic sand.

As for the difference in categories, one of the striking features of American steel-foundry practice is the extent to which green-sand moulding is practised. Apart from its being almost universally used for machine moulding, it is common to find jobbing castings up to five tons being made in green sand, and up to 25 tons by the skin-dried method. Nothing like the same proportion of green-sand moulding is done in England, although it is now coming into more favour, and the tonnage so produced is growing every year. A casting weighing five hundredweights is still considered a large one to make in green sand here, although castings up to one

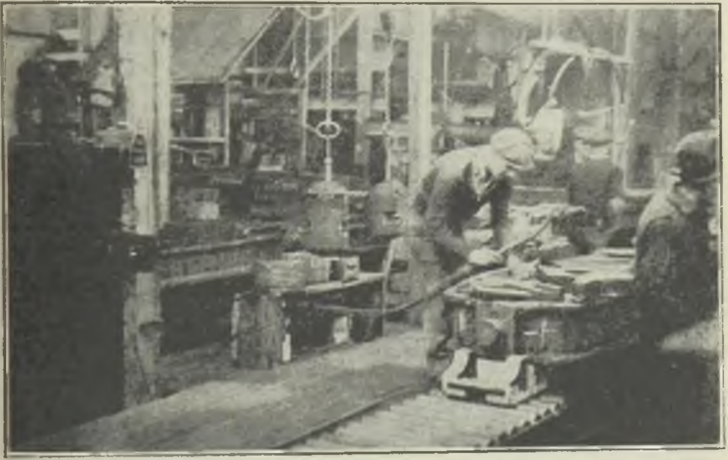

FIG. 3.—END OF AMERICAN GREEN-SAND MOULDING UNIT.

ton are made green in the foundry with which the author is connected.

A green-sand moulding unit for making steel castings weighing up to five hundredweights is shown in Fig. 2.

The reason why green-sand moulding has developed to a far greater extent in America than in England, where for many years it was used in only a few foundries, is no doubt the large-scale production in America, as green sand is the only logical method for large outputs. Fig. 3 shows the end of a production line of an American green-sand moulding unit which produces over one hundred castings weighing approximately 750 lbs. each in less than eight hours, and Fig 4 is a view of the casting floor with the moulds being poured.

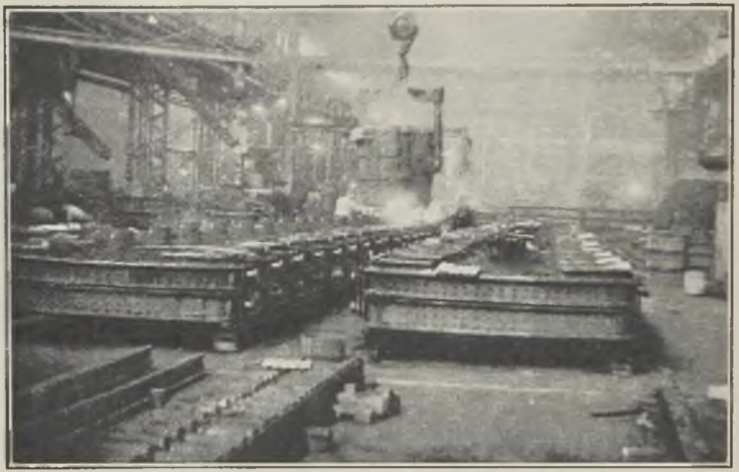

FIG. 4.—POURING AMERICAN GREEN-SAND CASTINGS.

Skin drying is an obvious development from green-sand moulding, as of course it has many of the same advantages, in that moulding boxes circulate more quickly and no drying stoves are required. It is, therefore, common to find American foundries making castings up to several tons in weight where there are no mould drying stoves.

The moulding sand mixtures for green-sand, skin-dried and also dry-sand work are practically all of the synthetic type, and are made from silica sand having varying small amounts of natural clay mixed with fireclays or bentonite, and in some cases one or more of the cereal binders. In America there is even less natural moulding sand available than in this country, and the author believes that before the last War a large quantity of Belgian sand was imported into America in the same way as it has been used for many years for the small amounts of green-sand castings that were made in England before the last five to ten years. It may be that it was the difficulty of obtaining this imported sand in America during the Great War that led to the rapid development of synthetic sand.

It is the rule rather than the exception to find some form of sand control in every American steel foundry, and particular attention is paid in foundries working in green sand to obtain a high permeability figure, this being as high as 200 for backing sand. Table I gives the mechanical grading and chemical analysis of typical silica sands used in America and in England for making green and dry sand mixtures. The appearance of the sands at a magnification of 25 diameters is shown in Figs. 5 to 9.

The silica sand used in American dry-sand mixtures is somewhat coarser than that used in the green sand, and is in fact coarser than the silica sand commonly used in this country. The heaviest steel castings made in the synthetic mixtures compare very favourably in finish with our castings of equal weight made in "compo," and one wonders why synthetic mixtures have not been developed more in this country, considering the relatively high cost of "compo." In England synthetic dry sands mixed on slightly different lines have been used for lighter castings, which in America would more often be made in green sand. Belgian sands are also much used for dry-sand work, although the author is sure that no castings have been made in England, using Belgian sand, as heavy as some made in the country in which it occurs, where 50-ton and heavier castings are made. Examples of moulds for very large English castings made in "compo" are illustrated in Figs. 10 and 11. Fig. 10 shows a mill housing, similar to those seen in Fig. 1, and Fig. 11 the coring up of the mould for an 80-ton press casting. Its appearance when ready for machining is shown in Fig. 12. Incidentally a similar casting believed to be the heaviest steel casting yet made in England and weighing 120 tons, has recently been made in the foundry with which the author is connected.

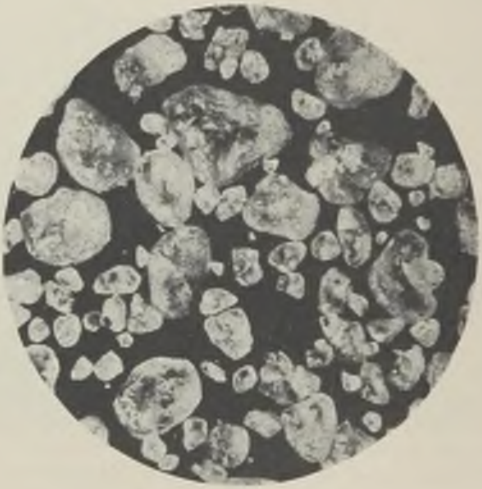

Fig. 5.—Ottawa Sand. × 25.

At times, in order to increase the dry strength of the mixture for top parts, and also to prevent penetration of steel into cores, the American practice is to add silica flour to the mixture to close it up.

For the bonding of cores the American steel foundries use both proprietary brands of core oil and their own core binders made from linseed oil and cereal binders or resinous compounds and other known binders. A larger proportion of the steel foundries make up their own mixtures than is common in England, possibly again because their outputs are larger, and therefore their requirements of core materials can be more economically met than would be the case in many British concerns. The properties and application of cereal binders for binding both mould and core materials are better understood in America than in this country, and they are used more extensively. This greater use of cereal

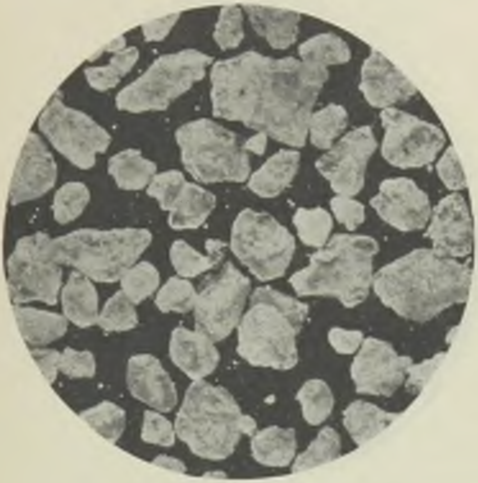

Fig. 6.—Kings Lynn Red Sand. × 25.

binders may be due to the fact that America is a large producer of cereals, and has therefore developed outlets for certain of the by-products, or perhaps founders demanded this material and developed it in collaboration with the producers. It is presumably due to the fact that proprietary core binders in this country have been easily available for the founder, that there has been less inducement for him to produce his own mixtures of binders.

Fig. 7.—American Sand (Source Unknown). × 25.

In reviewing the moulding materials used in both countries, it is impossible to conclude without reference to cement moulding, which is so much under discussion at present. One American concern in particular has taken up this process with enthusiasm, and has obtained considerable success. Castings of a general jobbing nature are produced with comparatively good results, equal to those made by any other process. It is particularly interesting to note that steel castings up to about 50 tons in weight have been produced, and from the photograph of one of these castings the process appears to have been very successful.

Sand Handling and Reclamation

Almost without exception every steel foundry in America handling green-sand castings has some form of sand handling plant, and in the larger concerns very elaborate equipment has been installed. There are no comparable plants in Britain, for the simple reason that there are no concerns handling such large quantities of sand, but most steel founders will be familiar with the type of plant, having seen somewhat similar equipment in iron foundries, of which an increasing number have been equipped with handling facilities in the last ten years or so. Nearly all the steel foundries in Great Britain that are extending their green-sand practice have installed some form or other of handling

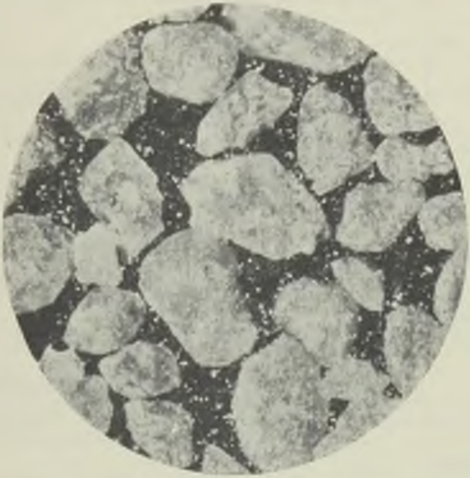

FIG. 8.—VENANGO SAND. × 25.

plant, and that which was installed over 10 years ago in the foundry with which the author is connected, and recently completely modernised, is perhaps the largest of its kind in the country for a steel foundry. Fig. 13 is a view of one 15 ton per hour green backing sand preparation unit in this foundry.

Examination of American plants shows many attempts at satisfactory sand reclamation, and one finds both mechanical grading and air separation in operation. Latest opinion appears to favour mechanical separation of the undesirable from the desirable grain sizes, and most of the new plants being installed are based on this principle. A process of which more will be heard in the future, but which at present is in its infancy, is the use of a classifier pump for sand, which can be used in conjunction with the hydro-

Table I.—*Typical Silica Sands Used in American and Engli*

Source.	Used in.	Percentages on B.S						
		8.	10.	16.	22.	30.	44.	6
For green sands—								
Ottawa ..	U.S.A.	—	—	—	0.43	11.33	40.0	24.
Kings Lynn	England	—	—	0.04	0.13	2.19	27.31	24.
For dry sands—								
X	U.S.A.	—	—	—	0.33	8.63	33.01	28.
Venango	U.S.A.	10.0	3.0	7.4	9.4	18.5	27.8	10.
Leighton Buzzard ..	England	0.34	0.21	1.75	8.35	31.3	44.9	10.

Table II.—*An Example of American Green Sa*

Condition.	Percentages on B.S.I. sie					
	16.	22.	30.	44.	60.	100.
Before reclamation..	0.25	0.4	10.76	32.24	23.14	17.18
After reclamation ..	0.06	0.15	8.72	35.9	31.92	15.13

blast system of cleaning castings. This system of cleaning, which is still in the process of development, merits a brief reference. It is a combination of the hydraulic method, using water only, which received publicity some few years ago, but which was not found really satisfactory for cleaning steel castings, and the use of sand. The sand is entrained in a high-pressure water jet, and projected at the casting being cleaned.

ynthetic Green-Sand and Dry-Sand Mixtures.

ieve Nos.					Total sand grade.	Analysis.			
100.	150.	−150.	Silt.	Clay.		SiO_2. Per cent.	Fe_2O_3. Per cent.	Al_2O_3. Per cent.	Loss on ignition. Per cent.
4.9	4.24	0.57	1.94	1.7	96.36	98.60	Trace	0.95	0.35
4.19	4.76	0.1	2.33	4.07	93.6	93.9	4.06	1.14	1.2
0.54	5.24	0.18	2.07	1.84	96.09	98.30	0.14	0.96	0.42
3.7	1.0	0.06	2.98	5.45	92.98	96.10	0.57	2.03	0.85
2.27	0.28	0.1	—	—	—	99.1	0.43	0.32	0.2

efore and After Reclamation by Air Separation.

os.				Total sand grade.	Analysis.			
50.	−150.	Silt.	Clay.		SiO_2. Per cent.	Fe_2O_3. Per cent.	Al_2O_3. Per cent.	Loss on ignition. Per cent.
.37	0.15	4.06	7.64	88.3	96.2	0.43	2.07	2.05
.8	0.07	0.61	5.55	93.74	96.30	0.28	1.92	1.87

Figs. 14 and 15 respectively show the appearance of an American green sand before and after reclamation by air separation, and Table II indicates the grading of this sand before and after treatment. The particular foundry from which these examples were obtained operates on less than 10 per cent. addition of new sand and is producing regularly green-sand castings up to ½ ton in weight.

It is interesting to note that climatic conditions compel most of the steel founders in America to hold large stocks of sand during the winter months, owing to the fact that snow and frost make it difficult to obtain the sand from the pits. This means that the foundries must have sufficient areas available to store their sand, and must be able to handle it. There being no such necessity in Britain, very few steel foundries here have facilities for storing such large quantities of sand.

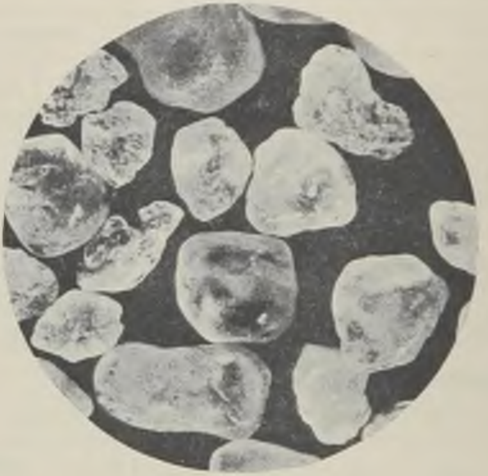

FIG. 9.—LEIGHTON BUZZARD SAND. × 25.

American Moulding Practices of Particular Interest

Before leaving the subject of moulding, the author would like to mention certain practices in America which are unique, and for which due credit must be given to our American colleagues. Perhaps the most striking of all, and one of which many steel founders in this country have no doubt read or heard, is that of making cast-steel locomotive frames with cylinders and other attachments such as boiler saddles, and horn block guides cast integrally. These frames, water bottoms for tenders and other castings up to a maximum of about 90 ft. in length, are made in low-carbon steel, unannealed, and are machined on special machine tools. There are two large works belonging to the same company in America making these castings, for which the equipment and layout are so extensive, and the machine tools used for finishing are so specialised, that it is extremely unlikely that similar castings will be made in any other parts of the world. Particulars of moulding methods used have been published in the technical journals, so that there

Fig. 10.—" Compo " Mould for Mill Housing.

is no need to describe the entire process, but in a few words it consists of building up the complete moulds in dry-sand cores placed on specially machined steel jigs in moulding pits (a normal frame consists of 600 cores). In one of these works, six-wheeled bogie truck castings are rammed in green sand on a jolt-ram machine of

Fig. 11.—Coring-up a "Compo" Mould for an 80-Ton Steel Press Casting.

70 tons capacity with a machine table 22 ft. long, which is probably the largest jolt-ram machine in the world.

Steel Melting Units

The melting units used in America and Great Britain for the supply of steel for making castings are more or less similar, with the exception that there are now very few Tropenas plants in America, where the most common unit for the small foundries is the electric furnace, usually with an acid lining, as against the almost universal basic lining in this country. It has been suggested that the reason why the acid electric furnace is so much used in America is again the effect of the Great War, when it was difficult and expensive to obtain basic linings. It has been said that the American steel foundries using electric furnaces have produced some very bad steel in the past, but now, at any rate, their steel appears to be generally improved. The acid electric furnace produces a greater output at

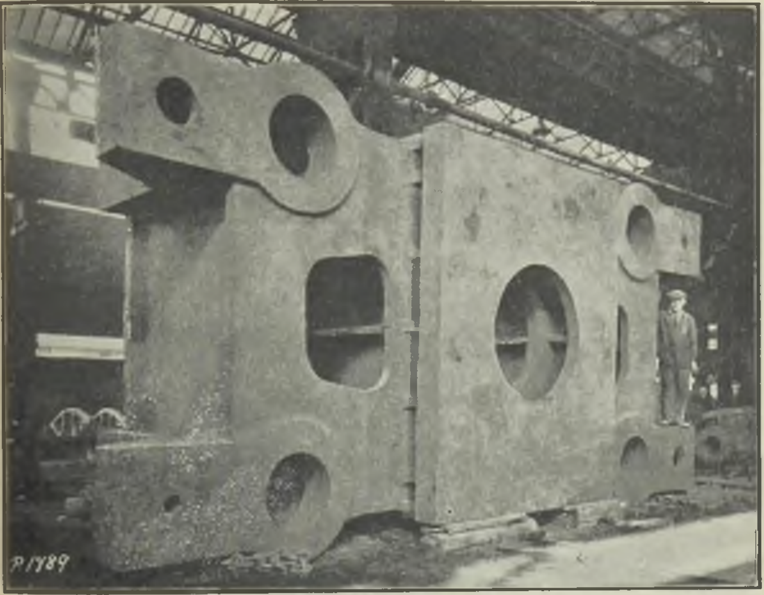

Fig. 12.—80-Ton Steel Press Casting, ready for Machining.

a lower cost price compared with a basic furnace of the same capacity, the steel having a fluidity which compares more favourably with Tropenas steel than does basic steel. This, together with its flexibility and probably also the availability of cheap electrical power, has no doubt led to the adoption of the acid electric furnace in the smaller foundries in preference to the surface blown converter.

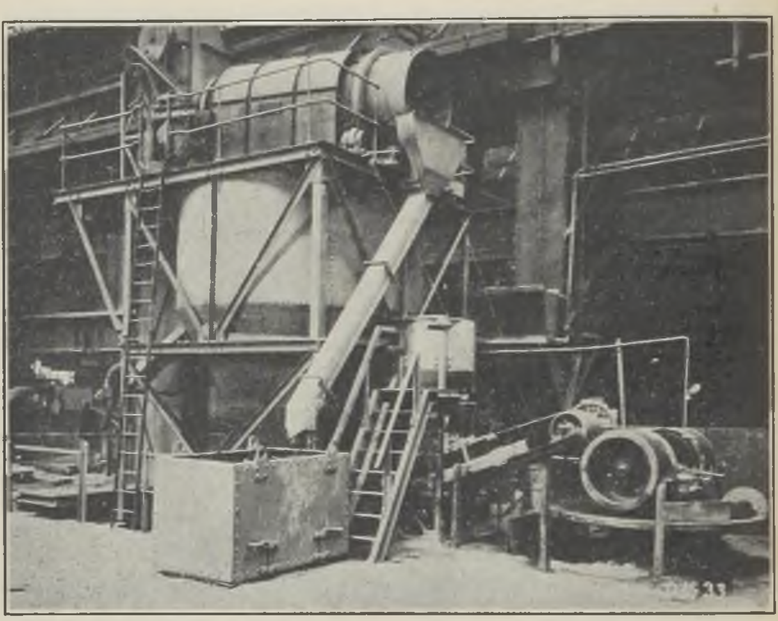

FIG. 13.—ENGLISH UNIT FOR PREPARATION OF GREEN BACKING SAND.

For larger outputs both acid and basic open-hearth furnaces are used, commonly fired by oil or natural gas, occasionally by producer gas. The average capacity of the large open-hearth furnaces in foundries devoted entirely to the manufacture of heavy steel castings appears to be about 50 tons maximum, whereas, in this country, in steelworks making both steel castings and ingots, the larger furnaces are usually of 60 tons capacity. Smaller furnaces are of course used in both countries. The most common size of acid-electric furnace is about 6 tons capacity, there being of course both larger and smaller furnaces.

Fig. 14.—American Green Sand before Reclamation. × 25

One might expect continuous casting systems with mechanical mould conveyors to be commonly employed in American production steel foundries, but this is not the case. The foundries having very large outputs of, say, five-hundredweight castings use open-hearth furnaces of approximately 30 tons capacity, and utilise extensive casting floors to accommodate the moulds for each charge.

Steel Specifications and the Use of Alloy Steels in Castings

Quite recently steel-casting manufacturers in both this country and America have been asked for, and have produced, qualities of castings of greater strength than the ordinary mild steel type to meet the demand of designers, and to meet the competition of articles made in other ways such as forgings, stampings and fabricated structures. The Americans have done more in this direction, partly because their markets spread over a wider field and therefore offer greater opportunities, partly because of their enthusiasm for anything new which they pursue energetically, and partly owing to the incentive to regain markets lost during the years of depression. Manganese, vanadium and nickel are common alloying agents for their so-called high-tensile steels, and one finds that different con-

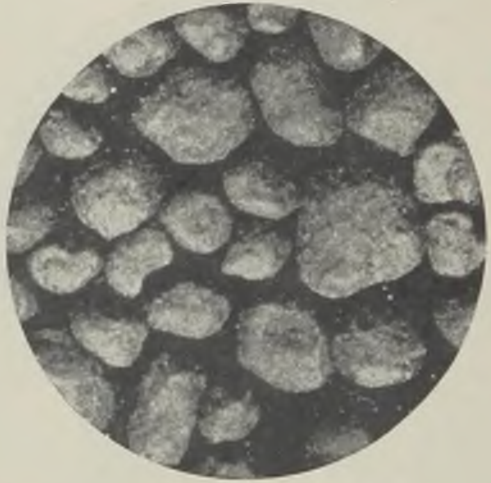

Fig. 15.—American Green Sand after Reclamation. × 25.

cerns concentrate on one or other combinations of these alloys. The use of titanium and other methods for controlling grain size is developing in America, but the author is not aware of any British manufacturers exercising grain size control for steel employed in castings.

There is a certain school of thought in the British steel-foundry industry which believes that in order to defeat the rivals of steel castings previously mentioned, the existing standard specifications for steel castings should be stiffened. The author does not agree with this method of dealing with the problem, but suggests that it might be solved by introducing further specifications for high-tensile steel castings similar to that of the latest specification for railway castings issued by the Association of American Railroads, which originally had a Grade " A " for unannealed castings, and a Grade " B " for annealed castings giving 16 tons per sq. in. yield. It has now slightly improved the Grade " B " by specifying a yield of 17 tons per sq. in., and an ultimate tensile stress of 31 tons per sq. in., and has introduced a new grade " C " for high-tensile steel with a yield of 24.5 tons per sq. in. and ultimate tensile strength of 40 tons per sq. in., with a minimum elongation of 22 per cent. and reduction in area of 40 per cent. A purchaser of this Grade " C " high-tensile steel will naturally pay a higher price than for the ordinary grades of steel, which are sufficiently strong for general purposes.

Heat-treatment Methods

Most of the heat-treatment furnaces used in the steel foundries of America are fired either by oil or natural gas, as against coal, producer gas or town's gas in this country. In America most small castings are heat-treated by normalising, with or without subsequent tempering. The heavier castings are, of course, annealed and cooled in the furnace, although it is noticeable that for very large castings the rates of heating and cooling are rather higher than those used in Sheffield. It is not likely that the difference in the rates can be attributed to any better scientific knowledge, but is probably due to the fact that with the smaller output in this country furnaces have been available to permit one to play safe with large masses, whereas in America the output has probably increased until they have been forced to speed up the annealing, apparently with success.

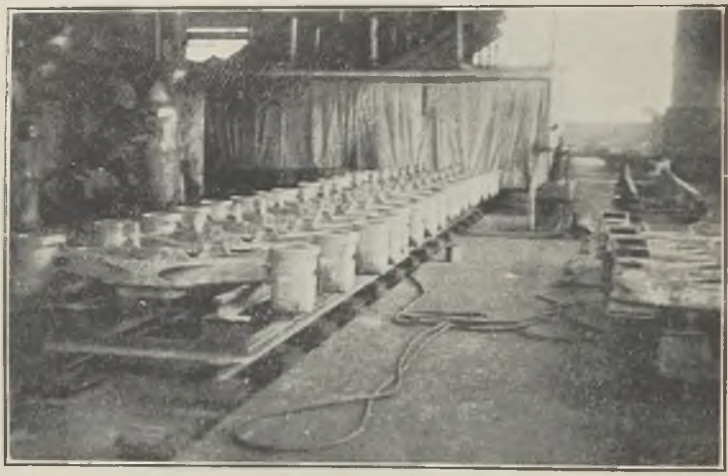

Fig. 16.—American Fettling Shop Conveyor Line.

Whereas large cast-steel anvil-blocks weighing from 20 to 100 tons made in British foundries are annealed, American opinion on the subject is divided; some steel foundries anneal big anvil blocks while others allow them to cool down over a long period in the moulds, as in the case of cast-iron blocks.

An interesting procedure in at least two American foundries is the differential hardening of different parts of small castings, to obtain improved wear resistance.

Fettling and Cleaning of Castings

The fettling shop methods or processes in both countries are similar, excepting that in certain cases in America the fettling shop can be very much better organised than in this country, as fewer types of castings pass through one particular shop. This makes it easier both to arrange for flow production and to set up a satisfactory organisation, which in the case of a fettling shop is as difficult a problem as any encountered in foundry management.

An example of an American conveyor line, where castings up to half a ton in weight, resting on grids, travel on gravity rollers past the various fettling operations, is shown in Fig. 16, whilst Fig. 17 illustrates one of the few conveying systems which have been installed in English fettling shops.

High-pressure compressed-air shot-blasting is becoming common in this country and is widely used in America. British foundrymen are also following the Americans in extending the use of the airless centrifugal shot-projector cleaning machines, the merits of which have been rapidly recognised in both countries. Whereas in England this type of machine has always been supplied in the form of a tumbler, or in its modified apron-conveyor form, excepting in one installation already in operation and in a further plant to be installed in the foundry with which the author is connected, the centrifugal airless shot projector has been applied in America to several types of special machines for specialised work. This is again because the justification for spending money on such elaborate equipment has arisen there more readily than in this country. One extremely interesting example of this application is the specialised cleaning of bogie castings weighing about five hundredweights each, which are cleaned at the rate of one every two minutes. Apart from the use of this method of cleaning on account of its economy in air and its convenience, the American manufacturers have been as interested as is the case here in its relation to the problem of silicosis.

The present attitude in America towards silicosis is very keen, and everything is done towards the elimination of this disease, some works having their own X-ray apparatus in the works first-aid department for keeping a check on all workers. This keenness is due to legislation, and has been increased because many foundries have been the victims of certain types of compensation cases.

Fig. 17.—Conveyor System in English Fettling Shop.

In view of the recent Factories Act in this country, the provision in many American foundries of works welfare equipment in the form of canteens, washing and locker accommodation is interesting. This equipment is better than that generally provided in our foundries, being equivalent to the type of accommodation installed at many modern colliery pitheads in this country. Particular attention is paid to the wearing of goggles, and all staff, foremen and even visitors have to wear goggles when passing through the fettling shops.

Labour Conditions

The question of labour in America, how much a man earns, how freely he spends his money, how he works and how he compares with the British labour would make the subject of a very interesting Paper in itself. There are many good workmen both in America and in this country, and in making comparisons one must consider conditions. Often comparisons are made without due consideration for this. The British workman, working on a production line with the opportunity to earn good money, will produce as much as the American, but so often comparisons are made between the American workman under production conditions with the British workman under jobbing conditions. Those in charge of foundries making motor car components are perhaps better able to express an opinion on this matter than the author. Trade Union conditions in America are not like those in this country, and at the present moment are causing the employers some anxiety. This is partly due to the fact that the Trade Union growth in that country is much more recent than here, and also to the very mixed races comprising American labour, coupled with political influences which it is out of place to discuss here.

Foundry Research

There is no doubt that in the post-war period the steel-foundry industry has advanced a long way both in Great Britain and in America, but the author is of the opinion that the Americans have moved relatively somewhat farther than is the case here. There are several reasons why this should be, one being the influence of specialisation which has been mentioned several times, and another that there are many more steel foundries in America than in England, and therefore more people giving thought to its products. A further important reason is that more time and money have been devoted to research in America. Apart from the larger concerns having devoted a certain amount of energy within their own organisations to this end, certain of the smaller foundries have grouped their resources, one instance, in the author's opinion, having been very fruitful. This was the Electric Steel Founders' Research Group, which was supported by five different concerns. A visit to three of them showed such a high standard generally in all their operations and in their finished products as to give convincing evidence of their wisdom in so spending their money during the depression period.

As in this country, other researches are taking place under the direction of various trade and scientific associations. In this direction and in many others our American brother organisation—the American Foundrymen's Association—with its wide membership, has a large influence. Particular mention might be made of the activities in this country of the Steel Castings Committees of the Institute of British Foundrymen and of the Iron and Steel Institute, but the members of these committees are also busy foundrymen and scientists. Would it not give us a quicker return if groups of manufacturers or the Trade Association were to initiate a research council on the lines of the American Electric Steel Founders' Group, who would have certain full-time investigators working in collaboration with the previously mentioned committees?

Conclusion

A visit to the United States of America to make a study of either a specialised steel-foundry production or a general survey of their practices is a most refreshing experience, and dispels the prevalent impression that their products are generally much inferior to British.

In view of the rapid developments that will still be made by our progressive friends, it is probable that one should renew acquaintance with their foundries every five years. Contact with them is very instructive, particularly, if one keeps a logical judgment regarding different conditions, without being too sceptical or sure that Britain is placed in such entirely different conditions that an adaptation of ideas is not practicable.

The reception accorded by the American foundrymen without exception to one of their own profession from this side of the Atlantic is as hospitable, instructive and helpful as one could possibly desire, and the author would like to take this opportunity of expressing his appreciation of the manner in which he was everywhere welcomed on his recent tour of American steel foundries.

The author wishes to express his gratitude to the directors of English Steel Corporation, Limited, for permission to present this Paper.

DISCUSSION

Quality of American Steel Castings

Mr. C. H. Kain, opening the discussion, thanked Dr. Dadswell for his Paper, and commented on the fact that, at long last, the author had exploded the idea that American steel castings were very much worse than British. He feared that a number of steel foundries had comfortably advanced that statement on occasions rather to cover bad practice than from a true knowledge of the facts. Undoubtedly, American castings recently had improved very considerably.

Dr. Dadswell had made reference to the drift from the foundry of skilled artisans into better-paid trades, and had suggested that one of the methods of overcoming this difficulty was by better technical control, presumably with the object of using unskilled labour. Mr. Kain suggested that this was rather a top-heavy sort of organisation. Executives ought at the same time to give serious consideration to improving the standard of their labour, and striving to achieve the same conditions which obtained in the better-paid and more secure sheltered trades.

Permeability of Steel Moulding Sands

The Paper naturally dealt very largely with sand and sand technique, because feeding steel castings in America was presumably much the same as here. The author had referred particularly to the high permeability sands commonly used in America, and gave the permeability figure of 200 as being high in a backing sand. The speaker suggested that such a figure was not particularly high for steel moulding sand, for green-sand work, and that a range of 350 to 400 was not uncommon and certainly gave better results with green sand.

The author had also stated that silica flour was occasionally used to prevent penetration of steel into cores, and to strengthen the mixture for use in top parts. Personally, Mr. Kain would consider it better practice to use a finer grain of sand than to use a coarse sand and to mix it with silica flour, as that was frequently a cause of surface scabbing.

Mechanical Sand Grading Preferred

It was interesting to note that there seemed to be general agreement that mechanical grading or mechanical separation of silt was superior to pneumatic methods. These had been tried for many years, and personal experience had shown them to be very erratic. There were a number of mechanical separating systems on the market which work very satisfactorily.

He asked the author what the reason was for the increase in grain size in the reclaimed sand. There seemed to be a greater quantity of sands on the 44/66 mesh sieves, which might, of course, be due to agglomeration or to concentration.

The Paper claimed that the acid furnace was very widely used in America, and he would like to know what scrap they had available for use in such furnaces, for one of the greatest difficulties in this country was to obtain low phosphorus scrap. It was also stated that the acid furnace produced steel at lower cost than basic. Could the author give any indication of the relative cost of the steel made by the two furnaces?

Grain-Size Control

Another statement was that grain-size control in steel castings was not practised in this country, but that was questionable, as he believed it was practised in a number of cases. One or two foundries certainly did it deliberately, and many others did it unconsciously by the addition of aluminium.

Dr. Dadswell had dealt with specifications, and the question was worthy of serious consideration The time would undoubtedly come when steel founders would have to meet very stringent specifications. He thought the author's suggested method of further grading rather than a general all-round increase of common specifications was greatly to be sought for, but he seriously doubted tho statement that the purchaser of these high-tensile steels would "naturally" pay a higher price than for the ordinary steel. Personal experience was that buyers wanted the higher grades at the same price. Dr. Dadswell had also made some suggestions for co-operative or joint research, which has undoubtedly produced very good results in the United States, and he agreed that the steel castings makers in this country might also give that subject very serious consideration.

American Steel Castings

Dr. Dadswell, after thanking Mr. Kain for his remarks, said he was not sure whether he had overstressed the quality and finish of American castings, as he was surprised with what he had seen, particularly in view of the general impression here that American foundries could satisfy customers with rougher products than was possible in this country. A visit lasting two months was insufficient to see every foundry, and only "impressions" could be gained.

As to the movement of skilled labour away from the steel foundry industry, he did not quite mean what Mr. Kain had apparently understood. What he had in mind was that by scientifically controlled production one could get larger outputs from the same number of men; for example, production could be increased by the elimination of waste movement by the workers concerned. In fact, one found that the level of earnings increased when the workers were on piece-work, as one obtained higher output. He had no desire to see the development of means generally to eliminate skilled men, and to employ in their place unskilled men, but rather to employ skilled men to better effect.

Permeability of Steel Moulding Sands

The figure of 300 to 400 for high permeability sand seemed rather high to him. He did not think many foundries used such material on green-sand work. The average permeability of his facing sand was, if he remembered rightly, about 180, and 160 to 180 for backing sand. He believed that in examining permeability figures one must bear in mind the nature of the sand which was being considered, the bonding agents, the amount of moisture, and so forth. The permeability of a synthetic sand might not necessarily be required so high as that of a naturally-bonded sand, which might take a higher moisture content and, therefore, generate more steam and gas.

Silica Flour and Steel Penetration

The question of mixing silica flour into moulding sand in order to increase its strength in top parts to prevent scabbing, it must be admitted, did appear rather odd. He failed to appreciate why a very fine sand should not be used, and he was trying that at the present time. He had tried the addition of silica flour as carried out in America, and found that it did have some beneficial effect. It was particularly useful in preventing penetration of steel into cores where they were surrounded by heavy sections of metal. Until one had seen it, it was difficult to visualise the amount of penetration that could take place into, say, a 6-in. dia. core, surrounded by 5 or 6 in. of steel. One objection to the addition of silica flour was that of cost. He believed that silica flour could be purchased much more cheaply in America than here.

As to the reclamation of sand, the American conclusion that the mechanical method was the most satisfactory and economical confirmed personal opinion after exhaustive tests.

Acid and Basic Steel Problems

He had with him no actual figures of the relative costs of acid and basic steel, but he would supply Mr. Kain with more information on that point later. It was not only the question of the cost of the steel which gave the acid some advantages over basic for certain types of production. For example, the acid furnace was a very rapid melting unit, but it was a little difficult to get accustomed to, and the composition was not so easily controlled as in the basic furnace, particularly for the carbon content of mild steel.

Grain-Size Control

He did not imagine that there were many foundries intentionally carrying out grain-size control. It had happened unintentionally, but he did not think that many of the basic electric foundries were doing it for their castings, because there had been a tendency to keep the aluminium as low as possible. It was usually insisted that one should add as little aluminium as possible to the steel, and the amount which was used in Sheffield varied from practically nothing up to half a pound per ton, which was insufficient to give a controlled grain size. Some interesting work on the effect of aluminium on electric steel had been published by Simms and his co-workers, according to whom the addition of half a pound per ton was the worst amount of aluminium that could be added to steel.

Casting Locomotive Frames

Mr. J. H. Cooper said the author had mentioned the casting of a locomotive frame up to a length of about 90 ft. He had seen some very large ones run, and he would like to ask whether the mould was heated before pouring, whether it was run at both ends, how many runners were employed, and finally the method of easing after pouring.

Dr. Dadswell, in reply, said he would not be certain, but he did not believe the moulds were warmed up after closing. The only reason for such a heating would be to dry any jointing materials between cores. The cores were very carefully checked over for size, as not one locomotive frame was made, but perhaps 30 or 40 frames, and therefore the core sizes were carefully controlled, and they were prepared to jigs The runners depended on the weight of the frames, but they usually took the form of one or more down-gates at the centre of the casting. with longitudinal runners at the bottom, having several ingates. The general principle was to run from the bottom with a longitudinal runner Unfortunately, he did not see a frame actually being cast.

Large Grain Sands Preferred

Mr. E. Longden said that the larger sand grains were more resistant to fritting than the smaller grains, so that a large grained sand with suitable refractory coating should be the aim.

Dr. Dadswell said that, despite very careful painting and the working of the paint into the face of the core and mould—he was referring to large castings of from 30 to 100 tons weight—examination of the sand after casting under the microscope indicated that metal was mixed with the sand.

Mr. Longden said it was possible to get definite fritting of the sand behind the blacking or refractory coat if unsuitable sand were used. Moreover, occasionally there were strains of metal which held in this. The use of silica flour if very fine would be preferable generally to fine-grain sand.

Steel Penetration

Mr. T. R. Walker said he had examined microscopically the specimens to which Mr. Dadswell had referred. Some of the cores were made from core sand with an oil binder, and the steel had penetrated between the sand grains. The grains were not fused together. If the specimens were broken up and analysed it was quite common to find that the steel amounted to 50 per cent. of the total weight, and it was actually steel of approximately the same chemical composition as the casting itself.

Regarding Mr. Kain's query respecting the increase of percentages of some of the sand grains after reclamation, an increase in the proportion of larger grains was only to be expected, since many of the small and very small particles had been removed. For example, if one had a sand mixture containing 80 per cent. of sand grains with 20 per cent. of clay, and all the clay were taken out, the material remaining would naturally contain 100 per cent. of sand grains. Actually, the removal of material in desilting was not so simple as that, as some proportion of the larger grains was removed at the same time as the required amount of silt and clay.

Grain Refinement

Mr. R. C. Tucker thought that when foundrymen were up against the question of permeability it was very much better to use a uniform grain sand, and stop it up with silica flour, which would be taken out by the silt plant, than to use two different grades of sand, one for the top and the other for core and sides of the mould. With regard to the control of grain size of metals by the addition of aluminium, he did not appreciate references to "controlled grain size." The expression "grain refinement" was preferable.

HEAT-TREATABLE ALUMINIUM-SILICON CASTING ALLOYS

Paper No. 634

By GASTON G. GAUTHIER*

[FRENCH EXCHANGE PAPER]

Summary

The author gives some of the results obtained in the course of researches made by the laboratory of the Compagnie Alais, Froges & Camargue on heat-treatable aluminium-silicon casting alloys containing in addition magnesium, manganese or cobalt.

Tables give the variation of the mechanical properties under the influence of the heat-treatments and under the influence of variations in the contents of Si, Fe, Mg, Mn, Co and Na.

It is not the purpose of this Paper to give new results. The alloys under discussion have been known since 1931, and much work has been done on them. The author's intention is simply to group the figures obtained in the course of extensive investigations made in the laboratory of the Compagnie Alais, Froges & Camargue, and to provide in this way comprehensive information useful to foundrymen and designers.

Ever since they have been in use, the alloys containing 13 per cent. silicon, modified by means of sodium and called Alpax or Silumin, depending on the country, have undergone considerable industrial development by reason of their casting properties, in other words, their excellent mould-filling capacity and the faithfulness with which the finest details are reproduced.

For manufacturing these alloys, their inventor, Aladar Pacz, endeavouring to utilise an aluminium of the lowest possible quality as base, very soon perceived that above 0.8 per cent. iron

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* Head of Research Department, Compagnie Alais, Froges et Camargue, Chambery (Savoy).

the elongation of these alloys rapidly drops, and he was led to investigate the means for obviating this disadvantage, due to the formation of flat, brittle crystals of a compound of aluminium, iron and silicon. As early as 1920, he took out patents for additions of manganese, cobalt, chromium, etc. These additions certainly had the effect of refining the grain of Alpax of high iron content, and of considerably increasing the mechanical properties of Alpax of normal iron content. The tensile strength remained below 20 kg. per sq. mm., the elongation attained at the most 10 to 12 per cent., and the elastic limit at 0.02 per cent. elongation remained in the region of 5 to 7 kg. per sq. mm., according to the quality and quantity of the additions made.

It was not until 1931 that an appreciable advance was made in this class of alloys by the appearance of heat-treatable alloys, the hardening component of which is a small quantity of the compound Mg_2Si. For counteracting the effect of the iron, one of the elements previously indicated by Pacz for this purpose is added, as well as the addition of magnesium. The latter has the effect of causing the formation of flat, brittle crystals of an alloy rich in iron and silicon, so that for such alloys it would be necessary to employ very pure aluminium and silicon as base, which would be a serious disadvantage. The additions of manganese and cobalt for counteracting this detrimental influence are the two additions which up till now have been most investigated and are the only ones which have been adopted in industrial practice.

The typical alloy contains approximately:—Si, 9 to 12.5 per cent.; Mg, 0.25 to 0.35 per cent.; Fe, $<$0.5 per cent.; with either Mn 0.3 to 0.5 per cent. or Co 0.4 to 0.6 per cent.

In this Paper, it is intended to deal successively with alloys containing manganese and alloys containing cobalt.

General Remarks

The investigations were made on sand-cast and chill-cast specimens, but only the results obtained on sand-cast specimens will be given in what follows. Casting in sand was effected with the use of green sand, that is to say, sand containing about 5 to 6 per cent. moisture. The mould carried two specimens connected together at both heads by channels. At one end of these channels is a gate, which has the form of a sawtooth roof for retaining the dross, and at the other end is the feeding head. The pouring temperature was always uniformly between 700 and 720 deg. C. The test specimens were about 15 mm. in diameter, and, after machining, the useful part was reduced to a diameter of 13.8 mm. and to a length of 105 mm., in order to measure the elongation on 100 mm.

All the melts (excepting, of course, those used for investigating the influence of small amounts of sodium) were subjected to an addition of sodium by the process known as "double modification." The bath of molten metal is provided with a surface layer of 0.3 per cent. of a mixture of 66 per cent. of NaCl and 33 per cent. of NaF as soon as its temperature reaches 750 deg. C. At 780 deg. C., 0.05 per cent. Na is introduced by means of a perforated bell-shaped tool. The metal is allowed to cool, and the samples are cast, as stated above, between 700 and 720 deg. C.

The specimens for the notched-bar impact test were made from the above samples, being machined on all faces. They were of square section of 10 by 10 mm., length 55 mm., and the notch was 2 mm. deep and 2 mm. wide (Mesnager specimen). The fatigue test specimens were machined from castings 20 mm. in diameter and of sufficient length, the dimensions being those laid down by the French Aircraft Standards for Alkan machines.

For the heat-treatments, an electrically-heated muffle furnace with temperature-regulating means was used for the heating before quenching. On leaving the furnace, the specimens were very rapidly plunged into cold water at 20 deg. C., so as to avoid 5 secs. at the most elapsing between the opening of the furnace and the quenching of the samples. Heating for age-hardening was carried out in an oil-bath, the temperature of which was controlled with the aid of a thermometer.

Plan of Discussion

For each of the alloys containing manganese or cobalt, the same plan of discussion will be adopted, as follows:—First of all an account will be given of the investigations made for perfecting the heat-treatment and of the variations in the properties depending on the heat-treatment, and after that the influence exerted on the properties by slight variations in the different additions for the heat-treatment adopted will be reviewed.

ALLOYS WITH THE ADDITION OF MANGANESE

Heat-Treatment

(A) *Quenching.*—The influence of the duration and temperature of heating before quenching was examined for numerous casts of the same composition, containing approximately:—Si 12.5, Mg 0.25, Mn 0.45, and Fe 0.35 per cent.

First of all the influence of the variation of the quenching temperature was investigated in the case of a uniform duration of heating of 10 hrs. Table I gives the results obtained for these various temperatures with specimens which in addition had been subjected to a uniform age-hardening treatment at 155 deg. C. for 24 hrs. This table clearly shows that the temperature of 565 deg. C. is too high.

For fixing the duration of heating before quenching, the mechanical properties attainable on specimens heated respectively for 3, 4½, 6 and 10 hrs. and then quenched were investigated for several temperatures below 560 deg. C. All the specimens were then subjected to a uniform age-hardening treatment at 155 deg. C. for 24 hrs. Table II gives these results for the temperatures 540 and 550 deg. C.

Consideration of Tables I and II permits one to say that the quenching temperature to be adopted for industrial practice may be fixed between 540 and 550 deg. C., according to the precision of the temperature-regulating device. The duration of heating may be fixed at 6 hrs., because the gain in properties obtained by prolonging the treatment is only very slight. Such a duration of treatment is relatively short and is satisfactory in practice.

(*B*) *Age-hardening Treatment.*—Employing the same lot of alloy as for the above tests, an investigation was also made to determine the age-hardening conditions. For this purpose, a batch of specimens was heated for 6 hrs. at 540 deg. C., quenched in cold water and subjected to an age-hardening treatment of varying duration and temperature. The chief results of practical interest have been reproduced in Table III, from which it may be gathered that various combinations of temperature and duration giving appreciably the same results can be selected. In practice, the temperature of 160 deg. C. has been adopted, this corresponding to a heating period of 10 hrs., because in these conditions a slight deviation either of temperature or duration of heating only produces a very slight modification in the resulting properties, this being a very important point.

TABLE I.—*Influence of Quenching Temperature in Alloys containing* 0·45 *Mn.*

	Temperature of heating.				
	520 deg. C.	530 deg. C.	540 deg. C.	550 deg. C.	565 deg. C.
Tensile strength, kg. per sq. mm. ..	28.7	29.2	29.0	29.5	27.5
Elongation, per cent. ..	1.75	2.0	2.0	2.25	1.75

It may be observed that up to 135 deg. C. the influence of age-hardening on the reduction of elongation is slight, which may be advantageous for certain applications of the castings, for example for small castings which are subsequently subjected to deformation stresses during assembly (riveting, for example).

In all the tests to be described below, the following heat-treatment was adopted:—heating for 6 hrs. at 540 deg. C., quenching in cold water, age-hardening for 10 hrs. at 160 deg. C.

Influence of the Silicon Content

Table IV shows the effect of varying the silicon content between 8.5 and 12.5 per cent. on the tensile strength, elongation, elastic limit at 0.02 per cent. of the permanent elongation, fatigue strength by reversed bending tests and hardness. It is found that the increase in the silicon content increases the tensile strength and also the elastic limit and hardness. The fatigue strength, on the contrary, appears to pass through a maximum between 9.5 and 11.5 per cent. silicon. This latter result may be explained as being due to the disappearance of the last primary crystals of silicon, which, being more brittle than the matrix of the alloy, are probably the seat of "notch effects," thus inducing premature fracture.

The notched bar impact figure is almost constant for all these alloys and is about 0.40 kg. per sq. cm.

The flowing power or "life" of the alloy is measured by the length of metal it is possible to obtain on pouring the alloy at 700 deg. C. in a spiral mould. The result of the test shows that this property tends to diminish slightly with decrease in the silicon content. For 9 per cent. Si, the "life" is 80 per cent. that of an alloy containing 12 per cent. Si.

From the examination of these properties, it follows that if castings are to be subsequently subjected to alternating stresses, it will be necessary to make them of an alloy having a silicon

Table II.—*Influence of Duration of Heating before Quenching.*

Temperature.	Duration of heating.							
	3 hrs.		4½ hrs.		6 hrs.		10 hrs.	
	T	E	T	E	T	E	T	E
540 deg. C. ..	28.5	2.5	28.7	2.0	28.9	2.0	29.0	2.0
550 deg. C. ..	29.3	2.0	30.2	2.0	29.0	1.5	30.0	2.25

T = Tensile strength, kg. per sq. mm.   E = Elongation, per cent.

content in the vicinity of 10 per cent. in order to be within the zone of maximum fatigue strength. In this case, there may be some slight additional difficulties in the foundry, due mainly to the formation of "pinholes," but this slight disadvantage is of little importance compared with the advantage of the improved behaviour of the casting in service. Where castings are not to be subjected to excessively severe alternating stresses, it will be preferable to cast with an alloy having about 12.5 per cent. silicon, so as to ensure a combination of high elastic limit, tensile strength and hardness.

Table III.—*Influence of Temperature*

Temperature.	As cast.	Quenched, non-age-hardened.	125 deg. C.			135 deg. C.		
Duration in hours.			5 hrs.	10 hrs.	20 hrs.	5 hrs.	10 hrs.	20 hrs.
Tensile strength, kg. per sq. mm.	18.1	22.8	23.8	23.9	24.5	24.8	25.4	26.9
Elongation, per cent.	4.25	4.0	5.0	4.7	4.5	4.5	4.2	4.0
Brinell hardness . .	66	90	90	92	97	—	98	105

Influence of the Magnesium Content

Table V gives the mechanical properties resulting from a variation in the magnesium content between 0.15 and 0.75 per cent. in alloys containing approximately Si 12.4, Fe 0.4, and Mn 0.5 per cent. In addition to the properties of the metal treated as above, this table also gives the properties of the metal as cast, because in this condition the influence of the magnesium is almost the same as on an alloy without manganese. As will be seen, the effect of magnesium is to increase the tensile strength, elastic limit and hardness, and to diminish the elongation very considerably, this latter effect being proportionally much more marked on the treated alloy than on the alloy as cast. These results permit the most appropriate magnesium content to be fixed as follows. Bearing in mind that from 0.25 to 0.35 per cent., the increase in the tensile strength is relatively slight as compared with the diminution in elongation (resulting in brittleness), the maximum content will be fixed at about 0.30 per cent. More exactly, this content will be fixed at 0.25 ± 0.03 per cent.

As is to be feared, upon each re-melting of scrap (runners, risers, etc.), chemical analysis, or better still spectrographic analysis, reveals a loss of magnesium. In the case of re-melts comprising only small pieces of scrap weighing a few hundred grammes, this loss may be put at an average of about 15 per cent. of the content. A very appreciable drop in the mechanical properties would follow if scrap only was employed. Fortunately, it is usual in the foundry to employ both new metal and scrap, the proportion being approximately slightly more than one-third of scrap for slightly less than two-thirds of new metal. To allow for the loss of magnesium, therefore, it is merely necessary either to employ a new alloy containing slightly more than the normal content of magnesium or to add magnesium or intermediate magnesium alloy to each melt.

nd Duration of Heating for Age-Hardening.

145 deg. C.			155 deg. C.			165 deg. C.			175 deg. C.		
hrs.	10 hrs.	20 hrs.	5 hrs.	10 hrs.	20 hrs.	5 hrs.	10 hrs.	20 hrs.	5 hrs.	10 hrs.	20 hrs.
25.2	26.5	29.5	26.5	28.7	29.4	29.0	28.7	27.8	28.4	28.0	28.0
4.5	4.2	3.0	3.5	3	2	2.2	1.7	1.0	1.5	0.7	0.5
95	97	105	96	105	107	103	105	106	110	100	97

In addition, it must be remarked that in the course of the heating prior to quenching, the surface of castings loses some of its magnesium (by oxidation and possibly by volatilisation), resulting in two facts:

(*a*) Reduction in the hardness of the surface layer: It is merely necessary to remove half a millimetre of metal to find a normal Brinell hardness again. The mean difference found is 10 to 15 Brinell units. This should be taken into account in reception tests.

(*b*) Inherent protection of castings against corrosion, the surface layer serving as protective layer on account of its low magnesium content.

Influence of the Quantity of Sodium

As stated above, all the foregoing results were obtained on cast specimens which had been subjected to " double modification," as described in the section headed " General Remarks," because maximum tensile strength, and, above all, maximum elongation, were obtained under such conditions. The following experiments showed the influence which small quantities of sodium are able to exert on the mechanical properties (Table VI).

TABLE IV.—*Influence of Silicon.*

Si. Per cent.	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.	Elastic limit 0.02.	Fatigue strength.	Brinell hardness.
8.5 ..	25.6	2.0	13.0	7.25	89
9.5 ..	25.0	2.0	13.2	7.25	90
10.5 ..	25.8	2.2	13.5	7.5	95
11.5 ..	28.0	2.5	14.0	7.25	97
12.5 ..	28.2	3.0	16.0	7.0	103

In each case, about 33 lbs. of alloy were melted from a batch of known composition, and for the first four melts 0.3 per cent. of the mixture NaCl 66 per cent. and NaF 33 per cent. was added at 780 to 800 deg. C. Then, after the lapse of 5 min., decreasing quantities of sodium were added at 780 deg. C. In two other melts, modification was effected with sodium without the previous addition of salts.

It will be seen that good properties cannot be secured in the absence of salts. The action of the latter must probably be that of degassing the molten metal before the introduction of the sodium. In addition, it is clear that at least 0.05 per cent. sodium must be added.

TABLE V.—*Influence of Magnesium.*

Mg Per cent.	Specimens as cast.		Treated specimens.			
	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.	Elastic limit 0.02.	Brinell hardness.
0.15	18.2	5.0	27.8	3.0	16.0	95
0.25	17.7	4.0	28.3	2.0	17.0	103
0.35	17.6	3.7	28.9	1.2	19.0	112
0.50	16.5	2.7	31.4	0.3	21.0	118
0.75	15.6	1.7	31.5	0.3	22.5	123

The presence of sodium increases the elongation and to a slight extent also the tensile strength and hardness. It may. furthermore, be observed that casts which have been subjected to double modification possess fewer "pinholes" than the others. This is due to the degassing action of the salts thrown on the surface towards the end of melting.

Influence of Manganese

The action of manganese in Al-Si alloys is to transform the brittle lamellar crystals of Al-Fe-Si into crystals of compact and less brittle form. The manganese thus exerts two effects which contribute in achieving the same object. By diminishing the surface of crystals rich in iron, it reduces the importance of the slip planes, while in addition it reduces the brittleness of these crystals rich in iron. It will be appreciated that the manganese content to be adopted for an alloy depends almost entirely upon the iron content.

TABLE VI.—*Influence of Sodium.*

Sodium added. Per cent.	Properties of treated alloy.		
	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.	Brinell hardness.
	With addition of salts.		
0.05 ..	28.6	3.0	108
0.025 ..	27.6	1.75	100
0.0125 ..	24.8	0.75	100
0	24.3	0.5	98
	Without addition of salts.		
0.025 ..	27.0	1.2	100
0.0125 ..	25.4	0.75	95

In practice, the iron content is less than 0.5 per cent. An addition of 0.4 to 0.5 per cent. Mn is therefore sufficient for the latter to exert its full effect. Tests show, moreover, that a variation between 0.25 and 0.5 per cent. Mn in an alloy containing 0.5 per cent. iron only very slightly affects the properties of the alloy. The content of 0.5 per cent. Mn will therefore be adopted, so as to allow for the possibility of an addition of iron which may always occur in the course of the manipulation of the alloy in the foundry.

Influence of Iron

Although in Al-Si alloys without additional components, but which have been modified by means of sodium or sodium salts, at least 0.7 to 0.8 per cent. iron is necessary to cause the appearance of crystals of Al-Fe-Si, these crystals appear in alloys containing magnesium for quite low contents, if there are no other additions, such as manganese. It may be said that from 0.3 per cent. these crystals are very clearly visible in micro-sections. In such circumstances, an addition of 0.25 per cent. manganese is sufficient to transform them. In the presence of 0.4 to 0.5 per cent. manganese, at least 0.7 per cent. iron is necessary to cause the appearance of the brittle Al-Fe-Si crystals. This is the content which has been adopted.

TABLE VII.—*Influence of Quenching Temperature.*

	Temperature of heating.				
	540 deg. C.	550 deg. C.	560 deg. C.	565 deg. C.	570 deg. C.
Tensile strength, kg. per sq. mm. ..	28.5	29.0	29.5	26.5	26.0
Elongation, per cent. ..	3	4.2	2.7	1	0.6

ALLOYS WITH ADDITION OF COBALT

As already indicated by Pacz for Al-Si alloys without any additions, about 1920 (French patent No. 523,665), cobalt has an even greater transformation action than manganese on the lamellar and brittle crystals of the compound Al-Fe-Si, and it was therefore natural to think that the manganese could be replaced by cobalt in the heat-treatable Al-Si alloys with advantageous results.

In the case of these alloys, the general tendency being to use a rather low silicon content in the vicinity of 9 per cent., the author adopted the following mean content (except, of course, when investigating the influence of silicon):—Mg 0.25, Fe 0.4, and Co 0.5 per cent.

Heat-Treatment

(A) *Quenching.*—The results given in Table VII indicate the properties of alloys heated at temperatures between 520 and 570 deg. C. for a uniform period of 10 hrs., quenched in cold water (20 deg. C.), and then all subjected to a uniform age-hardening treatment at 150 deg. C. for 33 hrs. It will be seen that the extreme quenching temperature is below 570 deg. C., because the properties corresponding to that temperature—especially the elongation—are very low, there being incipient fusion. The industrial quenching temperature may be fixed at 550 deg. C. in order to allow for any accidental variation in the temperature regulation.

Table VIII gives the influence of the duration of heating before quenching for the temperatures 545, 550 and 560 deg. C. It will be seen that quenching after heating for 10 hrs. at 550 deg. C. appears to be the most advantageous. A shorter duration of heating fails to give adequate elongation, and, except in the case of extremely well-equipped installations, it is not possible to propose a shorter heating at a higher temperature.

(*b*) *Age-hardening.*—The age-hardening temperatures were ascertained by treating a fairly large number of batches of samples from different casts which were always quenched in cold water after heating for 10 hrs. at 550 deg. C. Age-hardening was carried out at temperatures between 135 and 170 deg. C. for lengths

TABLE VIII.—*Influence of Duration of Heating before Quenching.*

Temperature.	Duration of heating.							
	3 hrs.		5 hrs.		10 hrs.		20 hrs.	
	T	E	T	E	T	E	T	E
540 deg. C. ..	—	—	26.5	2.2	27.0	2.2	27.2	3.2
550 deg. C. ..	28.0	1.8	28.2	1.8	29.0	2.5	29.0	3.0
560 deg. C. ..	28.7	2.7	29.2	2.8	30.1	2.9	30.1	3.0

T = Tensile strength, kg. per sq. mm.
E = Elongation, per cent.

of time varying from 5 to 33 hrs. Table IX gives the results obtained.

Consideration of this table shows that the maximum tensile strength is only obtained above 150 deg. C., and that it is then necessary to continue the treatment for a period of 33 hrs., a costly operation, owing to the furnaces being engaged for such a considerable length of time and the consumption of heating power. The author has adopted heating for 10 hrs. at 165 deg. C. as giving the best age-hardening treatment.

In the following considerations, the results will always be given on samples subjected to the following combination of treatments: heating for 10 hrs. at 550 deg. C., quenching in cold water, then age-hardening for 10 hrs. at 165 deg. C.

TABLE IX.—*Influence of Temperature and*

Temperature.	As cast.	Quenched, non-age-hardened.	135	
Duration of heating.			5 hrs.	10 hrs.
Tensile strength, kg. per sq. mm.	17.7	22.8	22.9	23.0
Elongation, per cent.	5.0	6.5	6.5	6.5
Brinell hardness	62	73	75	80

Influence of the Silicon Content

Table X gives the results obtained on treated specimens having a silicon content varying between 7 and 11 per cent., the contents of the other components being maintained at approximately the following figures:—Mg, 0.25; Fe, 0.35, and Co, 0.45 per cent. Between 7 and 11 per cent., the influence of silicon on the increase in the tensile strength and the variation of the elongation is relatively slight. The author is unable to give any definite results regarding the fatigue strength as the investigations are still in progress.

The influence of silicon on the flowing power or "life" is approximately the same as that mentioned for the alloys containing manganese.

Consideration of the influence of silicon shows that the content to be adopted may be fixed at about 9 per cent.

Influence of the Magnesium Content

The magnesium content was varied from 0.15 to 0.50 per cent. in alloys containing approximately: Si, 9; Fe, 0.35, and Co, 0.50 per cent.

The results are reproduced in Table XI, which shows very clearly that there is no advantage in magnesium contents higher than 0.25 per cent. As in the case of the alloys containing manganese, the elongation drops rapidly without this considerable drop being compensated by a sufficient increase in the tensile strength. The value of 0.25 per cent. will therefore be adopted as the mean magnesium content for these alloys.

Duration of Heating for Age-Hardening.

eg. C.		150 deg. C.				165 deg. C.				170 deg. C.
0 hrs.	33 hrs.	5 hrs.	10 hrs.	20 hrs.	33 hrs.	5 hrs.	10 hrs.	20 hrs.	33 hrs.	10 hrs.
25.0	26.5	24.5	27.5	28.0	30.0	27.7	29.4	30.2	30.1	30.5
6.0	5.0	5.0	5.0	4.0	3.0	4.0	4.0	3.7	3.5	3.0
90	95	90	98	100	104	100	105	107	107	107

Regarding the losses of magnesium on each remelt, the statements made in connection with alloys containing an addition of manganese are likewise applicable to alloys containing an addition of cobalt, the average loss of magnesium due to re-melting being the same for these two sorts of alloy. The same applies to the loss of magnesium from the surface of castings during the heat-treatment and the consequences of such loss.

As stated above, the action of cobalt on the crystals of the compound Al-Fe-Si is similar to that of manganese. This is quite apparent not only from the results of mechanical tests but also from examination of micro-sections. In such sections etched with 1 per cent. hydrofluoric acid, the Al-Fe-Si crystals appear light blue and are in the form of long needles. Increasing additions of cobalt show that at about 0.4 per cent. Co, the Al-Fe-Si crystals are transformed into more compact crystals, appearing brown in colour and shown up in micro-sections etched as above. At 0.6 per cent., the crystals increase considerably in size and appear darker brown in colour as the cobalt content increases. The dimensions become rapidly very large and above 0.6 per cent. Co, the crystals may attain several millimetres in length.

TABLE X.—*Influence of Silicon Content.*

Si. Per cent.	Tensile strength. Kg. per sq. mm.	Elastic limit 0.02.	Elongation. Per cent.	Brinell hardness.
7 ..	28.5	17	6	90
8 ..	29.0	19	5	95
9 ..	30.3	21	5	105
11 ..	30.3	22	5	108

TABLE XI.—*Influence of Magnesium Content.*

Mg. Per cent.	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.
0.15	26.5	5.0
0.25	30.2	3.0
0.35	30.2	1.7
0.50	31.5	0.7

For this reason, the cobalt content will be kept in the vicinity of 0.45 to 0.50 per cent because it is extremely likely that the large crystals appearing in the case of the higher contents are prejudicial to securing high fatigue strengths.

There is no appreciable difference between the influence of iron in alloys containing an addition of cobalt and that of the same metal in alloys containing an addition of manganese, the slight differences which always exist between any two melts of foundry alloys masking the slight difference, if any, of the influence of the iron.

Influence of Sodium

The tests were carried out exactly as for alloys containing manganese. The results are given in Table XII. Comparison of this table with Table VI shows that less sodium is required for alloys containing cobalt than for alloys containing manganese, when the surface of the metal has been protected during melting by 0.3 per cent. of salts. As in the case of the manganese alloys, protection of the metal during melting by means of salts diminishes the tendency to form "pin-holes," probably because the action of the salts is to effect degassing and a sort of deoxidation of the molten bath.

TABLE XII.—*Influence of Sodium.*

Sodium added. Per cent.	Properties of treated alloy.	
	Tensile strength. Kg. per sq. mm.	Elongation. Per cent.
With addition of salts.		
0.05	30.0	2.9
0.025	30.3	3.5
0.0125	29.7	3.2
0	20.0	1.7
Without addition of salts.		
0.025	30.7	2.0
0.0125	27.8	1.1

The heat-treatable aluminium-silicon casting alloys represent a considerable advance over ordinary silicon alloys. The latter merely have the following mechanical properties:—Tensile strength, 18 to 20 kg. per sq. mm.; elongation, 7 to 10 per cent.; hardness, 55 to 60 Brinell, and fatigue strength, 4.5 kg. per sq. mm.; whereas the alloys containing an addition of magnesium and manganese or cobalt have the following mechanical properties:—Tensile strength, 27 to 30 kg. per sq. mm.; elongation, 1 to 4 per cent.; hardness, 90 to 110 Brinell, and fatigue strength, 7.5 kg. per sq. mm.

In addition to their high mechanical properties, these alloys possess casting qualities almost equal to those of ordinary Al-Si alloys, this being an extremely important point. It is true that these properties are surpassed by certain alloys containing copper and titanium,* but it is possible to hope that further research will improve the results obtained and that industry will hear more of the Al-Si alloys with hardening additions.

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* For correction to this statement see author's reply to Dr. L. B. Hunt on page 258.

ALUMINIUM CASTING ALLOYS

Paper No. 635

By G. GÜRTLER*

[GERMAN EXCHANGE PAPER]

A study of the development of aluminium casting alloys in England and Germany shows that in both countries, as also in other countries, three very similar main types of alloys are in use. These are the alloys with the principal additions of Cu, Si or Mg. According to the demands which they have to meet, the alloys also contain further additions of a second of the above elements and/or Zn, Ni, Fe, Mn, Ti, etc.

In England, alloys on an Al-Cu basis with additions of Ni and Mg of the type of " Y " and " RR " alloys are largely employed for high-grade castings, whereas in Germany greater importance has been placed on developing the Al-Si alloys which possess good casting properties, are rendered age-hardenable by an addition of Mg and represent valuable constructional materials. These alloys, together with those of the Al-Mg group with various additions of Si and Mg, have the further advantage that their resistance to corrosion is far superior to that of alloys containing copper. In addition to these three main groups of alloys, there are also a number of special alloys which will be discussed later.

Some of the foundry and metallurgical problems which have been dealt with in recent times in Germany, and the knowledge thereby acquired, will be considered in this Paper, the author's intention being to discuss more particularly those alloys which are not so well known in England, and he will thus perhaps be able to throw out a few suggestions.

Gases in Aluminium

The problem of the removal of gases, especially hydrogen, from molten aluminium still plays an

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* Dipl.-Ing. Scientific Officer to the Metal Laboratory of the Metallgesellschaft A.G., Frankfurt a.M., Germany.

important part in melting and foundry practice. It is known that aluminium and its alloys absorb gas in quantities which increase with increasing temperature and pressure.[1,2] During melting, the presence of water vapour and hydrogen, and to a lesser degree also other gases, in the crucibles or the brickwork of the furnace and in the furnace atmosphere, generally results in an absorption of gases which, with the changes in temperature and concentration occurring during the subsequent course of melting and pouring, leads to a supersaturation of the melt with gas.

The first problem of an effective removal of gas is to establish an equilibrium as completely and as rapidly as possible between the gassed melt and an atmosphere which is free from gas or contains only inert gases. This is accomplished, for example, by lowering the temperature very slowly and re-heating rapidly,[3] by passing inert or chemically active gases through the molten metal,[3 4] and by the use of salts containing in particular chlorine and fluorine.[5 6 7] The most effective method is a combination of salt treatment and allowing to stand, during which time the temperature need not be allowed to fall. An example of a laboratory experiment employing relatively small amounts of molten metal will illustrate this point.

A melt of pure aluminium (99.5 per cent.) was gassed at 750 deg. C. in an electric furnace by passing hydrogen through it, and while the temperature was maintained, samples were taken at various intervals and their density after solidifying in sand was determined. A second melt was gassed at the same temperature in the same way, and after a first sample had been taken, about 1 per cent. of a mixture of sodium chloride and sodium fluoride was stirred in, a further sample being poured immediately after the salt treatment. The results of these two experiments are shown by the curves in Fig. 1, and indicate clearly the acceleration of degasification by the salt treatment. With the larger quantities of metal used in the foundry, degasification naturally requires a longer time. It is important to have an atmosphere which is perfectly free from hydrogen, particularly if the pouring temperature is to be high. In experiments with Al-Si alloys, for instance, it was observed that when the metal was allowed to stand in a gas-heated furnace which had been heated up and then put out of operation at the commencement of the standing experiment, it was impossible to secure complete degasification. The experiment was successful only when a container was provided in the furnace, the crucible being placed in the container and carbon dioxide being passed through the container as protective

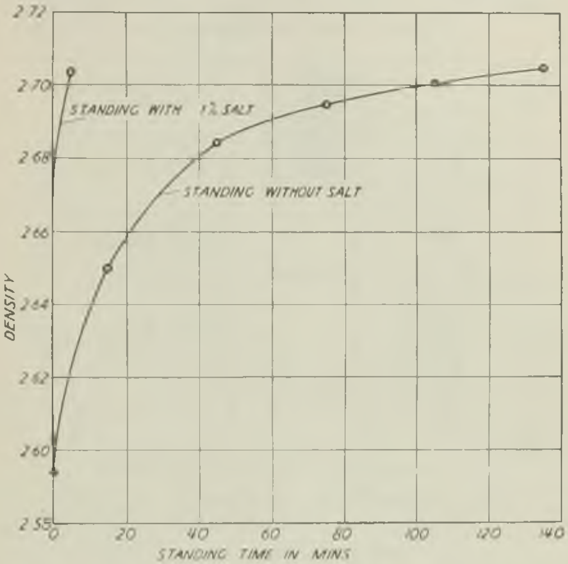


Fig. 1.—Results of Allowing Pure Aluminium to Stand with and without Salt.

gas during the standing period. Such dangers are not so great in the electric furnace. In the author's opinion, the best explanation of the effect of the salt treatment in accelerating the liberation of gas is that furnished by Scheuer, according to whom the oxide film forming on the surface of the melt and preventing the establishment of the gas equilibrium is destroyed by the salt, thus resulting in a better diffusion of the gases.

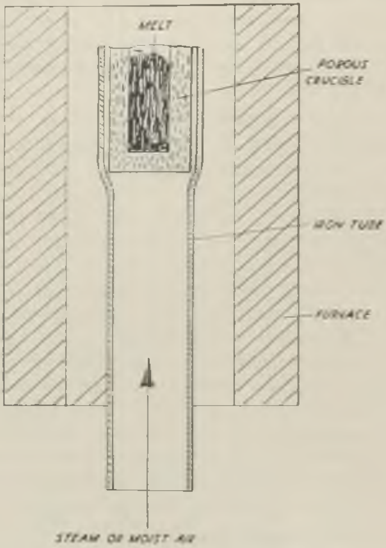


Fig. 2.—Experimental Apparatus for Investigating the Influence of the Mould.

Supersonic Vibrations

In the case of aqueous solutions, it has been observed that a very effective liberation of gas is produced by the action of supersonic vibrations. It is doubtful, however, whether molten metal can be degassed by supersonic vibrations, although it may indeed be assumed that gases in the state of supersaturated solution could be liberated and would escape in the form of minute bubbles, but the practical solution of the problem is very difficult and the author is not aware of any industrially and economically applicable method of introducing the necessary energy into the melt and transmitting such energy through it with the least possible loss.

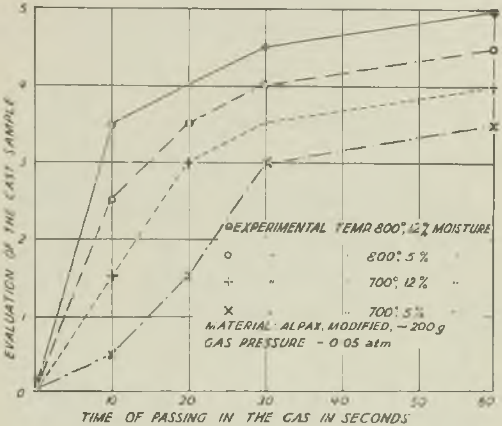


FIG. 3.—VARIATION OF GASSING WITH TEMPERATURE, TIME AND AMOUNT OF MOISTURE.

What Happens in a Sand Mould

The second and more difficult problem for the foundryman is to prevent the metal from reabsorbing gas while the mould is being filled. The moisture in the mould—in aluminium casting green-sand moulds are usually employed—is evaporated and is dissociated by the molten metal into hydrogen and oxygen. Even in the case of a highly permeable sand mould, atomic hydrogen in a relatively high concentration will appear in the boundary zone between the sand

and metal. This nascent hydrogen is very active and gases the metal so rapidly that the equilibrium between the melt and air cannot be established rapidly enough in the time elapsing before solidification. Even using dry moulds. it has been possible to observe in the foundry an increase in the gas content with certain alloys.

The following experimental apparatus was devised to provide a picture of the occurrences taking place in the mould:—

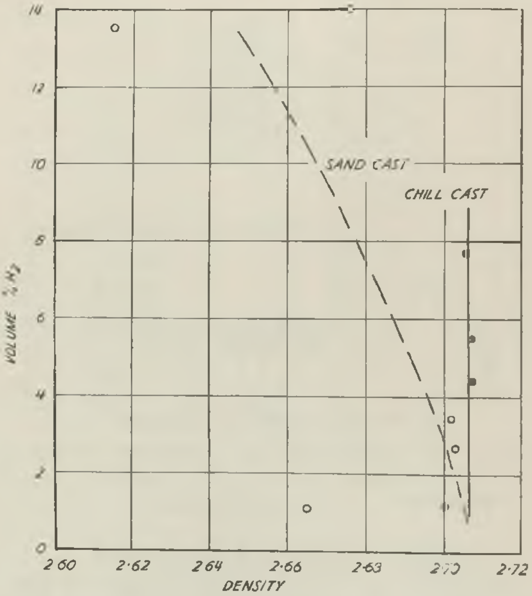


Fig. 4.—Gas Content and Density in Sand-Cast and Chill-Cast Specimens.

A porous crucible representing the mould and containing about 200 grms. of a Silumin (Alpax) melt, modified by means of sodium, was placed in a vertical tube standing in a cylindrical laboratory electric furnace. The metal was then heated to 700 and 800 deg. C. and air saturated with water vapour at 30 and 50 deg. C. was passed through the tube and the porous crucible at a moderate pressure (about 0.05 atm.), corresponding to a moisture content of 5 and 12 per cent. respectively. At the same time, the melt was stirred with a rod in order to imitate flow along the walls of the mould. Fig. 2 shows the experimental apparatus, and Fig. 3 the results of an experiment with modified Alpax (Silumin).

The evaluation of the results was made on small samples cast in an open carbon mould. The character of the surface of the samples—the gas, in escaping through the surface, leaves a crater of about pinhead size—is a fairly reliable measure of the degree of gas-content, as was shown by comparative measurements of the density and gas determinations by extraction *in vacuo*. Zero denotes a perfectly gas-free specimen, five a strongly-gassed specimen. It is always possible to effect a gradation according to a series of six samples of increasing gas content

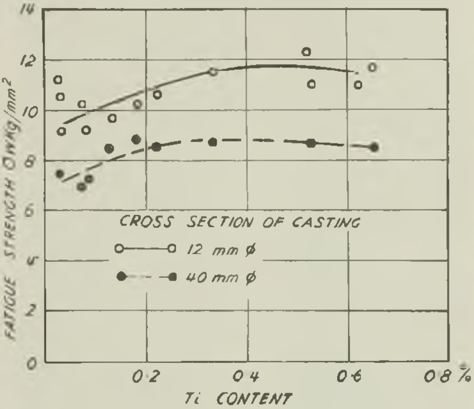


FIG. 5A.—VARIATION OF FATIGUE STRENGTH OF ALPAX-GAMMA WITH 10 PER CENT. SI WITH THE TI CONTENT.

taken as a standard.[8] The experiment shows the harmful effect of even slight quantities of moisture and the importance of keeping the pouring temperature as low as possible. In many cases, the foundryman will not want to forgo the rapid cooling effect of the green mould, and therefore the only means at his disposal will be the shortening of the path of flow, and hence the reduction of the time of flow, and the possibility of lowering the pouring temperature.

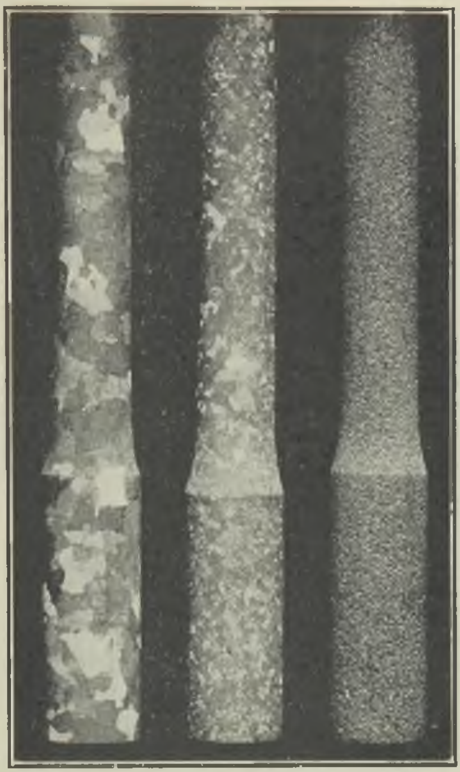
Rapid cooling even has a favourable effect, since in the case, for example, of chill castings, it is possible even with gassed melts to produce sounder castings than in the case of casting in sand. This means that, when solidification is rapid, the metal is able to retain in solution larger quantities of gas than correspond to equilibrium. Measurements of the density and the gas-content by hot vacuum extraction of bars (about 1 in. diameter and 8 in. length) cast simultaneously in sand and chill moulds from melts of different gas contents show that in the case of the sand-cast bars, the density diminishes with increasing gas content, but remains almost constant in the case of chill-cast bars (see Fig. 4).

The absolute quantities of gas, moreover, differ according to the method employed for determining the gas. The largest amounts have been found by Chaudron[9] in an electric discharge tube in which the specimen whose gas content is to be ascertained is exposed to a bombardment by ions and electrons. The foundryman, however, is not immediately interested in the absolute quantities of gas contained in the metal, but he is only concerned with the gas which is liberated during solidification and produces blow-holes and gas cavities.

The author will now discuss some metallurgical questions and results which should also interest the foundryman.

Influence of Titanium

To begin with, a few remarks on the influence of small additions of Ti to cast alloys Starting from the observation that in the case of the "Y" alloy with a very coarse macrograin, shrinkage cracks appeared along the boun-



0.03% Ti. 0.2% Ti. 0.5% Ti.

Fig. 5b.—Variation of Grain Size of Alpax-Gamma with 10 per cent. Si with the Ti Content.

daries of the large grains, an attempt was made to eliminate this phenomenon by making use of the well-known grain-refining effect of Ti, a successful result being achieved with an addition of 0.2 per cent. titanium.[10] In this connection. it was of interest to see whether the fatigue strength of cast aluminium increases with the increase in fineness of the grain. Gough,[11] it is true, failed to find any influence on the grain boundaries in the case of aluminium crystals, but Templin[12] observed an increase in the fatigue strength of about 20 per cent., by the refining of the macro-grain in the case of rolled material.

Endurance tests on cast bars of 12 and 40 mm diameter of "Y" alloy and Alpax-Gamma having a silicon content of 10 per cent. showed a fatigue strength increasing with increase in fineness of the grain.[10,13] The optimum Ti contents lay in the range of 0.3 to 0.5 per cent., an increase in the fatigue strength of 15 to 20 per cent. being observed (see Figs. 5A and B). The explanation that an increase in the number of grain boundaries would result in an increase in the fatigue strength appeared therefore to be

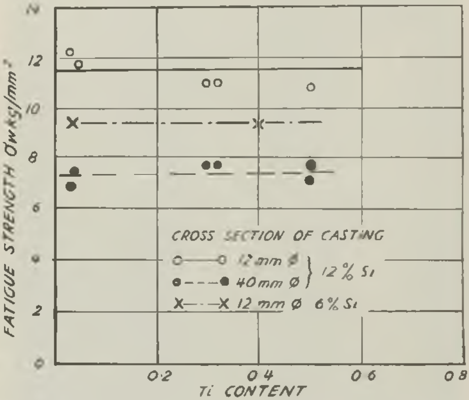


Fig. 6.—Variation of Fatigue Strength of Alpax-Gamma containing 12 per cent. and 6 per cent. Si with the Ti Content.

correct. When the tests were extended to Alpax with 12 per cent. Si and 6 per cent. Si, however, no change in the fatigue strength was found, despite the same grain refinement (Fig. 6).

Investigation of the fracturing process showed,

FIG. 7.—ALUMINIUM DENDRITE WITH SLIP BANDS. × 200.

in agreement with Gough and his collaborators,[14] that fracture is initiated by cracks along the slip planes in the aluminium primary crystals Fig. 7 shows an aluminium primary crystal with slip bands produced by stretching. The more extensive these slip planes are, *i.e.*, the larger and more continuous the aluminium primary crystals, the more pronounced will their notch-effect be when subjected to repeated stressing An alloy in which this unfavourable form of the primary crystals has been altered by the addition of titanium, this metal increasing the number of primary crystals and diminishing their size, as is shown in Figs. 8 and 9, may exhibit an increase in fatigue strength, while on the contrary, no improvement occurs when the shape of the aluminium dendrites is only materially altered, as is shown in Figs. 10 to 13 in the case of an Al-Si alloy with 12 and 6 per cent. Si.[13]

FIG. 8.—ALPAX-GAMMA WITH 10 PER CENT. SI AND 0 PER CENT. TI. × 40.

Age-Hardening by Mg_2Si

In a number of cast alloys used in Germany, advantage has been taken of the strength-increasing effect of the compound Mg_2Si attainable by heat-treatment, in the same way, for instance, as that of $CuAl_2$ in the case of the Al-Cu alloys. In alloys containing several per cent. of Mg, the solubility of the Mg_2Si is almost entirely prevented, while excess of Si only has a slight influence on the solubility of Mg_2Si. Thus, for instance, in the case of the Al-Si alloy, Alpax-Gamma with an addition of 0.5 per cent. Mg, a considerable increase in tensile strength, yield point and hardness is secured by annealing at 530 deg. C. and quenching in water, followed by heating for 20 hours at 150 deg. C.[15] (Fig. 14). In this connection, the behaviour of the fatigue strength is remarkable, as it is not affected by the Mg_2Si content like the static properties, this being shown by a comparison with an Al-Si alloy

FIG. 9.—ALPAX-GAMMA WITH 10 PER CENT. SI AND 0.4 PER CENT. TI. × 40.

free from Mg and one with 0.5 per cent. Mg in different stages of the heat-treatment (Fig. 15). The static properties attain their substantial increase by age-hardening at 150 deg. C. The fatigue strength is not affected, but attains its increase by the "homogenisation" heating. The Si solubility must therefore be held responsible for the change in the fatigue strength. As will be gathered from Fig. 16, the fatigue strength is also influenced much more than the static properties by the particular Si content in solution, according to a given thermal temperature.

Starting from a corrosion resistant alloy type with small additions of Mg and Si, in which the amount of the compound Mg_2Si was less than the maximum solubility of 1.85 per cent., the Si content was increased to about 4 per cent. for the purpose of improving the casting properties, particularly for chill castings, the Mg content being increased to about 3 per cent., so that the total content of Mg_2Si was about 4.5 per cent. Further additions are Mn and Ti. This alloy is known in Germany by the name "KSS 250," and heat-treatment imparts to it excellent mechanical properties. With chill-cast bars, a tensile strength of 10.3 tons per sq. in., an elongation of 1.6 per cent. and a hardness of 69 kg./mm.^{2} was obtained in the metal as cast. After a heat-treatment consisting of annealing at 540 deg. C. for 3 hrs. and age-hardening at 140 deg. C. for 20 hrs., a tensile strength of 21 tons per sq. in., an elongation of 1.3 per cent., and a hardness of 124 kg./mm.^{2} was obtained).*

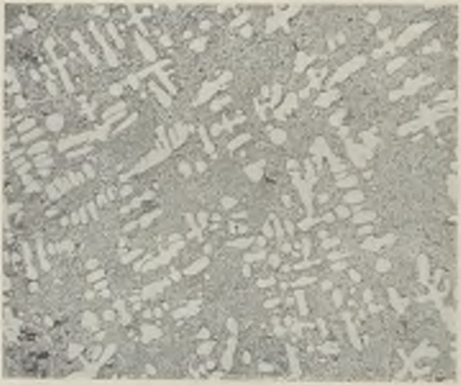


FIG. 10.—ALPAX-GAMMA WITH 12 PER CENT. SI AND 0 PER CENT. TI. × 40.

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* The author is indebted to Dr. Sterner-Rainer for these data.

FIG. 11.—ALPAX-GAMMA WITH 12 PER CENT. SI AND 0.4 PER CENT. TI. × 40.

FIG. 12.—ALPAX-GAMMA WITH 6 PER CENT. SI AND 0 PER CENT. TI. × 40.

Attempts to render alloys having an excess of Mg heat-treatable by additions of Ce, Zn and Mn have met with success, especially in the case of rapid solidification, when the Mg_2Si is obtained in a finely divided state, thus facilitating the diffusion during the artificial age-hardening treatment.[16] The optimum composition is 3 per cent. Mg; 0.8 per cent. Si; 0.3 per cent. Ce; 0.8 per cent. Zn; and 0.8 per cent. Mn. By a heat-treatment consisting of " homogenisation " at 600 deg. C. for 6 hours followed by age-hardening for 16 hours at 170 deg. C., a yield point of about 15.8 tons per sq. in. and a tensile strength of 17.1 tons per sq. in. for an elongation of about 2.5 per cent. are attained The corresponding values in the as-cast state are 7.0 tons per sq. in., 10.7 tons per sq. in. and 3 per cent.

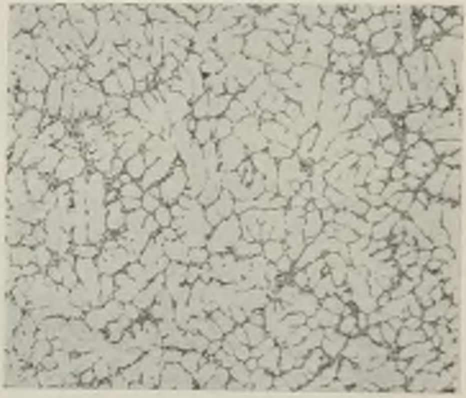

Fig. 13.—Alpax-Gamma with 6 per cent. Si and 0.4 per cent. Ti. × 40.

Age-Hardening by $MgZn_2$

Finally, reference may be made to another group of alloys which were not found serviceable as rolled alloys on account of a tendency to stress-corrosion but which afford certain advantages as cast alloys and have begun to be used on an increasing scale. These are the alloys known by the name "G 54," the hardening constituent of which is the compound $MgZn_2$ and to which Mg and Zn are added either in the proportions corresponding to the compound or with an excess of Mg or Zn.[17] The optimum alloys are those with a Mg-Zn ratio between 1 : 3 and 1 : 5.4, with which it is possible, after heat-treatment (annealing at 475 deg. C., quenching, and age-hardening at 150 deg. C. for 14 hours) to attain tensile strengths of over

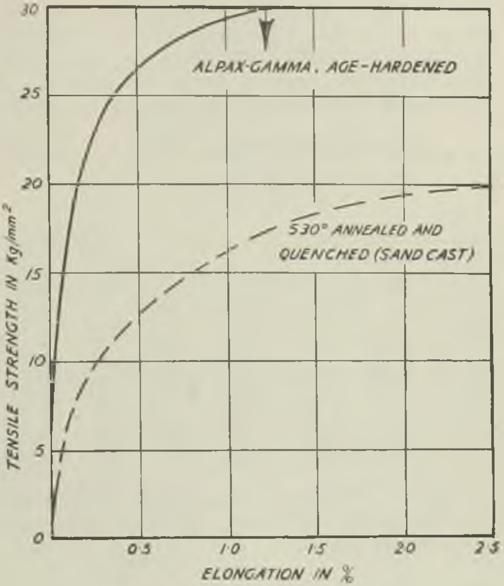

Fig. 14.—Increase in Tensile Strength of Quenched Alpax with 0.4 to 0.5 per cent. Mg by heating for 20 hrs. at 150 deg. C.

25 tons per sq. in. and hardnesses of over 140 kg./mm.², but with only a slight elongation. In this case, the total content of Mg + Zn lies at 9 per cent. A smaller addition, for instance 7 per cent. Mg + Zn, results in tensile strengths of 22.2 tons per sq. in. and hardnesses of 130 kg./mm.² with an elongation of 3 to 4 per cent.[18] The particular significance of these alloys, however, is that they are very suitable for treatment by anodic oxidation, a very uniform and attractive surface being produced. The alloy is therefore greatly in demand for purposes where a good appearance and good mechanical properties are required

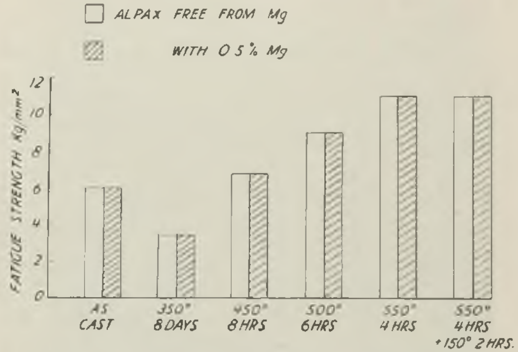

Fig. 15.—Fatigue Strength of Alpax with 0 and 0.5 per cent. Mg in Different Conditions.

Summary

Various problems relating to foundry practice and metallurgy recently studied in Germany are discussed. The removal of gases from the melt is best effected by a combination of salt treatment and standing in a neutral atmosphere. Absorption of gases from the mould can be reduced by lowering the pouring temperature, shortening the period of flow and increasing the rate of cooling.

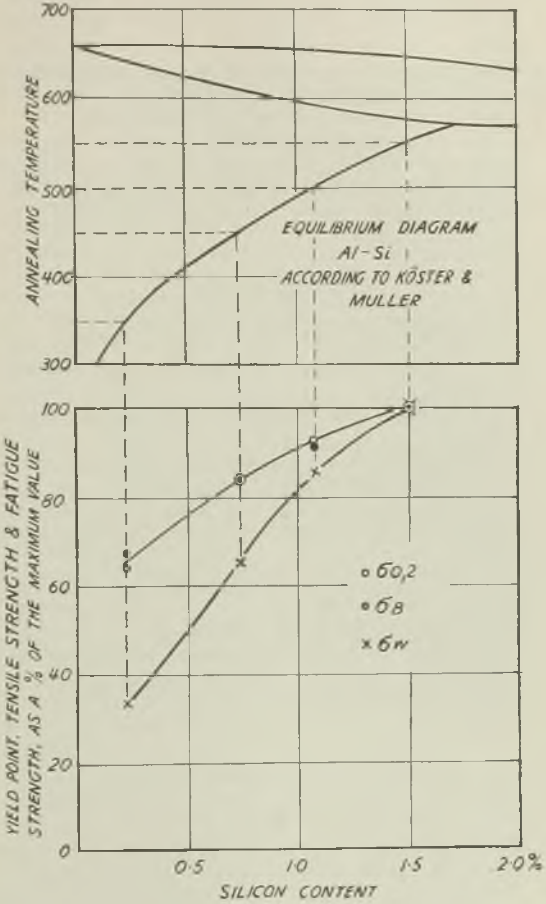

Fig. 16.—Variation of the Static and Dynamic Properties of Alpax with the Si Solubility.

The influence of Ti on the fatigue strength of Alpax with various Si contents is discussed, as is also the influence of various heat-treatments. In the case of this and certain other alloys, the increased solubility of Mg_2Si at high temperatures is utilised for improving the mechanical properties by heat-treatment.

The same property is also possessed by the compound $MgZn_2$ contained in the artificially age-hardenable alloys of the " G54 " group, distinguished for their excellent suitability for anodic oxidation.

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SOME PHYSICAL FACTORS IN CASTING HIGH-STRENGTH BRASSES

Paper No. 636

By J. E. NEWSON, M.Met.

In the third Edward Williams Lecture,[1] delivered in June, 1937, to this Institute by the author's former Professor, Dr. C. H. Desch, some of the most important physical factors in the casting of metals were discussed. In view of the very high standard of that address, it is with no little trepidation that the task has been undertaken in this Paper to consider some of the less important factors to which he then referred, with special mention of those which are of interest in the casting of high-strength brasses. These alloys have been chosen since they illustrate these factors very well, and because they are used for some of the largest non-ferrous castings in production. In such large castings the relative importance of these factors increases, and better facilities for studying them become available. They are, of course, of quite considerable significance for all non-ferrous castings, the degree varying with the mass of the casting and certain inherent properties of the alloys. These alloys possess many desirable mechanical and physical properties, but present certain difficulties to those foundrymen who have had little experience of them.

The mechanical properties of most alloys are influenced by the grain size, and the form and distribution of the constituents. In practice, the ideal of a uniform grain size is almost impossible of achievement, but a careful study of conditions and a recognition of the principles involved can be of some help in approaching the ideal. The grain size is controlled largely by the thermal conditions which prevail from the time the molten metal enters the mould until the cold solid casting is knocked out. It is important to remember that not only the total quantity of heat to be dissipated must be considered, but also the rate at which it is dissipated.

The thermal conditions can be divided under two heads:—(1) Those which are due to specific properties of the alloy itself and can only be varied by change of composition. These include the specific heat, the latent heat of fusion, the thermal conductivity, the temperature and extent of the freezing range. (2) Those which can be varied under control by external means, such as the casting temperature and degree of superheat of the metal, and the nature and properties of the mould material.

Factors for Control

It will be realised that some measure of control is possible and can be exercised to advantage, especially with large castings, by the foundryman who is prepared to consider this aspect of his craft. The alloy to be used, the mass of the casting, its sections and general design, and the ratio of cooling surface to volume are chosen by the designer, but these form the basis on which the casting temperature must be selected. The casting temperature, in conjunction with the specific heat and latent heat of fusion, establishes the total heat content of the molten metal poured into the mould.

The rate at which this heat is given up by the metal is dependent upon the initial temperature difference between the metal and the mould, the thermal conductivities of metal and mould, the properties of the surfaces of metal and the mould, and again the volume-area ratio.

In the past there has been a marked tendency to regard such properties as specific heat and latent heat as of academic rather than practical interest and importance. This is not surprising, as even to-day there is available very little published information except in the case of pure metals. It must be admitted that they are of real significance from two practical standpoints.

In the first case, the cost of melting alloys is directly related to the amount of fuel, be it coke, coal, oil or electricity, consumed to provide the necessary heat units to raise the alloy to the casting temperature and the number of heat units varies with the specific heat, latent heat and casting temperature. An opportunity arose of obtaining a direct example of this on a 650-lb. oil-fired tilting furnace, where a study of the oil consumption showed that almost exactly the same quantity of oil was consumed to melt 200 lbs. of aluminium alloy, casting at 650 deg. C., as to melt 650 lbs. of Admiralty gunmetal casting at 1,150 deg. C. Secondly, it must be remembered that when specific heat, latent heat and casting temperature are high, the total heat content to be dissipated is proportionately high. and will have an important influence on grain size and mechanical properties.

It would perhaps be as well at this stage to consider these several factors individually and then to examine their collective effect in the case of the alloys under review.

Specific Heat

This is usually expressed in metric units, and is the quantity of heat required to raise 1 gm. of the material through 1 deg. C. = calories per gram. per deg. C. The specific heat is not constant over all temperatures, and in general increases with rising temperature until the metal is molten, when a steady value is obtained. The specific heats of a number of metals of high purity have been determined at the N.P.L., and Table I is abstracted from their "Physical Constants of Pure Metals."[2]

These figures are quoted to show how the values vary for the different metals. The determinations in the case of alloys are much more difficult, being complicated by phase and allotropic changes during heating and cooling. In a recent Paper by Sykes and Wilkinson,[3] who were studying the atomic re-arrangements in brasses consisting wholly or in part of the β-constituent, the specific heats of these very pure copper-zinc alloys were published, covering a range of temperatures. A study of this Paper reveals the difficulties associated with precision measurements of this property of alloys, and it can readily be appreciated why so few data are known for the more complex alloy systems. Their "specific heat-temperature" curves show values of 0.094 cals./gm./1 deg. C. at 100 deg. C., reaching 0.104 cals./gm./1 deg. C. at 240 deg. C., rising sharply to a maximum of 0.27 cals./gm./1 deg. C. at the critical temperature of about 450 deg. C., falling away again to the previous curve. The high-strength brasses exhibit a break in the cooling curve at this critical temperature which will be referred to at a later stage.

TABLE I.—*Specific Heats of Common Non-Ferrous Metals.*

Metal.	Melting point. Deg. C.	Specific heat. Cals. per gm. per 1 deg. C.	
		At 100 deg. C.	Molten.
Aluminium ..	657	0.228	0.36
Copper ..	1,083	0.097	0.122
Lead	327	0.028	0.020
Tin	232	0.064	0.056
Zinc	420	0.095	0.124

Latent Heat of Fusion

The latent heat of fusion is the number of gram. calories required to convert 1 grm. of the material from the solid to the liquid state without change of temperature. Table II from the same N.P.L. Tables of Physical Constants[3] shows the values obtained for the same pure metals, but it should be noted that the value assigned to aluminium is still not finally settled. Here again the figures relate to very pure metals, and attention is drawn to the widely different values for the several metals.

It is very difficult to find reliable values for alloys, due perhaps in part to complications arising from heat of formation of compounds, but a new cooling curve method is being tried out at the N.P.L.

Thermal Conductivity

The thermal conductivity (K) is a measure of the heat transference, and is usually given as the number of gram.-calories which pass per second through one cubic centimetre of the substance when the temperatures of the opposite sides of the cube are maintained at a difference of 1 deg. C. The values generally decrease slightly with rising temperature, and average values are aluminium 0.50, copper 0.88, lead 0.075, tin 0.13 and zinc 0.26. This property is of some importance in large castings by affecting the time taken for temperature gradients to disappear and uniform cooling conditions to become established, thus affecting the initial grain size of the casting.

TABLE II.—*Latent Heat of Fusion of Some Common Non-Ferrous Metals.*

Metal.	Melting point. Deg. C.	Latent heat of fusion. Gm. cals. per gm.
Aluminium	657	92.4
Copper	1,083	49.95
Lead	327	6.26
Tin	232	14.6
Zinc	420	26.6

Freezing Range

A pure metal melts and freezes at a constant temperature, but in most alloys the process extends over a range of temperature, and at this stage both solid and liquid are present, giving rise to a pasty condition, which can be a serious hindrance to the effective feeding of a casting. As an alloy cools in the molten condition, it contracts with falling temperature. At the change from the liquid to the solid state there is (with only one or two exceptions) a marked shrinkage in volume, followed by a further steady contraction to normal temperatures. This phenomenon is well known to foundrymen, and is provided for by making patterns to the contraction rule, and by the judicious use of risers and feeding heads in the mould. The contraction allowance for high-strength brasses varies from $\frac{5}{32}$ in. to $\frac{3}{16}$ in. to the foot, and generous risers must be provided. Fig. 1 shows a typical cooling curve for an alloy of this type, and in view of the behaviour of the alloy in the risers of a large casting, the actual temperature interval of the freezing range is surprisingly short. On the other hand, the time interval is long, and the importance of this will be referred to when considering all the factors together.

Casting Temperature

This is the factor which lends itself most readily to control. It may be stated as a generalisation that in many non-ferrous metals slight variations of casting temperature have a more marked influence on the mechanical properties than quite appreciable variations in the proportions of the major constituents. This is particularly true of the gunmetal and tin bronzes, and to a less marked degree with the high-strength brasses. The choice of the appropriate casting temperature is frequently a matter of judgment and experience of the alloy. A useful basis is 10 per cent. superheat, that is, for an alloy melting at 1,000 deg. C. a basis would be 1,000 + (10 per cent. of 1,000) = 1,100 deg. C. For castings of thin sections and large surface a further addition would be necessary, and for large compact castings a reduction could be made.

A number of types of base-metal thermocouples and indicators, sufficiently robust for foundry use with reasonable care, are obtainable, and it is advisable to use a pyrometer to obtain consistently good results. Lighting conditions in most foundries are not ideal, and subject to considerable variation throughout one day, as well as from day to day, and, in addition, the oxide films present on the different kinds of metal make the estimation of temperature by colour very deceptive, and optical pyrometers unreliable.

Mould Material

The thermal properties of mould materials have not received much attention in the past, although

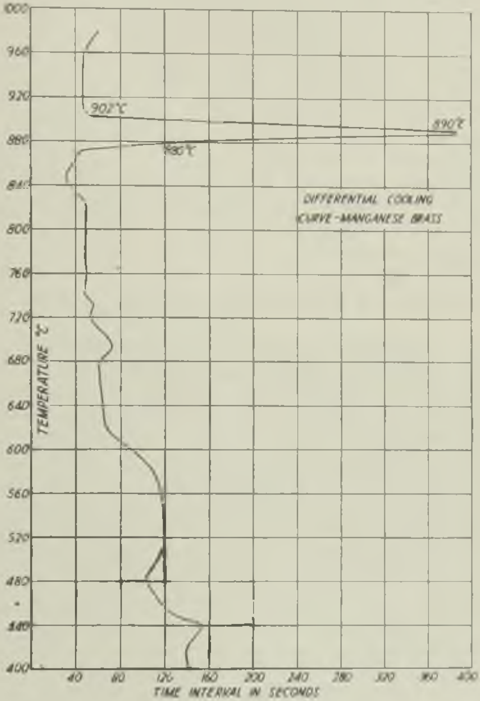

Fig. 1.

the use of metallic inserts into the mould, known as chills or denseners, is a common practice to accelerate the rate of cooling of heavy sections. Hudson[4] has carried out some interesting practical work on this subject, and in a recent article suggested the use of non-metallic materials of high thermal conductivity. In the course of his investigation he noted that most of the commonly used foundry sands, whether green or dry, had practically the same low thermal conductivity, but that graphite or silicon-carbide mixtures could be prepared, with suitable moulding characteristics, and thermal conductivities between that of mild steel and copper. He also noted the low thermal conductivity of ordinary foundry blacking, which compares unfavourably with a graphite base wash. The specific heat of the moulding material has a slight influence on the rate of cooling of a casting, but becomes insignificant in the case of sands of such low conductivity. The thermal conductivity (K) for sand is 0.00013, for Acheson graphite 0.300, whilst the specific heats are: sand 0.19 and graphite 0.467.

Effect of Fundamental Physical Factors

It is proposed to consider now in general terms the collective effect of these factors in the primary crystallisation of the high-strength brasses cast in sand. It is impossible to observe all that occurs in a mould during casting, but by studying a large number of partly-open moulds, one can visualise the flow of the metal and speculate as to the conditions existing in the mould. When a stream of high-strength brass enters a well-designed gate and passes thence to the mould quietly, a thin tenacious film of aluminium oxide appears on the surface of the metal. This film breaks and is continuously reformed, and to some extent serves as a protection to the metal. On the other hand, if the metal enters through a wrongly designed gate, and the stream of metal breaks into turbulent flow, zinc oxide or dross is formed and carried along by the stream, lodging against the walls or in recesses or angles of the mould to appear as defects in the casting. When the casting is stripped it should show a smooth surface of golden yellow colour, which is the natural colour of the alloy seen through a very thin transparent film of aluminium oxide. Very small percentages of aluminium are sufficient to produce this effect. whilst high percentages of manganese give a red or purple iridescent tinge to the film.

If now the thermal changes which occur be considered, it is obvious that heat is given up by the metal to the mould surface. The temperature of the mould face is raised and that of the metal lowered until a uniform temperature is reached where they meet. On account of the very low thermal conductivity of the sand only a very thin layer of the mould reaches the temperature of the metal, and a steep temperature gradient is established. In the metal, a certain number of heat units are lost to the sand, and, dependent upon the specific heat and the latent heat of fusion, a fall in temperature results; with normal casting temperatures this fall in temperature is sufficient to lead to the formation of a shell of solid metal.

The conductivity of the metal is high, and heat flow is further assisted by convection currents and movement of the liquid metal, and any temperature gradients will be slight. This rapid distribution of heat tends to equalisation of temperature, with the result that the temperature of the molten metal quickly falls to that at which it is in equilibrium with the solid metal formed. Hensel,[5] in a recent Paper on the primary crystallisation of metals, states that the degree of superheat regulates the thickness of the shell of solid metal—the lower the superheat the thicker the shell—and the temperature of the melt drops almost immediately to the temperature of solidification. " When casting a superheated melt into a hot sand mould, crystallisation started in this case only after the entire mass had cooled down to the melting point. The casting temperature affects greatly the time of solidification and therewith the velocity of crystallisation." He also stresses the importance of the latent heat of fusion and considers that the rate at which this can be dissipated largely controls the velocity of crystallisation.

The author had found previously by pyrometers placed in the heads of propellers up to 15 tons cast weight poured at 970 deg. C. that the temperature fell almost immediately to 890 deg. C., the temperature at which freezing began. Solidification was complete at 870 deg. C., an interval of only 20 deg., but the time to pass through this range is some hours, after which the rate of cooling is more normal. This freezing range is easily confirmed in the laboratory, where the time interval is again strikingly shown.

During the freezing, when liquid and solid phases are present together, the metal is in a pasty state, which accounts for some of the difficulties of feeding castings in these alloys. Such a slow rate of cooling through the freezing range tends normally to produce in alloys a coarse primary grain size. The grain size, however, is also affected by the number of nuclei which may be present. These alloys contain iron in amounts up to 1.5 per cent. and the action of the iron in refining the structure is important and interesting.

Bauer and Hansen[6] studied the effect of small iron additions to the copper-zinc system. They found that with an iron addition of about 1 per cent., a primary precipitation of an iron-rich copper-zinc compound occurred at about 905 deg. C.—a few degrees above the liquidus of the copper-zinc system. A few degrees lower a peritectic reaction occurs between part of this and the liquid melt. With an iron content below the critical value, all the primary compound was absorbed in the reaction; the compound entering into the reaction is precipitated later as a secondary form. When there is sufficient iron present for the primary to persist, it serves as nuclei for crystallisation of the metal. When it is absent, and the secondary form appears after the copper-zinc system has crystallised, the nuclei are not available. This appears to be the explanation of the striking differences observed in the fractures of test-bars taken from melts of high-strength brass when the iron is below normal, For these alloys the critical iron content appears to be about 0.75 per cent. Fig. 2 shows the fracture of finger test-bars, containing 0.68 per cent. Fe, 0.73 per cent. Fe and the more normal 1 per cent. Fe. The first shows what is known in the works as a " fibrous fracture," and the columnar crystals at right angles to face of mould persist across the section and meet. In the second, columnar crystals extend only partly across the section, and there is then a zone of equi-axed crystals. In the third case, only equi-axed crystals of very small size are to be seen and there are no columnar crystals. This type of columnar primary crystallisation has been observed on small chill bars, chill-cast extrusion ingots and sand castings when the iron content has been too low to provide the nuclei which lead to refinement of grain size. Some writers have referred to this iron-rich compound (also called the blue-etching constituent) as " excess hardener," but with normal compositions it is not so much an " excess " as a necessity, to obtain the desired structure. Recent work suggests that some other additions to high-strength brasses may through similar reactions act as refining agents.

A B C

Fig. 2.—Fractures of Finger Test-Bars: A, 0.68 per cent. Fe; B, 0.73 per cent. Fe; C, 1.0 per cent. Fe.

So much for the primary crystallisation of the high-strength brasses. On very large castings, combination of circumstances may in special instances lead to a phenomenon which modifies this primary structure. When the alloy changes from the liquid to the solid state it appears first as the β-solid solution. With further cooling there is a phase change and the α-solid solution is precipitated. During recent years much work has been carried out on recrystallisation and grain growth which occur on annealing cold-worked metals. Thanks to the classical researches of Carpenter[7] and Elam, this is now one of the most widely used methods of producing single crystal test-pieces. Various authorities[8, 10] also state that recrystallisation and grain growth can occur in alloys by reheating above a phase change-point, but it is difficult to trace any record of such examples having been examined. Logan[11] records an example in propeller brass. One characteristic which distinguishes this grain growth from coarse grains due to slow primary crystallisation is that in the first case large grains appear adjacent to very fine grains without intermediate sizes, whilst in the second case there may be a regular graduation of sizes.

Phase Changes

The phase change, necessary for grain growth, is due, in the high-strength brasses, to the resolution of the α-solid solution in the β-solid solution. The temperature of this change varies with the composition and is indicated on the thermal equilibrium diagram by the line separating the β from the $\alpha + \beta$ fields.

Thermal History of Large Castings

In a very large casting one can imagine how the conditions for recrystallisation and grain growth can arise. Immediately after casting, one has a mould in which is a shell of solid metal containing liquid metal. The face of the mould has been heated and the solid shell cooled until a uniform temperature is attained for a short time at the interface. The temperature of the metal in some areas may be depressed not only below the freezing point, but to the point at which the α-phase just begins to separate. But within the shell is metal which is still liquid, and is at a higher temperature, and this is a condition of unstable equilibrium. By convection and conduction heat is transferred from the hotter to the cooler metal (and it must not be forgotten that the latent heat of fusion is also liberated),

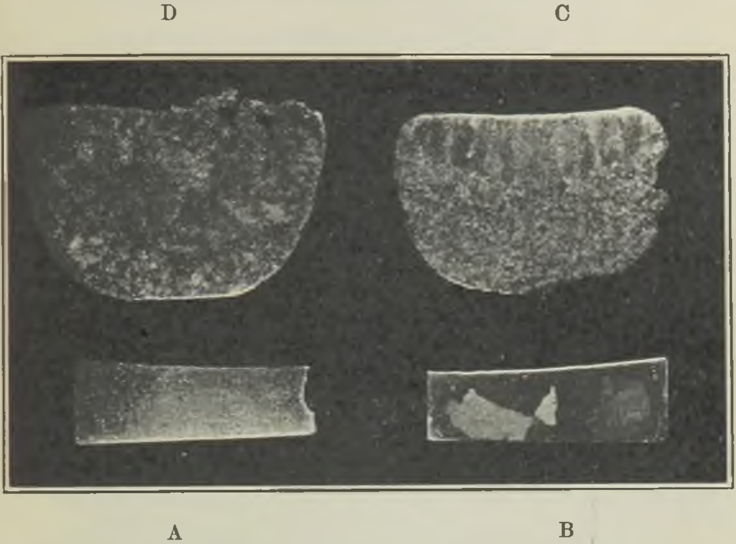

Fig. 3.—A, Finger Bar as Cast; B, Finger Bar Annealed at 700 deg. C. for 1 hr.; C, Normal Alloy, cooled, reheated above Phase Change; D, Low-Iron Alloy, cooled, reheated above Phase Change.

and this may raise the temperature of the cooled metal above the phase change point again. The temperature gradient in the metal now becomes very slight, and once the whole mass is solid, transfer of heat is by conduction only, and thus the second cooling down to the phase change temperature may be very slow. To verify these assumptions some experiments were carried out.

Experimental Evidence

(1) Chill-cast "finger" test-bars, about $\frac{1}{2}$ sq. in. cross-section, in which the rapid cooling restricts the separation of the α-constituent, were re-heated at 700 deg. C. for 1 hr., and recrystallisation and grain growth occurred so that the polished and etched specimen showed that the cross-section consisted of only 4 or 5 grains, *vide* Fig. 3 (A and B).

As the chill-cast bar may have been in a state of internal stress,[9] due to the rapid cooling, another experiment was made, which also served to illustrate the refining influence of iron.

(2) A small crucible containing 650 gms. of the normal alloy was heated in a vertical electric furnace and raised to a temperature of 980 deg. C., 90 deg. C. above the melting point of the alloy. The current was switched off, and the temperature fell until the phase-change temperature was approached, when the doors of the furnace were opened and the upper part of the crucible cooled more rapidly than the base. The doors were then closed, current switched on again and the temperature raised above the phase-change temperature, maintained for 1 hr. and then the temperature was lowered slowly (about 5 deg. C per minute). When cold the metal was removed from the crucible, sectioned, polished and etched, and it was found that recrystallisation had occurred in the region which had cooled below the phase change temperature and then been reheated. The line of demarcation of large and fine grains was well defined, as seen in Fig. 3 (C).

The experiment was repeated under identical conditions as to the weight of melt, heating and cooling conditions with an alloy containing 0.70 per cent. iron instead of the 1 per cent. in the previous case. It was then found that the recrystallised area was larger in extent and the small grains were coarser than in the first case (see Fig. 3 (D)).

The presence of the blue-etching constituent would therefore appear to inhibit grain growth.

Fig. 4, A.—As Cast.

Fig. 4, B.—Annealed.

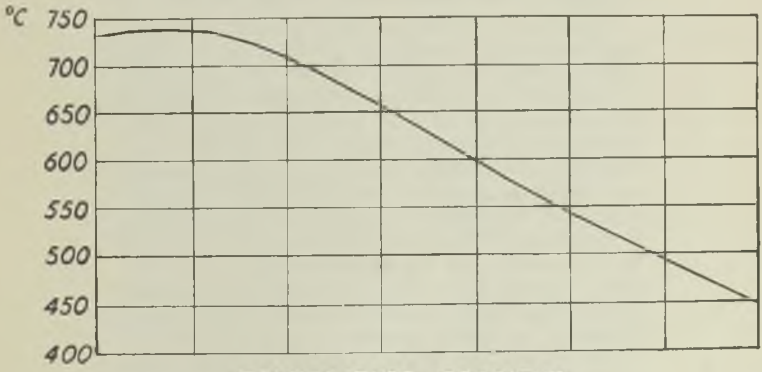

Fig. 4.

and this restriction by a separate phase under certain conditions has been noted in the case of recrystallisation following cold-work. In the above experiment, in which the metal was not cast, the possibility of stress being present in the pieces seems very remote, and the recrystallisation and grain growth are shown to occur purely as a result of the cooling and reheating.

(3) A portion of a sand-cast test-bar was cut, 1 in. by 1 in. by 7 in. long, and one face was polished, etched and photographed. The grain was uniform, as is shown in Fig. 4 (A). The bar was annealed for 1 hr. at 600 deg. C. to ensure freedom from stress, and was then heated in an electric furnace, so that one end was raised to 750 deg. C. and the other end projected from the furnace and reached 445 deg. C. A temperature gradient was thus established, Fig. 4. This was measured by a pyrometer inserted into holes drilled at 1 in. intervals along the bar. The temperature conditions were maintained for 4 hrs. to ensure that the phase-change would be completed at the hotter end of the bar, and after cooling in air the face was again polished and etched, with the result shown in Fig. 4 (B).

It should be noted particularly that, although the temperature varied evenly along the bar, the very striking change in grain is remarkably abrupt with no intermediate sizes, indicating that it has occurred only where the critical conditions have been fulfilled. Fortunately, the combination of these critical conditions occurs only rarely in practice, and now they are recognised, two methods of approach to the problem of eliminating them suggest themselves, namely, to avoid the initial fall of temperature below the phase change or to modify the alloy or mould material so that reheating above the phase change is not likely to occur.

The subsequent cooling of the casting leads normally to precipitation of the a-solid solution, the rate of cooling affecting the size and distribution. There is just one further point to be mentioned. When a large casting shrinks on cooling, it seems very probable that the casting

" sits down " on the lower part of the mould and shrinks away from the upper part. It is difficult to determine what will be the effect on the rate of cooling of the heated air space between the casting and the mould, particularly when it is remembered that the surface of the casting is covered by a thin film of aluminium oxide, a poor conductor of heat.

Whilst no attempt has been made in this Paper to describe the methods adopted in laboratories to determine the values of the properties discussed, it has been shown, it is hoped, that these physical factors have a very real practical bearing on some of the problems encountered in non-ferrous foundries.

The whole question of successful casting in all the commercial non-ferrous alloys is closely related to the thermal history and behaviour of the metal throughout the melting, casting and cooling cycle, and such properties as specific heat and latent heat of fusion, varying widely from system to system, cover a much greater range than in the ferrous alloys.

In some instances, a high specific heat, which may call for special measures in the foundry may be one of the valuable assets of the finished casting, as, for example, large aluminium alloy pistons for internal-combustion engines, where high heat capacity without large temperature increase is desirable.

It is pleasing to note that the lack of information on some of these properties is now recognised, and that work is proceeding at such institutions as the National Physical Laboratory and will become available to the industry.

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DISCUSSION ON PAPERS BY G. G. GAUTHIER, G. GÜRTLER, AND J. E. NEWSON

The Exchange Papers

Mr. Gauthier's Paper was introduced by Mr. V. C. Faulkner (Past-President), who reminded the meeting that it was one of a series of foreign Exchange Papers. The first Exchange Paper was presented to the Institute in 1921, at a meeting held in Blackpool; it was contributed from America, and had dealt with electric furnaces. The exchange system was maintained between England and America for a number of years, and subsequently had spread to almost all the industrial countries of the world. He attributed a great importance to the system, because no country had a monopoly of brains, and some countries progressed on distinctive lines. Mr. Gauthier's Paper, for example, showed that progress in France in connection with the alloys discussed in the Paper was on lines rather different from those followed in this country.

In the translation of the Paper it was decided to state the figures in the metric system because of the very small differences noted between them in some cases; if the results were expressed in tons per sq. in. instead of kg. per sq. mm., the differences in some cases would be almost imperceptible. If it were borne in mind that 18 to 20 kg. per sq. mm. was equivalent to about 12 tons per sq. in., one would get a better idea of the contents of the Paper than by translating each figure.

German and French Observations Compared

Herr G. Gürtler, in presenting his Paper, first conveyed to the British foundrymen the hearty greetings of the Technischer Hauptausschuss für Giessereiwesen, and of all their German colleagues. The results of the investigations presented by Mr. Gauthier, he continued, corresponded exactly with those made in the researches of the metallurgical laboratory of the Metallgesellschaft A.-G. In Germany, the usual amount of the Mg content was 0.4 to 0.5 per cent., producing a higher yield point, tensile strength and Brinell hardness than the alloys with a smaller addition of magnesium as used in France. On the other hand, according to the observations of Mr. Gauthier, the elongation decreased.

The heat-treatment consisted in annealing at 530 deg. C. for a period of from 3 to 4 hrs., quenching in water at room temperature, and age-hardening at 150 deg. C. for 20 hrs. The results obtained with specimens cast in the manner described by Mr. Gauthier were as follows:—

	Kgs. per sq. mm.	Tons per sq. in.
Yield point.. ..	22 to 28	13 to 18
Tensile strength ..	25 to 32	16 to 20
Brinell hardness ..	80 to 100	—
Elongation	0.5 to 4.0 per cent.	

According to the German observations, the fatigue strength was not influenced by the magnesium concentration. It was supposed that the variation of the fatigue strength with the Si content was influenced, not only by the appearance of the silicon primary crystals, but also by the variation of the kind of solidification with the different Si contents.

No difference in the effect of manganese or cobalt on the mechanical properties could be observed. A microscopic difference was found between the two crystals. The crystal containing manganese formed primary dendrites in the typical shape of "Chinese script," whilst the crystal containing cobalt solidified a little more in the shape of needles in the same time with the Al-Si eutectic.

Advantage of Eutectic Alloys

A considerable advantage of the eutectic Al-Si alloys over the Al-Cu, Al-Mg and other alloys with a long solidification range was that they showed the possibility of carrying out the heat-treatment of large castings in the same manner as that of test specimens without danger of deformation or cracking. Certain well-known castings, for instance, must be quenched in boiling water in order to reduce the rate of cooling.

The conditions for the production of a gas-free casting were (1) the preparation of a de-gassed melt by treating with salt and allowing to stand, and (2) the avoidance of the absorption of gases when filling the mould by lowering the pouring temperature and shortening the length and time of flow.

The investigations on the effects of the addition of titanium on the fatigue strength were being continued, and the results obtained so far did not differ from those given in the Paper.

Practicability of Double Treatment

Mr. W. West (Leyland Motors, Limited) said that the Papers by Mr. Gauthier and Herr Gürtler gave British foundrymen much useful information, for they indicated investigations in a direction different from that in which we in this country had been working, and afforded British workers opportunities to modify their line of attack in their researches on the alloys concerned.

Those who were working with aluminium alloys already knew the possibilities of modification by sodium treatment and some of the benefits to be derived by the additions of special elements like titanium, magnesium, etc. The question which arose in the minds of managers of aluminium foundries was whether the double modification as suggested in Mr. Gauthier's Paper did not over-step the limits of foundry working. Those who had tried modification in practice were more or less convinced that the single treatment was sufficient to go on with.

Regarding the fatigue figures as given in Herr Gürtler's Paper, these were very interesting and had promise of some great usefulness. Could the author of the Paper add to this information whether such alloys had been used in any extensive way for the production of castings which had been subjected to stress conditions in service? Those who had had extensive experience in magnesium alloy castings operating under conditions which could not be reproduced in the laboratory had found that fatigue figures were rather misleading.

Gas Removal

Discussing the removal of gases from molten aluminium alloys, Mr. West stated that he was familiar with a similar process which had been developed by the British Non-Ferrous Metals Research Association, but could Herr Gürtler indicate how far his methods had been successful in actual operation in the foundry? It seemed to be necessary that any method of gas removal should be of such a character that it could be applied by the ordinary man in the foundry.

Mr. West stated that Herr Gürtler was to be highly praised for the manner in which he had delivered his Paper in English, and more particularly for his excellent ability in dealing with the discussion in the same language.

High Casting Temperature Queried

Mr. N. C. Ashton, referring to Mr. Gauthier's Paper, asked why the aluminium-silicon alloy test-bars dealt with therein were poured at a temperature between 700 and 720 deg. C. He had wondered why it was the practice to pour the high-silicon alloys at so high a temperature, because with other types of alloys he had obtained better results when casting at a temperature of about 650 deg. C.

Discussing Herr Gürtler's reference to modification of alloys by means of titanium—though it was in effect a grain size reduction by means of titanium, and could hardly be described as modification—he suggested that a combination of manganese and titanium would be more effective. He had used manganese and titanium in ordinary normal silicon alloys—not sodium-modified—and had effected improvement, not necessarily in tensile strength, but in machinability. The photograph of slip bands in Fig. 7 of Herr Gürtler's Paper was a very good example.

Having had some experience of 10 per cent. zinc-aluminium alloys, he asked if Herr Gürtler could confirm that they were quite good from the point of view of corrosion resistance, and whether he supported the allegation that the zinc-aluminium alloys were hot-short. In 3L5 alloy was hot shortness due only to annealing, and if so was it due to the copper addition? The latter was probably the reason, because he did not think the aluminium alloys with zinc alone were necessarily to be condemned from that point of view.

Gas Elimination

Mr. S. H. Russell (Past-President) commented that one of the great problems of the aluminium founder was to eliminate gases, which, unfortunately, went into solution in the molten aluminium. The method in Herr Gürtler's Paper of de-gassing by lowering the temperature very slowly and re-heating rapidly was new to him, and he asked for some elaboration of it. He had always understood that when once an aluminium alloy was badly gassed it was practically ruined, unless it was subjected to modification. (In making that remark he had in mind the "Y" alloys rather than the silicon-aluminium alloys.)

The influence of titanium on aluminium alloys interested him particularly, because he had been studying a similar application to cast iron, and he asked how Herr Gürtler added the titanium to the aluminium alloy to give the beneficial results indicated in the Paper, because it had been found most difficult to add titanium to iron satisfactorily. The research had been complicated and disappointing in dealing with cast iron, because, although everything indicated that the titanium should appear in the iron, frequently it had got into the slag, and there was not sufficient in the iron to give the beneficial effect which undoubtedly could be obtained if it were really there.

Commenting on the statement in the summary of the Paper that the removal of gases from the melt was best effected by a combination of salt treatment and standing in a neutral atmosphere, he asked how that neutral atmosphere was to be obtained in commercial practice when handling pots containing, perhaps, 50 or 60 lbs. of molten aluminium. He asked whether the salt was merely placed on the top of the pot (it was stated in the Paper by Mr. Gauthier that the bath of molten metal was provided with a surface layer of 0.3 per cent. of a mixture of 66 per cent. NaCl and 33 per cent. of NaF as soon as its temperature reached 750 deg. C.), or whether it was stirred in. If the latter were the practice, was the salt stirred in at an early stage, that is as soon as the metal was molten?

Mr. F. Hudson said that the information given in the Papers by Mr. Gauthier and Herr Gürtler was so well expressed that it would prove of great value to the practical man. He was particularly interested in the very simple way in which Herr Gürtler had shown the effect of gases in light alloys. To the average foundrymen the effects of gases in metals were rather complicated, but from a reading of Herr Gürtler's experiments one could readily understand what was meant, and the members were indebted to Herr Gürtler for that information.

With regard to degasification being brought about by allowing the metal to stand after treatment, the graphs in the Paper showed the time allowed for small experimental melts, but he asked what was the approximate time that larger foundry heats should be allowed to stand.

Standing Time for Modification

Mr. W. N. Cook, B.Sc., after congratulating the authors upon their Papers, agreed with Mr.

Ashton that in the foundry it was customary to cast the alloys at a temperature between 650 and 670 deg. C., and said that in practice quite good results were obtained. Quite recently test-bars of ordinary Alpax (known also as " L33 ") gave figures between 11.3 and 12 tons per sq. in. Supporting Mr. Hudson's request for information as to the length of time during which the metal should be allowed to stand after single modification with sodium, he said that in the foundry a 100-lb. pot would stand for possibly half an hour.

When a metal was allowed to become too hot, the furnaceman would cool it by inserting a gate, detached from a previous casting, and the amount of gas that was evolved when the gate entered the metal was amazing. There was no doubt that the cooling action of the gate caused a considerable release of gas, which was evolved in a huge bubble.

Originally, sodium was used for modification, and there had followed a large number of Patents involving the use of complex salts and other things, but in England foundrymen had reverted to the original sodium modification, which was found to be most satisfactory. He had found that about 1 oz. of sodium to a 70-lb. pot of aluminium was a satisfactory amount. He asked what was the practice in German foundries.

Relative Casting Properties

Dr. L. B. Hunt said that the Paper by Mr. Gauthier indicated the very great advance that had been made by the development of the heat-treated aluminium-silicon casting alloys over the previously-known " as-cast " aluminium-silicon alloys. That was a very important advance, and he believed that because of it the future would see quite an extension of their use in the engineering industry.

Commenting on the statement in Mr. Gauthier's conclusions that the heat-treatable aluminium-silicon casting alloys possessed casting qualities almost equal to those of ordinary aluminium-silicon alloys, although surpassed by certain alloys containing copper and titanium, he said one would have thought that any aluminium-silicon alloy would have much better casting properties than any copper-containing alloy. Therefore, he asked if Mr. Gauthier would elaborate that point.

Dealing with Herr Gürtler's interesting survey of recent German researches, he commented upon the method of de-gassing by means of a salt flux and a neutral atmosphere such as nitrogen or CO_2, and suggested that Herr Gürtler was a little unfair to British research, because he believed Hanson and Slater, at the British Non-Ferrous Metals Research Association (and not Dr. Scheuer) had advised that method and had explained its working by the breaking down of the oxide film.

Vote of Thanks

Finally, Dr. Hunt proposed a hearty vote of thanks to the authors for their Papers, and expressed appreciation particularly of the fact that Herr Gürtler had come to this country in order to present his Paper personally.

Mr. F. Hudson seconded the vote of thanks, which was accorded with acclamation.

The Chairman (Mr. W. B. Lake) expressed appreciation of the greetings conveyed by Herr Gürtler on behalf of his colleagues in Germany, and said that the British foundrymen heartily reciprocated; he asked Herr Gürtler to convey their good wishes to his German colleagues.

Mr. Faulkner said that he hoped to meet Mr. Gauthier personally in the near future, and would have pleasure in telling him that his Paper had been well received and was much appreciated. He confirmed the statement by Mr. Ashton that, according to the British literature, the pouring temperature of the aluminium-silicon alloys was about 650 deg. C., and said that the temperature of 720 deg. mentioned in Mr. Gauthier's Paper seemed somewhat high.

AUTHOR'S REPLY

Herr Gürtler, replying to the discussion on his Paper, said that modification by means of sodium was carried out at many foundries in Germany, and no great difficulties had been experienced with it. Degasification by means of metallic sodium alone was very slow, however, and in the great weights of metal dealt with in foundry practice the process was accelerated by the addition of salt. Crucibles containing 80 or 100 kg. of metal would degasify sufficiently if they were allowed to stand for 15 or 20 mins.

Experience of the addition of magnesium and zinc to aluminium casting alloys was not yet very great in Germany, and the results he had given were the outcome of laboratory experiments. He supposed that those alloys were not very good from the point of view of hot-shortness, due to the great rate of solidification by the hypo-eutectic composition. Experiments had been made on anodising them. However, he believed that such alloys would be found to be useful for small castings, in which the tensile requirements were small and where a good surface was required.

He agreed with the view that the casting temperatures given by Mr. Gauthier for the heat-treatable aluminium-silicon casting alloys were rather too high, and said that in Germany it had been found advantageous to lower the casting temperature a little. But the lowest temperature that could be used for aluminium-silicon alloys in the foundry was about 700 deg. C., because at lower temperatures the properties of the metal were not such as would allow adequate feeding of the castings. With very large castings it was necessary to use temperatures as high as 750 or 770 deg. C. However, the problem of lowering the casting temperature was bound up with the form of the mould.

Replying to the question as to the method of introducing titanium into aluminium alloys, he said that small pieces of an alloy of aluminium with 20 per cent. of titanium were added to the melt, so as to produce an alloy having a titanium content of 5 or 6 per cent. The temperature must be very high—about 1,200 deg. C. Then small pieces of the alloy containing 5 or 6 per cent. of titanium were added to the melt of the casting alloy; in that way the final alloy having the required content of titanium was produced. The titanium was absorbed at a temperature of about 800 deg. Another method consisted in introducing the titanium during the electrolysis process by means of TiO_2.

In the degasification process, a small amount of salt was melted with the metal in the crucible. Then a layer of salt was deposited on the surface of the metal, and subsequently it was allowed to stand. The improvement of the machining properties of the alloys was a difficult problem, and he suggested that the most advantageous method of dealing with it was to make a careful choice of the tool steels used for machining.

Mr. Ashton commented that manganese helped, in his experience.

MR. NEWSON'S PAPER

The discussion of the Paper by Mr. J. E. Newson was opened by Mr. F. Hudson, who said that foundry practice was a gigantic jig-saw puzzle, and Papers such as that by Mr. Newson could be likened to the pieces which worked into the picture. Until the characters of all the pieces were known and recognised, the many foundry problems could never be solved. The Paper was very refreshing, for it contributed pieces to the jig-saw puzzle in no small measure.

Conductivity of Mould Materials

Commenting on the statements in the Paper concerning the heat conductivity of mould materials, and the reference to some of the work which he had carried out some years ago, Mr.

Hudson said that that work had been carried a step further by independent investigators. He mentioned particularly that C. A. Parsons, of Newcastle-upon-Tyne, had taken out a Patent[*] for a similar process, quite independently, and were actually using this in foundry practice. Admittedly they were using it on cast iron; they had found it to be very beneficial in the making of large grey iron castings, particularly where sections varied.

At the risk of appearing greedy, he asked for Mr. Newson's comments on the fluidity or "life" of the high-strength brasses, for that was a phase about which a good deal more information was needed. In the course of some work he had carried out a few years ago on fluidity he had been interested to note that some of the non-ferrous alloys had actually much less "life" than ordinary cast iron. Phosphor-bronze, for instance, had given a much lower "life" test than ordinary cast iron, although it had a much more searching action on the mould. That brought into the picture factors of surface tension and other conditions, and he felt that work in this connection could very profitably be continued.

Finally, he expressed the hope that further Papers of the kind presented by Mr. Newson would be contributed, in order that the facts should be made available for reference.

Controlling Grain Growth by Chromium

Mr. J. E. O. Little asked if Mr. Newson could give information on the control of the grain growth of high-strength brasses by chromium instead of iron. Some work had been done, he said, particularly by Gonser and Heath, in which 0.17 per cent. of chromium was claimed to inhibit grain growth altogether. So far he personally had tried only one experiment, and in that experiment the grains had certainly grown. In this, however, it was found that the

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[*] British Patent 470,972.

chromium had not gone into solution properly, so the experiments would be continued.

Mr. H. Taylor asked whether small additions of nickel, up to 1 per cent., lowered the tensile strength of high-tensile brass, in Mr. Newson's experience. His own experience was that such additions of nickel did lower the tensile strength, though they might increase the elongation.

Latent Heat and Melting Costs

Mr. S. H. Russell (Past-President) said he had never realised so clearly, before reading Mr. Newson's Paper, the importance of latent heat in regard to melting costs. He had always imagined that aluminium alloy was melted in the foundry more cheaply than Admiralty gunmetal; but it seemed that in an oil-fired tilting furnace the consumption of oil during the melting of 250 lbs. of aluminium was about the same as the consumption in melting 650 lbs. of gunmetal (which was of about the same bulk), the latter to be cast at 1,150 deg. C. He would take care to bring that fact to the attention of his costing department. It emphasised the great importance of giving close consideration to the factors discussed in the Paper.

High-Tensile Brass Casting

Commenting on the cooling curve in Fig. 1, he said he did not understand fully how it was made up, for the curve was so remarkably horizontal in the early part of the cooling range. A period of about 390 secs. had elapsed during the reduction of the temperature from about 902 to 890 deg. But he could not reconcile the other figures with the seconds. Many minutes, and probably three-quarters of an hour, must have elapsed before the temperature of the metal had been reduced to 300 deg. C., unless it was cast in thin sections. In his very limited experience of high-strength brass, the thermo-couple and the immersion type of pyrometer were extraordinarily reliable. Some 15 months ago, when dealing with a contract for Admiralty gunmetal and a small quantity of high-tensile brass, he had first had a talk with a Past-President of the Institute, and had then cast some test-bars, each one of which had a tensile strength of 42 tons. On the advice of that Past-President, 30 cwts. of castings were made, using the thermo-couple, and no trouble at all had been experienced. On the other hand, in dealing with a high tin-content phosphor-bronze some trouble had been experienced, although he had not expected trouble.

There was a great deal of interest in Mr Newson's explanation of his conception of the manner in which the metal entered the mould. and the formation of the tenacious film of aluminium oxide on the surface, which protected the metal, provided the metal was not broken up too much by turbulence; the result was beneficial, and a smooth surface of the golden or yellow colour was produced. He personally had succeeded in achieving that result in the very small quantities of material he had handled.

The problem was extraordinarily fascinating, for different conditions arose with each different alloy. Mr. Newson's contribution, dealing with one of the most difficult alloys to manipulate, was indeed valuable.

Mr. T. Henry Turner, M.Sc. (Doncaster), recalled discussions in the Institute concerning the raising of the status of the foundry industry, and said it was clear that the status must be raised if foundry moulding materials were to be understood in the manner indicated by Mr. Newson's Paper. When such matters as the specific heats and conductivity of the individual constituents in moulding sands were being studied, the Institute was definitely moving in the right direction.

AUTHOR'S REPLY

Mr. Newson replied to the discussion. After expressing appreciation of Mr. Hudson's remarks, he said he had purposely avoided the problem of fluidity, because it had been dealt with so fully by Dr. C. H. Desch in the third

Edward Williams Lecture delivered to the Institute in June, 1937.

Dealing with Mr. Little's reference to the control of grain-growth by means of chromium, he said the original intention was to control the grain-growth of alloys which had been subjected to cold work, followed by annealing. In view of the success of this work he had tried some experiments on cast alloys, but it had proved to be very difficult to get a chromium-copper alloy to dissolve satisfactorily in the high-strength brasses. In the Paper he had mentioned the use of materials other than iron which would have a refining action, and he had had chromium in mind then. He had realised that other additions might have a refining action, although he did not know whether the action was precisely the same as the iron-rich phase in the manganese bronzes. The photographs in Fig. 2 of the Paper were intended to emphasise the important influence of iron, which was more easily introduced than chromium.

Balanced Additions

Discussing Mr. Taylor's question concerning the effect of nickel, he said that in considering high-strength brasses one must take account of all the elements present, and must maintain a correct balance of the various metals added. He thought that in certain alloys, 1 per cent. of nickel would not have a marked effect on the tensile strength, but in a normal manganese bronze 1 per cent. of nickel definitely effected general improvement; a higher percentage of nickel effected even greater improvement, provided a correct balance was obtained with the other metals in the alloy. "Turbadium," an alloy introduced about the year 1910, contained 2 per cent. of nickel, and it was the most successful alloy introduced up to that date for resisting erosion.

Latent Heat and Melting Costs

As to the effect of latent heat on the cost of melting, he assured Mr. Russell that the figures given in the Paper in that connection had been checked over quite a long period of working, making the ordinary "2L5" alloy, and it was true that as much oil was required to melt 250 lbs. of aluminium as was required to melt 650 lbs. of gunmetal. Incidentally, he pointed out that a burn caused by aluminium alloy was often far more severe than a burn caused by gunmetal or bronze, for the reason that more heat was stored in the metal.

Differential Cooling Curves

The differential cooling curve in Fig. 1, upon which Mr. Russell had commented, was presented in the recognised form. The thermo-couple was immersed in a crucible of metal, and the whole crucible, with the thermo-couple immersed, was allowed to cool very very slowly in an electric or other suitable furnace. By means of a metronome or stop watches, the time occupied by the fall of temperature over a certain number of degrees was measured. In his experiments, the time interval was measured accurately for successive decreases of 10 deg. C., the temperature of any prolonged arrest being noted. The time intervals in seconds were plotted against temperature. During the fall from 910 to 900 deg. there was a long hold-up at 902 deg., and at 890 deg. the metal had held the temperature for 400 secs. Then there was a slight kick forward on the curve, because the temperature of the surroundings of the crucible had fallen slightly lower than the temperature of the metal in the crucible; thus, the rate of cooling was accelerated whilst equilibrium conditions were re-established. Any phase change should be marked clearly, and there was a well-marked point in the case of the manganese bronzes at about 450 deg.; but there were also other minor points on his curve which might be due to external influences.

Foundry Handling of High-Tensile Brasses

After congratulating Mr. Russell on the good results he had obtained with high-tensile brasses, without having previous experience, he said that sometimes foundrymen experienced trouble with such alloys because they did not understand the form of skim gate to use to prevent dross formation, etc.; further, it was necessary to use very generous heads in order to allow for contraction and for the very difficult pasty range. In large jobs the heads were always rod fed, but that was not so necessary in smaller jobs.

With regard to the surface film on the alloys, he said he had carried out a number of experiments with open moulds in order to study the flow of metal into the mould, and the reactions between the metal and the various types of mould materials and dressings. In very large jobs one could sometimes see the succession of lines, indicating the continual re-forming of the film. If the metal was poured without providing proper control at entry, trouble would be experienced, as zinc would be volatilised and, combining with oxygen of the air, would form zinc oxide, which, floating on the surface of the metal, could give rise to drossy, dirty patches when trapped.

On the motion of Mr. W. B. Sallitt, seconded by Mr. V. Delport, a hearty vote of thanks discussion on his Paper.

MR. GAUTHIER'S REPLY

Mr. Gaston G. Gauthier writes as follows in reply to the various questions raised during the discussion on his Paper.

To Mr. West: Double modification as detailed and used in the research is no more difficult to apply in practice than single modification either by sodium or salts. The first addition of 0.3 per cent. of salt is made in totality during melting, especially whilst the metal is increasing in temperature and such a method introduces no additional difficulty. It can be made by the workman responsible for the supervision of the furnaces. As to the introduction of sodium, this is a well-known and currently used operation.

To Mr. Ashton: The casting temperature cited, that is from 700 to 720 deg. C., is that which has given in practice test-bars showing the best mechanical results. Thus, as was pointed out by Mr. Gürtler, the casting temperature depends on the mould to be filled and is fixed in practice by the pathway the metal has to follow. In order to clarify the situation, the photograph, Fig. A, shows the actual test-bar referred to. A metre rule is included so as to indicate the dimensions.

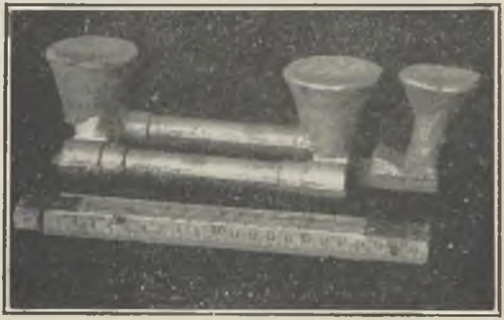

Fig. A.—Test-Bar Used.

To Dr. Hunt: The question raised by Dr. Hunt arose from a typing error, for which the author apologises. The phrase should have read: "It is true that the mechanical properties are surpassed by those of certain alloys containing copper and titanium, etc."

CHEMICAL CHANGES IN CUPOLA MELTING **Paper No. 637**

By JAMES T. MACKENZIE*

[AMERICAN EXCHANGE PAPER]

The cupola is a hollow shaft of refractory open at the top to admit solid fuel, metal and, incidentally, flux, with openings near the bottom to allow air to enter, and below these to let the slag and metal flow out. The usual steel shell is incidental to holding the refractory shell together, and the other metal appurtenances are mechanical contrivances for delivering the blast, holding slag and iron until ready for delivery, etc. Primarily, the purpose of the refractory is to hold heat and cause it to be absorbed by the iron. The flux is to render fusible the ash of the coke and such silicious material as is charged with the metal or is melted from the lining. Most of the principles of physics and chemistry are at work simultaneously during a heat, but it is often difficult, if not impossible, to determine at a given point, time or level, which ones are in control and which in abeyance.

Assuming that the lining is of a fairly satisfactory refractory, there are really five factors which control the effluent metal:—

(*a*) The metallic charge—its chemical composition and the ratio of its surface to weight or, generally, the size of the pieces.

(*b*) The fuel—its composition, size, shape and structure, and its weight in proportion to the iron.

(*c*) The blast—its temperature, moisture content and velocity (local as well as mean).

(*d*) The structural details of the cupola.

(*e*) The amount and quality of the flux.

The changes in the iron are mainly due to the oxygen of the blast and its reaction with the

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* Chief Metallurgist, American Cast Iron Pipe Company, Birmingham, Ala., U.S.A.

coke, the carbon and sulphur of the coke, and the fluxing power of the flux. Other changes are due to temperature-solubility relationships, but practically no change is a linear function of any one condition, reaction or property. Table I shows a list of the variables to be found in ordinary practice, and even this may not be complete, not only for the obvious reason that the author has overlooked some, but that there may be some not yet recognised by anyone. Fortunately, however, many of these can be held constant for all practical purposes, so that others can be studied, if not exactly singly, at least in small groups. It should be remembered that such studies should be reported only in the past tense as a warning that the exact conditions of the experiment might never occur again.

This Paper does not attempt to cover the work that has been done along these lines by other investigators, but is frankly a review of the work done by the author and his collaborators at the American Cast Iron Pipe Company in Birmingham, Alabama, and reported to the Institute of British Foundrymen,[1] and to the American Foundrymen's Association,[2 3 4] together with some tests not previously published.

The Three Zones

The most important changes in the iron (at least, so it seems to-day) are:—(1) The oxidation of iron, carbon, silicon and manganese, and (2) the absorption of carbon and sulphur. There are three laboratories in the cupola fairly easily defined on paper, but which are not so easily separated in the furnaces, it is thought, as foundrymen are prone to think. These are: the *shaft*, where the metal is still solid; the *melting zone*, where the oxygen of the blast is used up, where the ash of the coke is being released to form slag, and the iron is trickling through the burning coke; and the *hearth*, where the liquid iron and slag collect in the interstices of a mass of coke to separate before withdrawal.

TABLE I.—*Variables in Cupola Melting.*

(*a*) Metal.	(*b*) Coke.	(*c*) Blast.	(*d*) Construction and operating details.	(*e*) Flux.
Size	Size	Velocity	Size of cupola	Size
Shape	Shape	Temperature	Shape of lining	Shape
Carbon, free	Carbon	Moisture	Size, shape and distribution of tuyeres	CaO
Carbon as carbides	Ash, amount and composition	Sulphur	Depth of well	MgO
Silicon	Volatile	Oxygen	Height from tuyeres to charging door	Na_2O
Phosphorus	Sulphur		Height of bed	SiO_2
Manganese	Organic		Size and distribution of charges	CO_2
Sulphur	Sulphide		Method of slag and iron removal	Sulphates
Oxides	Sulphate		Ratio of iron to coke and flux	Sulphides
Nickel	Strength			Other oxides
Chromium	Cell space			
Molybdenum	Moisture			
Copper	Reactivity			
Titanium				
Vanadium				
Arsenic				
Possibly others usually insignificant				

Of the reactions in the shaft the most important is apparently the absorption of sulphur and some oxidation. In the Paper on size of coke[4] the initial absorption of sulphur on the small coke is very high, as compared to the large coke (Fig. 1), as long as the original filling of the cupola was being melted (through the 7th tap), and this was the only variable so affected. The bed height being the same in both cases, a great deal more small coke was burned before melting began than large, with consequent exposure of the solid iron in the shaft to the sulphur. High beds are notoriously prone to high sulphur on the first charges. Table II gives some hitherto unpublished tests on height of bed, which show that while the sulphur pick-up on the 3rd and 5th ladles changed from 0.044 to 0.076 per cent., on the first ladle it rose from 0.044 to 0.119 per cent. as the bed was raised from 30 to 50 in. (tests on the 21-in. cupola used in (3)).

Reactions in the Stack

Oxidation is probably a minor reaction in the stack. With about 10 per cent. coke ratio (normal cokes) Piwowarsky shows virtually constant CO_2 and CO ratio above the melting zone. Probably most of the oxidation of small scrap is from solid pieces falling through the coke down into the lower part of the melting zone, where there is free oxygen.

Carburisation in the stack is also exceedingly small. The Boudouard relations show nearly 80 per cent. CO necessary for reduction of oxide at 1,200 deg. C., and few cupolas run over 60 per cent., most, probably, running below 50 per cent. In running a test with a still steel residue,[1] the blast was on for over an hour with no melting. When the bottom was dropped a piece of wrought iron was found which had just begun to melt, and this was examined microscopically. About one hundredth of an inch around the circumference was found to be carburised to approximately 0.50 to 1.50 per cent.

INSTITUTE OF BRITISH FOUNDRYMEN.

PROCEEDINGS—VOL. XXXI. 1937–38.

ERRATA.

PAPER ON

"CHEMICAL CHANGES IN CUPOLA MELTING."

Page 262.—Line 35, delete *steel*.

Page 271.—Between columns 9 and 10, insert column "*Sulphur in Melt*," the figures for which are: Dayton 0.195; Sewanee 0.104; Fine Creek 0.10; Bradford 0.113; A.B.C. 0.118; Barrett 0.102; Bayonne 0.146; Parco 0.133.

Page 283.—Footnote to Table VII should read:

Melt No. 1.—Oxygen, 0.005; Nitrogen, 0.013.

Melt No. 15.—Oxygen, 0.014; Nitrogen, 0.007.

Page 286.—6 lines from bottom, for *grades* read *sizes*. 4 lines from bottom, for *fine* read *thin*.

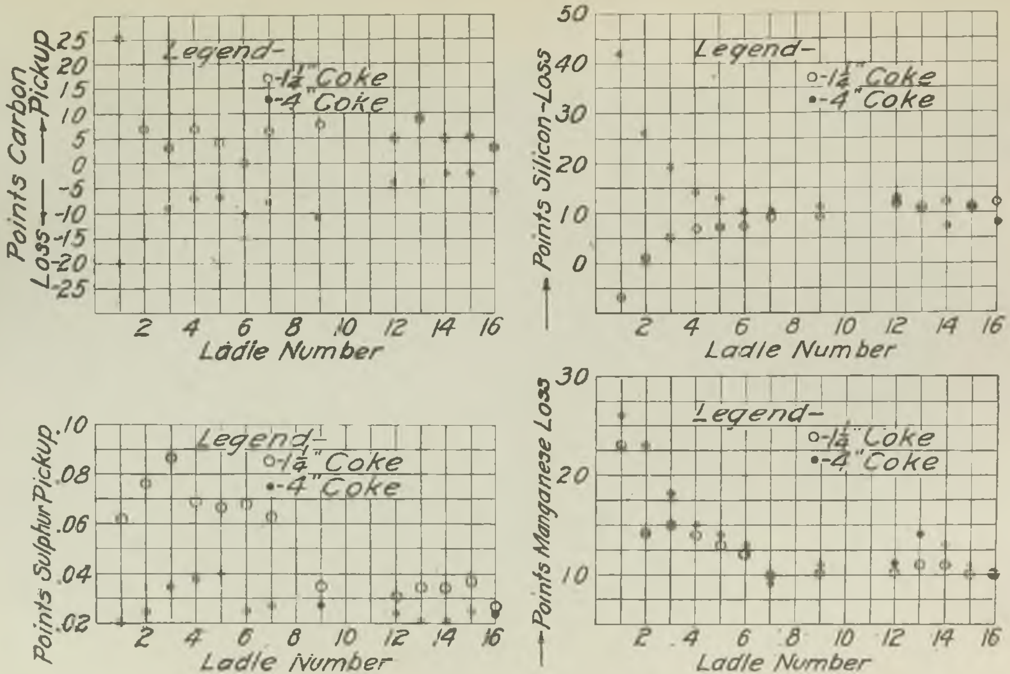

FIG. 1.—VARIATIONS IN DIFFERENT ELEMENTS IN HEATS OF LONG DURATION WHEN USING VARIOUS-SIZED COKES.

carbon. This must have been in a very high CO atmosphere rich with hydrocarbons for the full time, for the coke was about 18 per cent. volatile and the flames were a deep rich red, reaching a height of 20 ft. or more above the stack, as compared to a pale blue of about 5 ft. for a normal (ABC) coke with the particular bed, blast and coke ratio used. The fact that no iron melted showed that the reaction to CO was too rapid to raise the temperature to the melting point.

Hearth Reactions

The hearth is also comparatively simple. The Paper by Johnson[3] showed that whatever effect the depth of the hearth has on carburisation, it was obscured in so many cases that no rule could be postulated. Fig. 2 shows that in three out of five pairs of tests the low (4 in.) tuyeres gave higher carbons than the high (16 in.), but that in all three pairs of intermittent taps *versus* continuous flow, the intermittent tap gave higher carbons than continuous flow, this effect being far greater on the low tuyeres than the high. A personal thought is that the amount and fluidity of the slag interfere so with the iron-coke contact that depth of coke below the tuyeres is of secondary importance. Then, again, the coke at the level of, and just below, the tuyeres must be much hotter than that farther down. In continuous flow, the coke will in general be well covered with slag with only a shallow bath of iron, but in the periodical filling of the hearth during tapping the iron lifts the slag with it as it rises and thus has a chance to come in contact with clean coke.

Needless to say, all other open-hearth and puddling furnace reactions are possible, but are seldom encountered. A slag with high iron oxide will decarburise or oxidise the silicon and manganese, depending on the temperature, and a basic slag will doubtless desulphurise, but when these unusual slag conditions occur, the melting zone reactions are usually so affected that it is

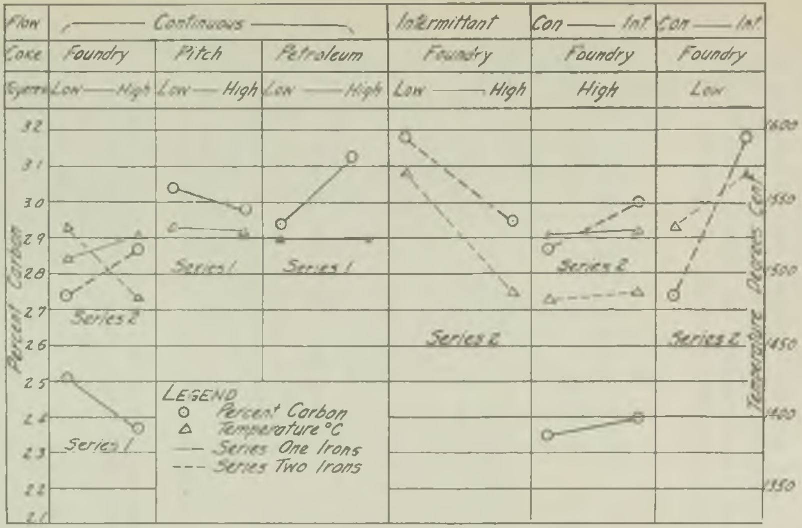

FIG. 2.—CARBON PICK-UP AS AFFECTED BY HEIGHT OF TUYERE AND BY INTERMITTENT AND CONTINUOUS FLOW.

difficult to say that the relatively short time of contact of slag and iron in the well was responsible, especially considering the relative quietness and the presence of a volume percentage of about 65 per cent. of coke, which quite probably interferes with the usual oxidation reaction of the open hearth. Several cases of lowering sulphur by adding limestone, soda ash, and sometimes by increasing the volume with sand or gravel, have been reported (at least one case in large-scale production reported to the author personally by a competent metallurgist), but it seems that the explanation is more likely to be found in sulphur absorption in the stack by the increased basic oxides, or in improvement of the melting conditions by an increase in slag volume or fluidity, than in actual reaction in the hearth.

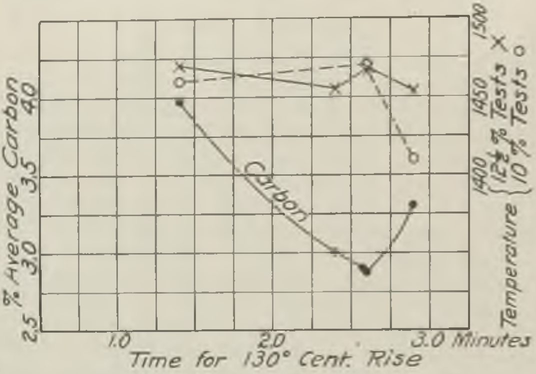

Fig. 3.—Relation between Burning Time of Coke and Average Carbon and Temperature of the 8th, 9th and 10th Melts. The 12½ and 10 per cent. Tests refer to the Amounts of Coke used in the Melts.

The melting zone is the laboratory where most of the necessary work is done and most of the reactions occur. Cupolas are operated with very little stack and almost no hearth. Here the

TABLE II.—*Effect of Bed Height on Analysis Changes.*

Coke.—ABC. Size 3 in. by 1½ in.—10 per cent. of metal charge.
Flux.—Dolomite. 2 per cent. of metal charge.
Blast pressure.—4.4 ozs.

Bed height.	Sample.	Temp., deg. C.	C.	Si.	S.	Mn.	P.	Pick-up, per cent.		Loss, per cent.	
								C.	S.	Si.	Mn.
					0.052*						
	As charged		3.55	1.75	0.060	0.41	0.71				
30 in.	1st ladle	1,443	3.55	1.70	0.096*	0.29		0.00	0.044	0.05	0.12
	3rd and				0.096*						
	5th ladles	1,448	3.49	1.68	0.110	0.34	0.69	−0.06	0.044	0.07	0.07
					0.062*						
	As charged		3.40	1.48	0.072	0.47	0.65				
40 in.	1st ladle	1,398	3.57	1.44	0.104*	0.30		0.17	0.042	0.04	0.17
	3rd and				0.126*						
	5th ladles	1,498	3.43	1.40	0.136	0.40	0.64	0.03	0.064	0.08	0.07
					0.053*						
	As charged		3.48	1.48	0.063	0.49	0.68				
45 in.	1st ladle	1,482	3.65	1.55	0.106*	0.34		0.17	0.053	−0.07	0.09
	3rd and				0.112*						
	5th ladles	1,515	3.45	1.42	0.120	0.43	0.69	−0.03	0.057	0.06	0.06
					0.061*						
	As charged		3.52	1.55	0.070	0.38	0.69				
50 in.	1st ladle	1,387	3.46	1.69	0.180*	0.31		−0.06	0.119	−0.14	0.07
	3rd and				0.129*						
	5th ladles	1,515	3.50	1.50	0.146	0.35	0.65	−0.02	0.076	0.05	0.03

* Evolution, others estimated gravimetrically.

oxygen of the blast combines with the carbon of the coke to form carbon dioxide, which acts on more carbon to form carbon monoxide—the first generating heat and the second absorbing it. It is a mistaken idea to think of these two reactions as occurring in steps. For that reason words instead of symbols have been used, for when the following reactions are written:—

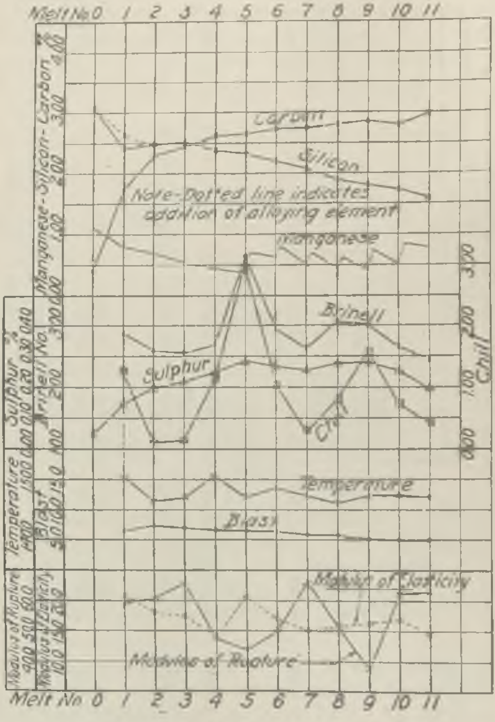

Fig. 4.—Effect of Repeated Melting. (See Table V.)

$$R_1 \ldots\ldots\ldots\ldots\ldots O_2 + C = CO_2$$
$$R_2 \ldots\ldots\ldots\ldots\ldots CO_2 + C = 2CO$$

it always gives a personal impression that after reaction R_1 was all finished with, the meeting adjourned and convened next day, say in London,

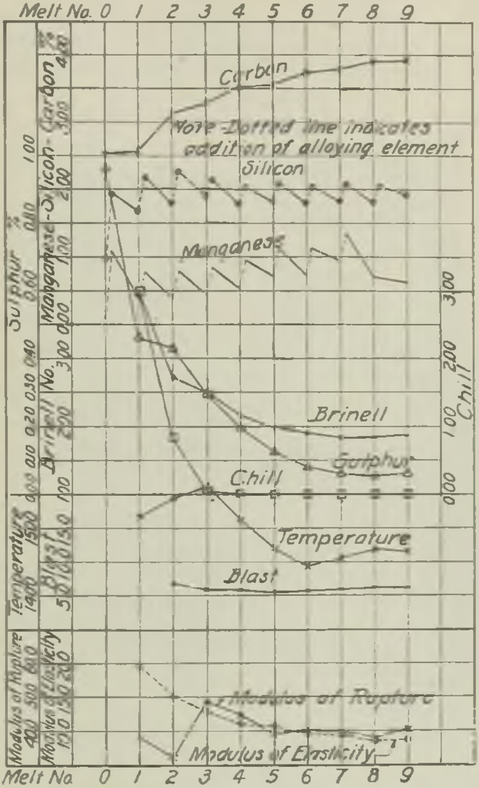

FIG. 5.—EFFECT OF REPEATED MELTING.
(See Table VI.)

where reaction R_2 was carried out, whereas it is known that CO is being formed while there is still considerable free oxygen present and that some oxygen may form CO directly.

Minor reactions with the coke are the burning of sulphur to the dioxide or trioxide, the decomposition of the water of the air into hydrogen and eventually carbon dioxide and, in the cooler parts of the stack, a possible reversion of the carbon monoxide to carbon dioxide and carbon. The metals and metalloids of the charge react with the rust and other oxides in the charge, including coke ash, with the refractory lining, and with the oxygen from the blast.

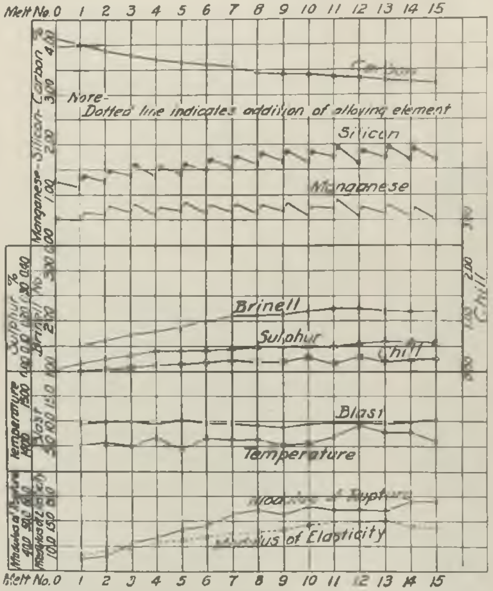

Fig. 6.—Effect of Repeated Melting. (See Table VII.)

The physical reaction due to heat alone is primarily that of melting, but in addition there is decomposition of the carbonate fluxes with liberation of carbon dioxide in the stack, volatili-

TABLE III.—*All-Steel Charges + 50 per cent. Fe-Si and 80 per cent. Fe-Mn.*

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

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

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

Shatter is amount remaining on 2-in. screen after four drops from 6 ft.

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

Charge about 0.4 per cent. carbon and 0.04 per cent. sulphur.

sation of metallic manganese, and decomposition of the pyrites which are present in many limestones.

Reactions and Temperature

The rapidity of the reaction of the carbon of the coke with the oxygen of the blast is the

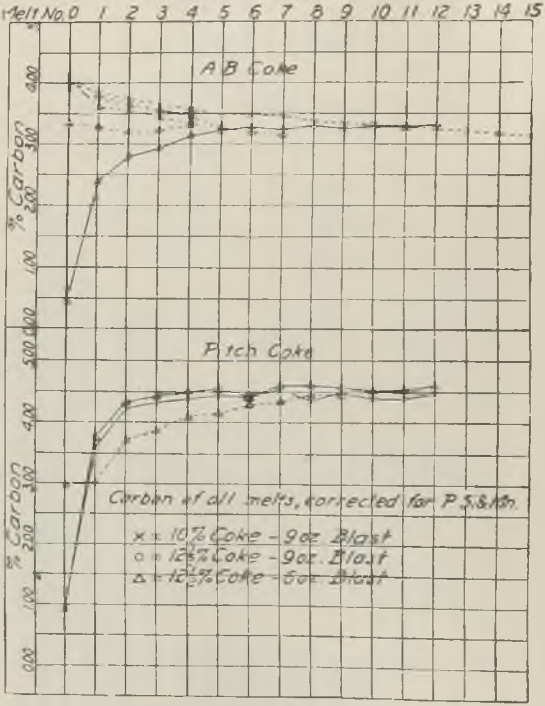

Fig. 7.—Carbon of All Melts, corrected for P, Si and Mn.

governing factor in most cases. If the coke reacts sluggishly with CO_2 in the stack, a large amount reaches the melting zone to react, though perhaps sluggishly, with the oxygen, whereas a coke reacting rapidly in the stack gives less carbon in the melting zone. Conversely, a coke

TABLE IV.—*Physical and Chemical Data on Cokes Used in Investigation.*

Symbol.	Kind.	Temp. of ignition, Deg. C.‡			Mins. for 250 deg. Fahr. rise.‡	Max. temp. rise, deg. Fahr.‡	Shatter.§	Cell space.§	Ash. Per cent.	Volatile matter. Per cent.	Sulphur. Per cent.
		Min.	Max.	Avg.							
R.H.	Special*	—	—	—	—	—	69	49	13.6	0.8	1.0
R.B.	Furnace*	562	604	585	2.6	256	63	49	14.6	1.3	0.9
W.B.	Furnace*	515	554	533	2.4	269	70	54	9.6	1.8	1.0
A.B.	Foundry*	568	624	590	2.9	241	73	49	10.0	0.8	0.6
Q.B.	Pitch† ..	493	537	518	1.4	350	88	47	0.4	0.9	0.4
H.C.	Foundry†	504	571	540	2.6	259	79	59	10.2	1.0	0.7

* By-P.—By-product oven. † B.H.—Beehive oven. ‡ Boegehold burning test. § A.S.T.M. tests.

which burns rapidly at the tuyeres, thus giving a localised high temperature, reacts rapidly with the CO_2 formed to lower that temperature by forming CO. This is probably the reason why such unsatisfactory results have been obtained when correlating reactivities and melting temperatures. Fig. 3 is a good illustration[2] of this—a fact which has been noted by other investigators, most recently by Pearce.* It also explains why increasing coke affects the temperature so little, for as the amount of coke increases the CO percentage increases with considerably greater rapidity. In American practice the temperatures range from about 1,350 to 1,600 deg. C., with

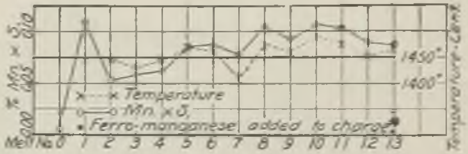

FIG. 8.—MN × S AS AFFECTED BY TEMPERATURE OF MELT. CHARCOAL PIG-IRON WITH 10 PER CENT. H.C. COKE (0.7 PER CENT. S).

coke ratios varying from about 6 to 17 per cent. —a 16 per cent. increase in temperature for a 200 per cent. increase in coke, although the superheat (temperature above freezing) of the melt is about doubled :—

$$\frac{1600 - 1130}{1350 - 1130} = \frac{470}{220} = 214 \text{ per cent., or an in-}$$

crease of 114 per cent.

The highest temperatures are obtained only by a combination of high blast velocities (volumes) with high coke ratios, which makes a deep zone of high temperature for the molten iron to fall through.

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* Proc. Inst. Brit. F., Vol. XXX, p. 196.

Table V.—*Data on Repeated Melts with Charges of* R.H. *Coke* (12½ *per cent.*) *and Steel, using 34-in. Bed and 3 per cent. Dolomite Flux.*

Melt No.	Added		Blast pressure.	Temp. Deg. C.	C.	Si.	S.	Mn.	P.	Ti.	Chill.		Brinell.	Mod. of rupture.	Mod. of elasticity.
	Si.	Mn.									Last white.	First grey.			
Orig.	2.90	0.80	—	—	0.40	3.08	0.045	1.12	0.20	0.45	—	—	—	—	—
1	0.00	0.00	6.4	1,503	1.74	2.40*	0.146	0.78	0.20	0.07	1.56	0.95	288	58.6	20.8
2	0.00	0.00	7.3	1,463	2.31	2.47	0.198	0.68	0.20	0.04	0.14	0.06	260	61.0	18.0
3	0.00	0.00	7.0	1,468	2.45	2.53	0.218	0.54	0.21	0.04	0.15	0.10	257	65.8	17.5
4	0.00	0.00	6.7	1,504	2.64	2.40	0.249	0.44	0.25	0.03	1.13	1.13	268	47.8	14.2
5	0.00	0.00	6.4	1,470	2.65	2.33	0.285	0.38	0.27	0.01	3.00	3.00	413	43.7	20.7
6	0.00	0.32	6.4	1,485	2.74	2.20	0.268	0.63	0.27	—	1.05	1.04	295	49.9	17.0
7	0.00	0.16	5.8	1,472	2.76	2.07	0.253	0.52	0.27	—	0.30	0.24	263	66.7	15·3
8	0.00	0.16	5.8	1,461	2.80	1.90	0.278	0.45	0.27	—	0.83	0.76	307	51.5	16.0
9	0.00	0.16	5.2	1,475	2.85	1.81	0.279	0.41	0.29	—	1.90	1.26	302	37.5	16.5
10	0.00	0.32	5.2	1,475	2.81	1.74	0.253	0.52	0.30	—	0.84	0.64	267	62.3	17.1
11	0.00	0.32	5.2	1,472	2.99	1.59	0.195	0.79	0.30	—	0.46	0.37	246	63.0	15.0

* Weighted average all taps gives 2.64 Si, 0.84 Mn.

The factors that have been studied by the author, which have been suggested as most important, are:—

The properties and size of the coke.
The pressure (volume) of the blast.
The composition and size of the metallic charge.

The studies have been made largely on the basis of the changes in carbon, silicon, sulphur and manganese, and the temperature, chilling properties of a 1½-in. by 3-in. by 6-in. block, and strength and stiffness of 2-in. by 1-in. test-bars tested flatwise on 24-in. supports. Some effects which might be of importance in feeding and shrinkage problems, or the chilling of light sections, etc., would pass unnoticed in these tests.

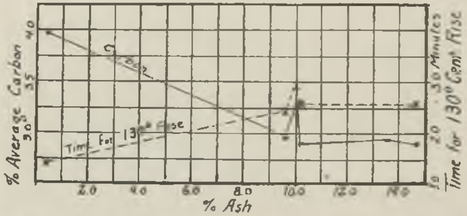

FIG. 9.—RELATION OF ASH CONTENT TO BURNING TIME OF COKE AND AVERAGE CARBON OF 8TH, 9TH AND 10TH MELTS.

The 1927 Paper[1] gave the results from a very wide range of cokes, the data on carbon and sulphur being shown in Table III. These were all-steel charges, except for silicon and manganese alloys, which averaged about 0.40 per cent. carbon and 0.040 per cent. silicon. This shows a variation in carbon absorbed of 2.54 per cent. (from 1.73 to 4.27 per cent.) and in sulphur of 0.093 per cent. (from 0.102 to 0.195 per cent.). Apparently, the ash is an important factor in the absorption of carbon, but other properties can outweigh it to a large extent.

TABLE VI.—*Data on Repeated Melts with Charges of Q.B. Pitch Coke (12½ per cent.) and High-Sulphur Pig, using 34-in. Bed and 3 per cent. Dolomite Flux.*

Melt No.	Added		Blast pressure.	Temp. Deg. C.	C.	Si.	S.	Mn.	P.	Ti.	Chill.		Brinell.	Mod. of rupture.	Mod. of elasticity.
	Si.	Mn.									Last white.	First grey.			
Orig.	—	—	—	—	2.55	0.97	0.970	0.10	0.85	—	—	—	—	—	—
1	1.00	1.00	N.R.	1,518	2.58	1.70	0.461	0.39	0.85	0.01	3.00	3.00	398	38.2	19.8
2	0.50	0.40	6.9	1,546	3.17	1.78	0.430	0.41	0.87	—	0.84	0.84	273	32.7	15.5
3	0.50	0.40	6.1	1,563	3.31	1.91	0.296	0.47	0.84	—	0.05	0.05	251	48.9	12.6
4	0.25	0.40	6.0	1,514	3.55	1.79	0.198	0.57	0.89	0.01	0.02	0.02	219	45.2	11.2
5	0.25	0.40	5.7	1,471	3.57	1.84	0.130	0.73	0.88	—	0.01	0.01	202	39.4	10.8
6	0.25	0.40	6.0	1,446	3.74	1.81	0.084	0.73	0.86	—	0.00	0.00	193	40.7	9.7
7	0.25	0.40	6.1	1,459	3.80	1.83	0.064	0.97	0.85	—	0.01	0.00	184	40.0	9.7
8	0.25	0.00	6.4	1,472	3.91	1.82	0.059	0.73	0.88	—	0.00	0.00	185	38.0	8.6
9	0.25	0.00	6.4	1,467	3.91	1.93	0.065	0.63	0.87	—	0.00	0.00	189	40.5	8.8

For example, Fire Creek gave low carbon with low ash, but it had an extremely high shatter test and high porosity. The Bradford was so weak (shatter 50) that much of it blew out of the stack in small pieces during the melt. There may be other reasons for these two out-of-line results, but these are at least suggested by the Table.

The 1930 Paper[2] gave a large number of results on the six cokes shown in Table IV. These tests were started on some 1,000 to 2,000 lb. heats and repeated until there was only about 500 lbs. left (the loss being melting loss, including spillage, and test specimens which had to be kept for future reference). Typical records are shown in Table V, Fig. 4, an all-steel charge; Table VI, Fig. 5, starting from a most unusual high-sulphur pig-iron; and Table VII, Fig. 6, a normal coke and normal pig-iron. This last is also of interest, in that oxygen and nitrogen were determined on the first and last heats. These tests showed clearly that, for any given coke, the carbon tended to reach a certain value, but that this value was strikingly different for the different cokes, as was shown in Fig. 3,

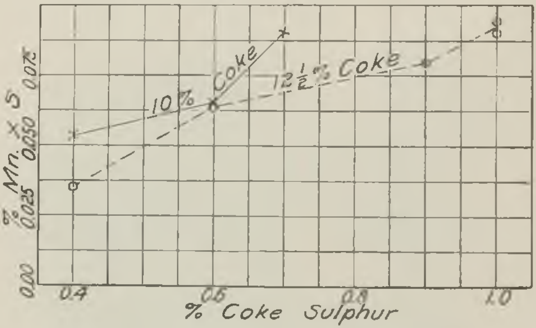

Fig. 10.—Relation between Sulphur of Coke and Mn × S on 8th, 9th and 10th Melts.

which gives the average carbon of the 8th, 9th and 10th melts plotted against the results of the Boegehold test.

Influence of Coke

Fig. 7 shows the comparative results on ABC (a good coke used regularly in the author's foundry) and pitch coke starting with different raw materials. Sulphur also tends towards an equilibrium if the manganese be kept constant. If the manganese be allowed to decrease, the sulphur rises to keep the product Mn × S constant. Fig. 8^2 shows how this constant varies with temperature. Carbon also has an effect on

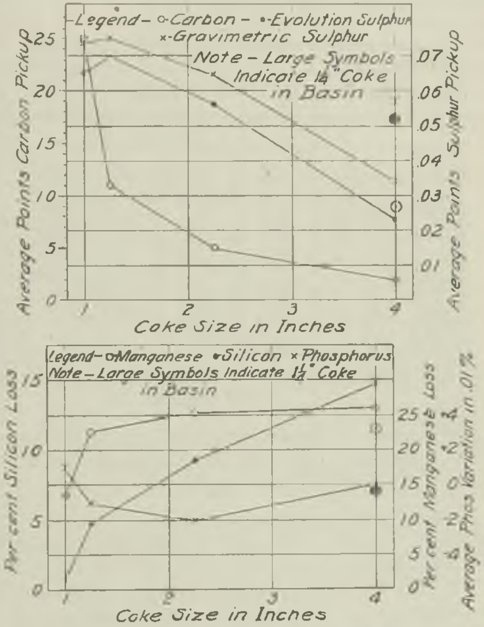

Fig. 11.—Average Changes in Analyses with each succeeding Change in Coke Size.

the Mn × S constant and *vice versa.* In the melt of the high-sulphur pig with pitch coke shown in Fig. 5[2] the carbon rose from 2.55 to 3.91 per cent. with a sulphur decrease of 0.905 (0.970 to 0.065) per cent., whereas the same pig with R.H. coke decreased only 0.825 (0.970 to 0.145) per cent., with a carbon increase from 2.55 to 2.95 per cent. The relation between carbon equilibrium and ash is shown in Fig. 9[2], and that between the Mn × S constant and the total sulphur is shown in Fig. 10[2]. This Paper is much too long and involved to be presented in any further

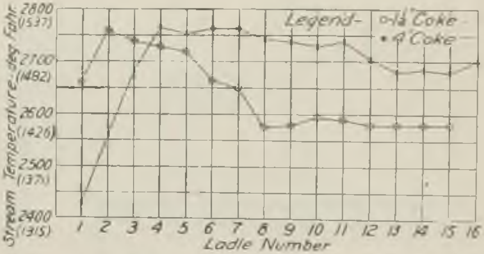

FIG. 12.—VARIATIONS IN TEMPERATURE IN HEATS OF LONG DURATION WITH VARIOUS SIZED COKES.

detail here, but it may be worth while to quote the conclusions:—

> "103. Different cokes have a considerable influence on the carbon of the molten iron. In general, the ash content is a large factor; but differences of 3 or 4 per cent. ash can be quite overshadowed by differences in the burning rate or other characteristics of the coke.
>
> "104. For ordinary cokes, the higher the temperature, the lower the carbon-equilibrium point. This probably is not true at either extreme of temperature, for pitch coke gives both high temperature and high carbon, while it is well known that a temperature low enough to cause oxidation gives low carbon. Whether

this is due to oxidation during melting, or to reactions with the slag, is not known to the writer.

"105. Some cokes did not give the same carbon, irrespective of the original carbon content for the number of melts tried. In other words, the tenth melt of a pig-iron still had higher carbon than the tenth melt of a steel charge. Some cokes, however, gave the same carbon on the fifth melt of both pig-iron and steel.

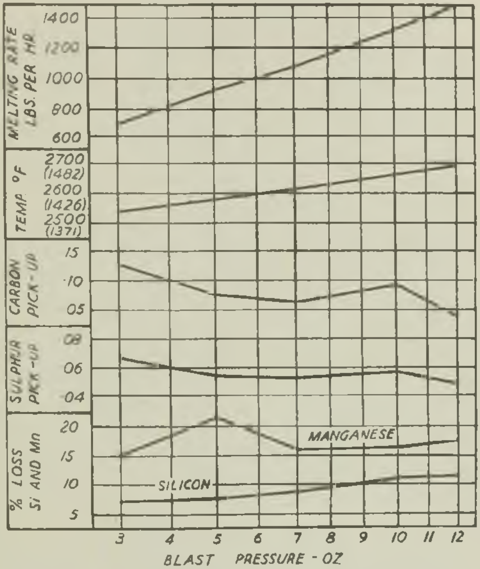

FIG. 13.—EFFECT OF BLAST PRESSURE ON MELTING OF PIPE SCRAP.

"106. The time for 130 deg. C. rise in the burning test was high on the coke giving the highest carbon (except for the pitch coke). It showed a minimum carbon at 2.6 min. There were not enough points on the curve to be sure of this.

"107. Sulphur increases with the sulphur of the coke, all other things being equal.

"108. Manganese has a strong influence on the sulphur, especially around a critical point which depends on the other constituents of the metal and on the sulphur and burning characteristics of the coke.

"109. The manganese-sulphur product tends to remain constant with a given coke. It is raised by ferro-manganese additions and increases with the temperature.

"110. Carbon and sulphur are mutually repellent. A high-sulphur iron is difficult to carburise and, on the other hand, a low-carbon iron absorbs sulphur readily.

"111. A coke which gives low carbon gives a higher sulphur absorption than one of the same sulphur content which gives high carbon."

The work for the Paper on coke size[4] was also carried out in a small cupola (18 in. dia.) using a fan blower. Fig. 11 shows the comparative results for some shorter heats, which, however, give undue prominence to the results of the first few taps. The comparative results for the largest and smallest cokes are shown in Fig. 1, which gives the results on melts of pipe scrap for each element on each tap.

Effect of Coke Size

Evidently the effects of size tend to fade out as melting proceeds, except in the case of carbon, and here it is not particularly important on carbons approximating to the equilibrium point. In the Institute of British Foundrymen's Paper,[1] 2-in. coke gave 2.50 per cent. carbon on an all-steel melt, as against 2.17 per cent. for a 4-in. coke. The temperatures are shown in Fig. 12,[4] which indicates again that oxidation and temperature are tending to counteract each other in the case of the carbon. No effects of blast were observed other than those accountable for by the changes in analysis.

TABLE VII.—*Repeated Melts, Charges A.B. Coke (10 per cent.), Charcoal Pig.*

Melt No.	Added		Blast pressure.	Temp. Deg. C.	C.	Si.	S.	Mn.	P.	Ti.	Chill.		Brinell.	Mod. of rupture.	Mod. of elasticity
	Si.	Mn.									Last white.	First grey.			
Orig.	—	—	—	—	4.13	1.26	0.011	0.57	0.51	0.02	—	—	—	—	—
1	0.00	0.00	9.6	1,400	4.01	1.16	0.035	0.48	0.49	0.02	0.01	0.00	153	34.7	7.8
2	0.20	0.16	9.9	1,407	3.89	1.27	0.052	0.61	0.50	—	0.07	0.03	162	36.2	9.2
3	0.20	0.16	10.0	1,400	3.78	1.39	0.067	0.66	0.50	—	0.14	0.06	174	41.3	9.3
4	0.20	0.16	9.9	1,419	3.70	1.36	0.084	0.59	0.50	0.02	0.17	0.10	180	43.2	10.8
5	0.20	0.16	10.3	1,394	3.64	1.41	0.083	0.68	0.52	—	0.21	0.12	188	46.4	11.1
6	0.20	0.16	9.8	1,419	3.58	1.49	0.087	0.63	0.49	0.01	0.23	0.15	201	48.0	11.9
7	0.20	0.16	9.8	1,413	3.57	1.55	0.094	0.66	0.47	—	0.30	0.16	212	52.8	12.6
8	0.20	0.16	9.3	1,413	3.44	1.61	0.103	0.63	0.49	—	0.24	0.15	212	54.2	12.8
9	0.20	0.16	9.0	1,403	3.42	1.66	0.101	0.68	0.50	—	0.25	0.15	215	52.2	13.2
10	0.20	0.16	9.6	1,407	3.40	1.64	0.101	0.60	0.49	—	0.35	0.23	221	55.8	14.3
11	0.20	0.16	9.8	1,419	3.33	1.74	0.099	0.73	0.52	0.01	0.20	0.12	225	54.2	14.7
12	0.20	0.16	9.9	1,442	3.34	1.64	0.114	0.58	0.52	—	0.40	0.24	225	54.6	14.7
13	0.20	0.16	9.6	1,428	3.27	1.74	0.120	0.64	0.51	—	0.26	0.14	221	53.8	51.1
14	0.20	0.16	9.9	1,430	3.24	1.70	0.120	0.57	0.53	—	0.29	0.20	220	58.4	14.0
15	0.20	0.16	10.4	1,410	3.20	1.70	0.117	0.52	0.52	—	0.30	0.23	222	57.6	14.0

Melt No. 10.0—O 05, N 0.013. Melt No. 15—O 0.014, N 0.007.

Effect of Coke Ratio

A few tests have been made on changes in coke ratio without other changes. These show that carbon and sulphur pick-up increase and manganese and silicon losses decrease as the coke is increased. A change from 25 to 35 per cent. of pitch coke on all-steel charges raised the carbon from 3.38 to 3.98 per cent., and the sulphur from 0.086 to 0.105 per cent. Manganese and silicon were added as rich ferro-alloys, 80 and 50 per cent., so the results are not reliable, but apparently the effect is rather small on these two elements. Fig. 1[4] shows a very distinct gain in silicon when starting with a high bed using small coke, and silicon losses are commonly quite low when using high coke ratios of 12 to 16 per cent., but manganese, on account of its reaction with the increased sulphur, and due to actual volatilisation at high temperatures, tends to lose at a more nearly constant rate. If the blast be increased to give the same melting rate, an increase of coke scarcely affects the analysis at all.

The blast pressure (volume) has also been investigated. It has been observed for some years at the author's foundry that relatively enormous changes in driving rate can be made without any significant changes in the charge and the composition of the melted iron; for instance, blast pressures of from 10 to 30 ozs., with a consequent change in melting rate from 15 to 25 tons without changing the charge, the coke ratio (except adjustment of the bed height) and with no resultant change in the analysis of the iron. In order to check this more accurately, the tests shown in Figs. 13 and 14 were run. The first material was a cast-iron scrap charge, and the second was a high-silicon steel cast into pigs for these tests. These were on a 21-in. cupola (with a positive-pressure blower), hence the relatively low blasts. By far the most important effect was on the temperature, although the manganese and silicon losses increased slightly and the sulphur pick-up decreased slightly with increased blast. The carbon lost slightly on the 3.40 per cent. carbon scrap and gained slightly on the low-carbon (0.65 per cent.) steel. Probably increase in oxidation tends to reduce the carbon, but the increase in temperature prevents it.

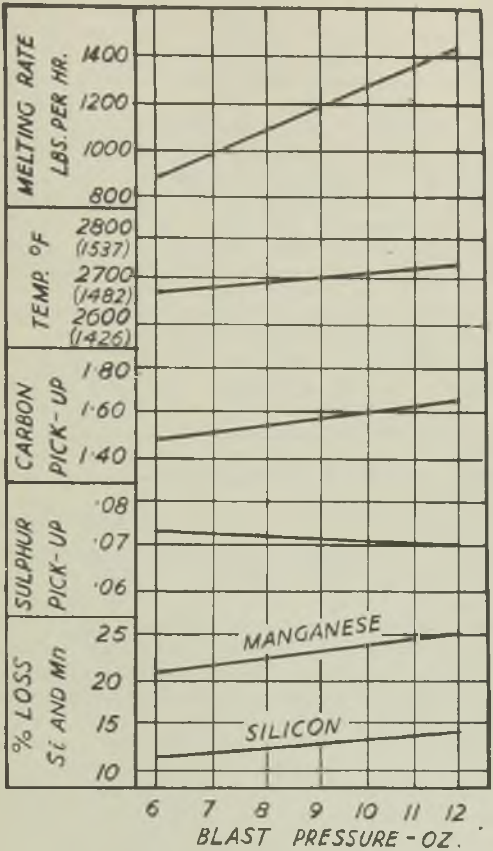

Fig. 14.—Effect of Blast Pressure on Melting Silicon-Steel Pigs.

Influence of Size of Steel Scrap

A great deal has been shown incidentally in the previous discussion, and especially in the details of the several Papers as to the effect of the composition of the charge. One test on size of steel[1] as charged may be of interest. Three sizes of steel scrap were melted, with results as shown in Table VIII. These tests were made with 4-in. coke which was somewhat too large for the 18-in. cupola but the results are interesting. Neither the large nor the small steel gave the best results for carbon pick-up, but the difference in sulphur is quite consistent. The silicon and manganese were again added as rich alloys and are only approximately indicative of what was going on. A personal view is that the large pieces of steel melted too slowly and reached so far into the bed that it was slightly oxidised, while the thinner material melted high but in such a number of small drops that it was oxidised on its downward path. The medium steel melted at the top of the normal melting zone and came down in large drops, thus escaping oxidation. The silicon outran the large pieces of steel, while the oxidation and high sulphur of the finer grades of steel used up the manganese of the melt. Certainly, the writer can testify that the melt from the fine steel was wild. The results of the test-bars confirm this, for bars from the thin steel were weak compared with the others, largely due to

TABLE VIII.—*Influence of Type of Steel Used as a Raw Material on Composition and Transverse Test.*

Load.	C.	Si.	Mn.	S.	Test-bar.	
					Load.	Defl.
					Lbs.	Ins.
3¼ in. round steel ..	2.18	1.38	0.40	0.097	4,100	0†31
¾ in. round steel ..	2.34	1.63	0.53	0.124	4,100	0.29
⅛ in. to ¼ in. strip ..	2.07	2.20	0.30	0.145	3,600	0.26

unsoundness. With fine scrap it is often economical to increase the bed height and coke ratio, which protects it from oxidation and pays by increasing the amount of molten iron recovered, saving of the lining, and generally increasing the smoothness of operation of the cupola besides giving a quiet melt and sounder castings.

It seems that there might be a difference in the carbon of the melt whether the charge of a given carbon content were made up of a uniform material like a special low-carbon pig or a mixture of high-carbon pig and steel scrap. To confirm this a cast was made of some 3 per cent. carbon pig (pig-iron + blown metal) and tests were made. The average result of two heats of 3 per cent. straight pig and 3 per cent. mix (25 per cent. steel and 10 per cent. cast-iron scrap) gave 3.27 per cent. C for pig-iron and 3.32 per cent. C for the mixture. The sulphur showed the same on both—0.035 per cent. pick-up; the manganese loss was 11 per cent. (of 0.75 per cent.) for the pig and 17 per cent. for the mix; and silicon lost 0.09 per cent. out of 1.60 per cent. for the pig and 0.23 per cent. on the mix. These results are the average of five heats on each mix on the 72-in. by 102-in. cupolas, each representing about 250 tons.

This Paper is submitted to the Institute of British Foundrymen with the best wishes of the American Foundrymen's Association and the hope that it will help to clarify some of the ideas as to what happens in the cupola. The statement of complicated inter-reactions given in the first part is not meant to frighten the beginner but rather make him pause before arguing from some one law of physics or chemistry to the exclusion of so many others—a fault too common with young technical graduates. There are, as has been shown, many compensating reactions, otherwise cupolas could not be run so successfully on an entirely empirical basis as they have been for many years.

It is important to remember that, to the human mind, even three or four simultaneous variables are bewildering, and the only real answer in cupola practice is the result obtained with the materials and equipment available.

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COPPER IN CAST IRON

Paper No. 638

By A. J. NICOL SMITH, B.Sc. (Associate Member)

Introduction

This Paper records the results of experimental work which was carried out by the British Cast Iron Research Association on the influence of copper in cast iron. The author wishes to express his thanks to the Council of the Association for permission to present the Paper and to his colleagues on the staff for their assistance in the work recorded.

When this investigation was initiated, the literature on the subject was in a very confused and contradictory condition. Thus, for example, Lipin[1] claimed that copper up to 7 per cent. increased the fluidity of cast iron, while Hamasumi[2] concluded that copper was without effect. The addition of copper was said by Lipin and Boegehold[3] to increase chill; Spencer and Walding,[4] Söhnchen and Piwowarsky,[5] Stead[6] and Hamasumi found no influence of copper on this property; Smalley,[7] Donaldson,[8] Rolfe,[9] Pfannenschmidt,[10] Hurst,[11] Hotan,[12] Long and Maclaren[13] decided that copper acted as a graphitising agent, while Taniguchi[14] decided that the depth of chill in iron rolls decreased up to 4 per cent. copper, but increased with copper beyond that percentage. Similar contradictions are evident in the work on the solubility of copper and in other properties, such as wear resistance. It was generally agreed, however, that additions of copper increased the hardness and strength and the corrosion-resistance of cast iron. Gregg and Daniloff[15] had recently summarised and correlated most of the available information on the subject, and while in some connections the position was clarified, yet in others the conflicting nature of the published information was emphasised.

It was thought that most of the confusion in the literature arose because most investigators had experimented with only a limited copper addition and often only on one base iron. It was decided that this investigation should first deal with the addition of relatively widely-spaced additions of copper to a series of base irons covering a wide range of composition, previous experience having shown the difficulties of drawing accurate metallurgical conclusions from experiments on a limited range of compositions. The first part of this report therefore deals with the preliminary investigation. This is followed by a second part which deals in greater detail with the influence of smaller quantities of copper on a more limited range of base materials, covering approximately the engineering irons of the present day.

Manufacture of Irons

The irons used in the preliminary investigation were made from Swedish white iron or hematite with additions of steel, ferro-alloys, nickel " F " shot, etc. In each case a 50-lb. charge was melted in a natural-draft coke-fired crucible furnace. After a set of bars had been cast, copper was added to the melt and stirred in. The crucible was then reheated for a short period and a second set of bars cast. More copper was added and the procedure was repeated. By this method five sets of varying copper content were obtained from each charge. The set of bars consisted of one bar each of 1.2 in., 0.875 in., 0.6 in. and 0.4 in. diameter, each 16 in. long. The bars were moulded in green sand, two to each box, and were cast at an angle between 20 deg. and 30 deg. to the vertical. Electrolytic copper in lumps of approximately two ounces weight was used for the copper additions.

The Alloying of Copper

Copper is a metal less readily oxidised than iron and melting at 1,083 deg. C. It is of greater density than iron. There is a negligible loss by oxidation on adding copper to cast iron, and reasonably large ladle additions, *e.g.*, up to 3 per cent. of copper, are possible. Provided that the melt is properly stirred to prevent segregation of liquid copper as a bottom layer, there is no difficulty in the alloying of copper.

Analysis of Bars

The analyses of irons made in this preliminary investigation are shown in Table I. The heavy drop in total carbon and in silicon shown in series A235 to A239 was due to improper melting. The steel of the charge was not dissolved in the melt when the earlier bars were cast. The results given for the irons of series A240-244, A245-249, A300-304 and A305-309, are estimated analyses, while all other results are actual analyses.

Influence of Copper on Chill

The fractures of the test-bars, which from their variation in size constitute a sensitive chill test, show that the early additions of copper tend to graphitise the iron and to break down cementite. This action continues up to a copper content of about 3.5 per cent. With additions of copper in excess of this value, there is a reversal of the behaviour of copper and the chill increases as the copper content rises. This is well shown in Fig. 1, which shows the fracture of the series of bars A225-A229.

This effect of reversal of chill may be due directly to the copper or it may be an indirect effect due to reheating or some other cause, or it may be due to a diluting effect of copper present in excess of the solubility limit. To throw light on this question, some small melts were made and cast into dry-sand wedges. The charges used and the depths of chill obtained were:—

(1) Hematite + 15% steel + 0% Cu – $\frac{15}{32}$ in. chill.
(2) Hematite + 12% steel + 3% Cu – $\frac{3}{32}$ in chill.
(3) Hematite + 7% steel + 8% Cu – $\frac{3}{32}$ in. chill.

This inverse variation of steel content with copper content was designed to keep the dilution of the hematite constant and under these condi-

TABLE I.—*Composition of Experimental Bars.*

Bar no.	Analysis. Per cent. 1.2-in. bars.						
	T.C.	G.C.	C.C.	Si.	Mn.		Cu.
A210	3.69	0.04	3.65	0.37	0.42	—	Nil
A211	3.43	1.39	2.04	—	—	—	1.76
A212	3.33	2.18	1.15	—	—	—	3.31
A213	3.25	2.11	1.14	—	—	—	4.61
A214	3.20	2.04	1.16	0.29	0.30	—	4.77
A215	3.20	0.04	3.16	0.27	0.41	—	Nil
A216	3.07	0.09	2.98	—	—	—	1.86
A217	2.84	1.58	1.26	—	—	—	3.50
A218	2.88	1.56	1.32	—	—	—	5.41
A219	2.85	0.16	2.69	0.23	0.32	—	7.42
A220	3.31	2.28	1.03	1.61	0.72	—	Nil
A221	3.33	2.34	0.99	—	—	—	1.62
A222	3.19	2.21	0.98	—	—	—	3.43
A223	3.16	2.14	1.02	—	—	—	4.72
A224	3.21	2.37	0.84	1.41	0.62	—	5.47
A225	3.07	1.57	1.50	1.32	0.70	—	Nil
A226	3.93	1.90	1.03	—	—	—	1.79
A227	2.88	1.81	1.07	—	—	—	3.55
A228	2.82	1.70	1.12	—	—	—	5.63
A229	2.77	1.82	0.95	1.13	0.56	—	8.85
A230	3.21	2.39	0.82	2.38	0.61	—	Nil
A231	3.12	2.28	0.84	—	—	—	1.25
A232	3.10	2.24	0.86	—	—	—	3.07
A233	3.02	2.28	0.74	—	—	—	5.41
A234	2.93	2.29	0.64	2.08	0.63	—	5.79
A235	3.21	2.37	0.84	2.79	0.78	—	Nil
A236	2.57	1.79	0.78	2.14	—	—	1.70
A237	2.47	1.65	0.82	—	—	—	3.74
A238	2.24	1.59	0.65	—	—	—	8.19
A239	2.15	1.63	0.52	1.75	0.57	—	12.13
A240	3.7	—	—	0.4	0.4	1.5 Ni	Nil
A241	—	—	—	—	—	—	1.75
A242	—	—	—	—	—	—	3.50
A243	—	—	—	—	—	—	5.25
A244	3.4	—	—	0.3	0.3	1.5 Ni	7.00
A245	3.25	—	—	0.30	0.4	1.5 Ni	Nil
A246	—	—	—	—	—	—	2.0
A247	—	—	—	—	—	—	4.0
A248	—	—	—	—	—	—	6.0
A249	3.0	—	—	0.25	0.3	1.5 Ni	8.0

tions the chill has remained unaltered from 3 to 8 per cent. of copper. Evidence will later be brought forward that under normal casting con-

TABLE I.—*continued.*

Bar no.	Analysis. Per cent. 1.2-in. bars.						
	T.C.	G.C.	C.C.	Si.	Mn.		Cu.
A250	3.54	0.89	2.65	1.18	1.32	—	Nil
A251	3.47	2.23	1.24	—	—	—	1.79
A252	3.42	2.24	1.18	—	—	—	3.39
A253	3.11	2.23	0.88	—	—	—	4.99
A254	3.36	2.37	0.99	1.07	1.25	—	6.85
A255	3.13	0.25	2.88	1.32	1.63	—	Nil
A256	3.10	1.72	1.38	—	—	—	1.50
A257	2.95	1.80	1.15	—	—	—	2.72
A258	3.04	1.85	1.19	—	—	—	4.13
A259	2.76	1.75	1.01	1.12	1.37	—	8.48
A260	3.34	2.33	1.01	2.25	2.22	—	Nil
A261	3.26	2.28	0.98	—	—	—	1.15
A262	3.16	2.17	0.99	—	—	—	3.90
A263	3.16	2.05	1.11	—	—	—	4.58
A264	3.01	2.06	0.95	1.98	1.91	—	8.19
A265	2.83	1.86	0.97	2.17	1.98	—	Nil
A266	2.80	1.78	1.02	—	—	—	1.92
A267	2.79	1.68	1.11	—	—	—	4.06
A268	2.67	1.55	1.12	—	—	—	5.46
A269	2.57	1.46	1.11	1.94	1.82	—	7.02
A270	3.30	2.48	0.82	2.25	0.71	0.45 Cr	Nil
A271	3.21	2.49	0.72	—	—	—	1.92
A272	3.13	2.31	0.82	—	—	—	3.61
A273	3.07	2.35	0.72	—	—	—	5.28
A274	2.97	2.37	0.60	2.00	0.63	0.43 Cr	7.68
A275	2.79	1.91	0.88	2.50	0.79	0.54 Cr	Nil
A276	2.75	2.08	0.67	—	—	—	1.95
A277	2.66	1.92	0.74	—	—	—	3.68
A278	2.56	1.77	0.79	—	—	—	5.89
A279	2.60	1.78	0.82	2.23	0.58	0.44 Cr	7.14
A300	3.4	—	—	1.2	0.7	0.7 Mo	Nil
A301	—	—	—	—	—	—	1.75
A302	—	—	—	—	—	—	3.50
A303	—	—	—	—	—	—	5.25
A304	3.25	—	—	1.1	0.6	0.65 Mo	7.0
A305	3.1	—	—	1.3	0.7	0.7 Mo	Nil
A306	—	—	—	—	—	—	2.0
A307	—	—	—	—	—	—	4.0
A308	—	—	—	—	—	—	6.0
A309	2.8	—	—	1.1	0.5	0.65 Mo	8.0

ditions, copper dissolves up to a limit of 3.5 per cent. It seems reasonable to assume, therefore, that up to this percentage copper acts as a graphitising agent, while the reversal of chill beyond this percentage is an indirect effect due probably to dilution.

Effect of Copper on Graphite Size and Formation

The graphite size, as seen from the microstructure and from the fractures of the test-bars, is refined by additions of copper. In many cases where copper is present above the liquid solubility limit, *i.e.*, where there are globules of primary copper present in the microstructure, the graphite is found to be refined completely and is present as supercooled graphite. The probable explanation of this is that the globules of copper present collect and coat the slag particles in the melt, thus promoting supercooling.

Solubility of Copper

It was decided not to attempt to determine the equilibrium solid solubility of copper in cast iron, since the system is known to be very sluggish, which would make the determination difficult and since a knowledge of this figure would not be expected greatly to affect practical application. It was soon noticed, however, that there is what might be termed a "practical solubility," that is, a limiting amount of copper which can be added to cast iron without producing the characteristics of a duplex alloy.

Evidence, which will be detailed later, obtained from the Brinell hardness, the chill, microscopic examination, thermal analysis and heat-treatment results, combined to show that this limit of solubility of copper is at about 3.5 per cent. The value is little affected by rate of cooling, *i.e.*, by the section of the casting, nor is it changed noticeably by variations in the composition of the base iron, with the exception that in the presence of nickel, copper is somewhat more soluble. The influence of nickel is marked. The Mond Nickel Company's work indicates that the addition of every 1 per cent. of nickel in-

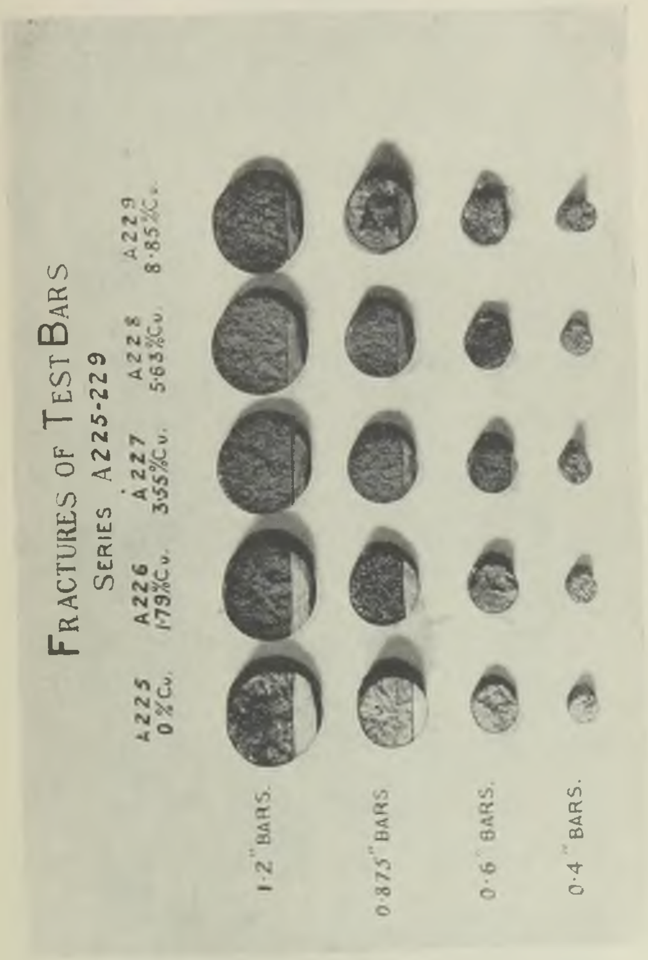
FRACTURES OF TEST BARS
SERIES A225-229
A225 0%Cu.
A226 1·79%Cu.
A227 3·55%Cu.
A228 5·63%Cu.
A229 8·85%Cu.
1·2" BARS.
0·875" BARS
0·6" BARS.
0·4" BARS.

Fig. 1.

creases the solubility of copper by 0.5 per cent. The figure of 3.5 per cent. copper given above refers to an iron free from nickel.

Heat-treatment tests with specimens of copper cast iron show that it is extremely difficult to precipitate copper from solution and equally difficult to persuade free copper present in the cast condition to enter into solution. The solution of copper is unlikely to be altered by any ordinary heat-treatment.

It must be emphasised that the figure of 3.5 per cent. given for the solubility of copper in cast iron refers to the amount which remains dissolved under ordinary casting conditions and not to the solid solubility under equilibrium conditions. The latter is probably much lower.

Influence of Copper on the Structure of Cast Iron

The introduction of copper into cast iron produces no marked changes in the microstructure. There is a refining action on the pearlite, a slight refining action on the graphite and in the lower carbon irons, a tendency to the formation of well-marked dendrites. By its graphitising effect, copper additions remove from the microstructure any free carbides that may be present, though copper does not tend to decompose pearlite.

No new constituent is introduced into the microstructure until the solubility limit is exceeded, when free copper appears. The free copper, which contains silicon, iron and possibly other elements in solution, occurs in two forms. What has been termed primary copper occurs in globules which are readily visible with the naked eye on the fracture or on a polished or machined section. These particles of copper are spheroidal in form and are entrapped as liquid copper when the melt solidifies. They are found on microexamination nearly always to contain a dove-grey inclusion which is probably manganese sulphide. Primary copper begins to appear in the structure of grey cast iron at a copper content of from 5 to 5.5 per cent., which may therefore be taken as the liquid solubility under normal conditions of casting.

There is also another form of free copper which may be termed secondary copper. This form occurs in particles which vary in size, but may be classed as microscopic. These particles begin to appear in the microstructure at a copper content of about 3.5 per cent. The exact figure is difficult to determine, since at reasonable magnifications the secondary copper is visible only as small black dots. Its first appearance is therefore not readily detected. In irons with a ferritic matrix, this copper is easily rendered visible by ordinary etching reagents. It was found, however, to be much more difficult to see in pearlitic irons, since most reagents brought out the pearlitic structure readily and thus disguised the copper particles. It was found, however, that a weak solution of iodine in alcohol (1 per cent. solution) was capable of revealing the copper without etching the pearlite. With this reagent the copper assumes the form of small dark dots visible at magnifications of 500 × to 1,000 ×. At high magnifications in the region of 1,500 × to 2,000 × it is possible to see the colour of copper in the particles.

The secondary copper begins to appear at a content of 3.5 per cent. and increases in amount until primary copper appears, after which the amount of secondary copper remains constant. It was thought that by quenching irons containing secondary copper from various temperatures, it would be possible to determine at what stage during the cooling the particles separated. It was found necessary to use a temperature of 1,100 deg. C. to effect the solution of the copper, and this indicates that on cooling the separation must be complete just below the solidus point of cast iron.

Effect of Copper on Mechanical Properties

Transverse Strength.—The test-bars were broken in transverse on 14-in. centres after most of the adhering sand had been removed and any

TABLE II.—*Moduli of Rupture and Deflections in Transverse.*

No.	1.2-in. bars.		0.875-in. bars.	
	Strength. Tons per sq. in.	Deflection. Inches on 14 in.	Strength. Tons per sq. in.	Deflection. Inches on 14 in.
A210	23*	0.07	27*	0.09
A211	25*	0.08	21*F	0.07
A212	26	0.12	30*	0.11
A213	25	0.12	24*	0.09
A214	21	0.10	25*	0.10
A215	30*	0.07	31*F	0.08
A216	28*	0.08	29*F	0.10
A217	23*F	0.09	23*F	0.09
A218	25*F	0.11	31*	0.13
A219	27*F	0.10	26*F	0.10
A220	23	0.15	25	0.20
A221	28	0.12	27	0.15
A222	26	0.15	30	0.18
A223	21	0.09	24	0.13
A224	25	0.08	27	0.12
A225	33*	0.09	24*	0.07
A226	27	0.10	31*	0.12
A227	21F	0.09	24F	0.12
A228	23	0.09	25	0.09
A229	18F_f_	0.06	32*_f_	0.12
A230	25	0.13	27	0.15
A231	26	0.13	26	0.13
A232	26	0.13	28	0.17
A233	24	0.11	29	0.11
A234	26_f_	0.08	23_f_	0.11
A235	27	0.17	27	0.19
A236	25	0.06	27	0.11
A237	26	0.10	—	—
A238	26_f_	0.09	29*	0.12
A239	25_f_	0.08	—*_f_	—
A240	24*	0.06	21*F	0.07
A241	24	0.08	30*	0.14
A242	25	0.11	26	0.13
A243	29	0.14	28	0.12
A244	29F	0.14	28	0.16
A245	31*	0.06	35*F	0.11
A246	25*	0.06	35*	0.09
A247	26	0.08	33*F	0.12
A248	24	0.09	24*	0.10
A249	—_f_	—	20*F	0.11

* Indicates that the fracture of the bar is either white or mottled.

Table II.—*continued.*

	1.2-in. bars.		0.875-in. bars.	
No.	Strength. Tons per sq. in.	Deflection. Inches on 14 in.	Strength. Tons per sq. in.	Deflection. Inches on 14 in.
A250 ..	26*	0.07	24*	0.08
A251 ..	28	0.13	30*	0.14
A252 ..	27	0.14	30	0.16
A253 ..	25	0.11	30	0.11
A254 ..	31*f*	0.12	33**f*	0.12
A255 ..	27*	0.04	26*F	0.05
A256 ..	30*	0.11	32*	0.11
A257 ..	29	0.12	30	0.11
A258 ..	26F	0.12	25F	0.10
A259 ..	30*f*	0.10	39*	0.15
A260 ..	29	0.14	33	0.17
A261 ..	29	0.14	29	0.16
A262 ..	26	0.12	29	0.15
A263 ..	28	0.10	30F	0.18
A264 ..	30*f*	0.11	39*F	0.16
A265 ..	30	0.10	32	0.14
A266 ..	28	0.11	34	0.15
A267 ..	29	0.11	33	0.11
A268 ..	26	0.10	31	0.13
A269 ..	30	0.11	36*	0.10
A270 ..	25	0.12	32	0.17
A271 ..	27	0.13	32	0.17
A272 ..	27	0.13	31	0.12
A273 ..	23	0.10	31	0.15
A274 ..	26*f*	0.10	38*f*	0.15
A275 ..	29	0.11	35*	0.14
A276 ..	30	0.11	32	0.11
A277 ..	29	0.10	31	0.09
A278 ..	27	0.10	29	0.08
A279 ..	24	0.08	33*	0.12
A300 ..	26*	0.07	31*	0.08
A301 ..	33	0.15	34	0.23
A302 ..	33	0.18	34	0.23
A303 ..	32	0.16	33	0.17
A304 ..	28*f*	0.13	22**f*	0.10
A305 ..	32	0.16	36*	0.17
A306 ..	35*	0.10	39*	0.09
A307 ..	35*	0.11	36*	0.08
A308 ..	26*	0.06	36*	0.11
A309 ..	37*F	0.12	46*F	0.16

F Indicates that there is a flaw in the fracture.

f Indicates that there is free copper visible in the fracture.

flashing ground off. The transverse results are given in Table II, where the strengths have been converted to moduli of rupture in tons per sq. in., and the deflections are given in inches on the 14-in. span.

The results show that copper has not a great influence on the transverse strength of grey cast iron. Its general tendency, however, is to give rise to an increase in this value with the first addition of copper, that is, in quantities of 2 per cent. or less. The strength tends to decrease with the appearance of free copper though the decrease is not so marked as entirely to prohibit the use of these materials. The influence of copper on the deflection in transverse seems somewhat random, although a decrease in deflection values occurs when free copper appears.

TABLE III.—*Tensile Test Results.*

(Specimens machined from the broken halves of the 1.2-in. bars.)

Specimen no.	Breaking load. Tons.	Diameter. In.	Breaking load. Tons per sq. in.	Transverse strength. Tons per sq. in.
A212	8.50	0.812	16.40	26
A221	7.55	0.798	15.10	28
A228	9.30	0.798	18.60	23
A229	7.40	0.798	14.80*f*	18F*f*
A232	6.90	0.798	13.80	26
A237	3.80	0.798	7.60F	26F
A243	9.95	0.798	19.90	29
A252	7.61	0.792	15.40	27
A257	9.07	0.798	18.14	29
A259	7.50	0.798	15.00*f*	30*f*
A261	8.96	0.798	17.92	29
A267	8.43	0.794	17.50	29
A272	7.60	0.798	15.20	27
A276	9.23	0.798	18.46	30

F Indicates that there was a flaw in the fracture.

f Indicates that there was free copper visible in the fracture.

The last column gives the transverse rupture stress on the bar from which the tensile specimen was machined.

Only a few tensile tests were carried out on these irons, in each case from a specimen machined from the 1.2 in. bars after breaking in transverse. The results are given in Table III, and they are insufficient to enable any conclusions to be drawn concerning the effect of copper on the tensile strength.

Influence of Copper on the Hardness of Cast Iron

Copper is a graphitising element and tends to break down any free cementite present in cast iron. It does not have any marked graphitising action on the carbide of pearlite and in this respect it resembles nickel. The addition of copper to irons containing free cementite results in the softening of the iron owing to the decomposition of this constituent. That is to say, white or mottled irons are turned grey and therefore become softer. The addition of copper to ordinary cementite-free grey cast iron, on the other hand, results in an increase in hardness. This is due to the solution of copper in the matrix. It is well known that increased hardness of this type does not give rise to appreciably greater difficulty in machining as does increased hardness of the type due to the presence of carbide or other hard constituent.

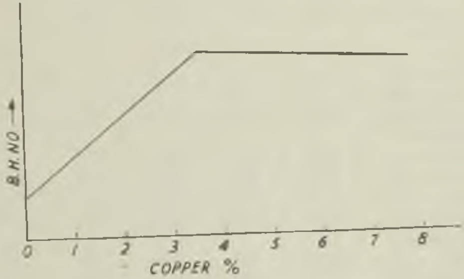

Fig. 2.—Influence of Copper on the Brinell Hardness of Cast Iron.

The hardness test results were taken with a 10-mm. ball and 3,000-kg. load, on flats ground on the sides of the 1.2-in. diameter bars alongside the transverse fracture and also on the

TABLE IV.—*Brinell Hardness Test Results* (30/10/3,000).

The 1.2-in. bars were tested on flats ground on the sides and on the centre of a cross section where the bars could be sawn.

Specimen.	A210	A211	A212	A213	A214
Hardness—					
Side ..	435*	356*	250	263	223
Centre ..	—	—	256	263	255
Specimen.	A215	A216	A217	A218	A219
Hardness—					
Side ..	388*	415*	380*	337*	406*
Centre ..	—	—	—	—	—
Specimen.	A220	A221	A222	A223	A224
Hardness—					
Side ..	200	239	234	255	248
Centre ..	167	190	215	211	215
Specimen.	A225	A226	A227	A228	A229
Hardness—					
Side ..	295*	246	275	283	268
Centre ..	—	226	272	268	252
Specimen.	A230	A231	A232	A233	A234
Hardness—					
Side ..	188	224	237	255	256
Centre ..	173	202	212	229	229
Specimen.	A235	A236	A237	A238	A239
Hardness—					
Side ..	197	225	293	283	272
Centre ..	167	235	280	282	256
Specimen.	A240	A241	A242	A243	A244
Hardness—					
Side ..	448*	208	240	256	257
Centre ..	—	186	223	239	241
Specimen.	A245	A246	A247	A248	A249
Hardness—					
Side ..	444*	467*	325	321	315
Centre ..	—	—	295	311	319

TABLE IV.—*continued.*

Specimen.	A250	A251	A252	A253	A254
Hardness—					
Side ..	429*	231	271	280	275
Centre ..	—	230	240	256	255
Specimen.	A255	A256	A257	A258	A259
Hardness—					
Side ..	368*	235*	297	286	319
Centre ..	—	—	285	263	283
Specimen.	A260	A261	A262	A263	A264
Hardness—					
Side ..	246	253	283	283	293
Centre ..	217	229	257	249	269
Specimen.	A265	A266	A267	A268	A269
Hardness—					
Side ..	259	285	315	309	315
Centre ..	245	250	298	300	302
Specimen.	A270	A271	A272	A273	A274
Hardness—					
Side ..	214	240	255	260	266
Centre ..	193	224	229	237	241
Specimen.	A275	A276	A277	A278	A279
Hardness—					
Side ..	249	268	295	280	274
Centre ..	228	268	277	269	269
Specimen.	A300	A301	A302	A303	A304
Hardness—					
Side ..	309*	266	302	385	313
Centre ..	—	253	—	—	—
Specimen.	A305	A306	A307	A308	A309
Hardness—					
Side ..	240	406*	441*	412*	319*
Centre ..	219	—	—	—	—

* Mottled or white fracture.

centre of a section of these bars where machinability permitted. The results are shown in Table IV.

The hardness increases with the copper content up to a value of about 3.5 per cent. copper.

The addition of copper beyond this percentage has very little effect. It actually causes a slight softening due to the appearance of a softer constituent, free copper. It will be seen that in general the influence of copper on hardness of cementite-free grey cast iron could be represented by a graph of the type shown in Fig. 2. This break in the hardness curve at 3.5 per cent. copper is part of the evidence that it is at this

Table V.—*Repeated Impact Tests.*

(Specimens machined from the halves of the 0.875-in. bars.)

Specimen ..	A220	A221	A222	A228	—
Blows ..	562	758	416	191	—
	415	678	540	—	—
Specimen ..	A230	A231	A232	A233	A234
Blows ..	327	518	725	267	230
Specimen ..	A235	A236	A237	—	—
Blows ..	384	365	—	—	—
	452	259	63	—	—
Specimen ..	—	—	A252	—	—
Blows ..	—	—	300	—	—
Specimen ..	—	—	A257	—	—
Blows ..	—	—	520	—	—
Specimen ..	A260	A261	A262	—	—
Blows ..	950	651	340	—	—
	548	1722	153	—	—
Specimen ..	A265	A266	A267	—	—
Blows ..	338	313	274	—	—
Specimen ..	A270	A271	A272	—	—
Blows ..	695	758	946	—	—
Specimen ..	—	A276	—	—	—
Blows ..	—	1043	—	—	—
Specimen ..	—	A301	—	—	—
Blows ..	—	5780*	—	—	—

* Indicates that the specimen was taken from the 1.2-in. bar.

figure that the solubility limit is exceeded and free copper first appears.

The difference in hardness between the centre and the edge of the bars does not decrease markedly with rise of copper content. Thus, although copper has the effect of equalising the hardness of thick and thin sections of a casting by graphitising thin portions and hardening the matrix of thick ones, yet it has only a small influence in equalising the hardness throughout thick sections.

TABLE VI.—*Influence of Heat-Treatment on the Hardness.*

(Hardness tests were taken with a 5-mm. ball and a 750-kg. load. In each case the figure given is the mean value for two or three tests.)

A.—Prolonged Treatment at 450 *deg. C.*

(Specimens air-cooled after each successive treatment.)

Treatment ..	A235	A236	A237	A238	A239
As-cast	172	239	264	280	269
After 30 min. at 450 deg. C. ..	165	242	279	276	264
After 1 hr. at 450 deg. C.	175	247	266	280	271
After 2 hrs. at 450 deg. C. ..	176	249	275	284	263
After 4 hrs. at 450 deg. C. ..	179	244	269	275	262

B.—Successive Treatments at Increasing Temperatures.

(Specimens air-cooled after each successive treatment.)

Treatment ..	A235	A236	A237	A238	A239
As cast	174	233	261	277	268
After 1 hr. at 400 deg. C.	162	236	262	276	263
After 1 hr. at 500 deg. C.	186	267	263	269	270
After 1 hr. at 600 deg. C.	168	256	255	263	251

Influence of Copper on Resistance to Impact

Several of the irons made in this investigation have been subjected to a repeated impact test.

The test is a modified form of the Stanton test. It was carried out on the halves of the 0.875 in. bars after they had been broken in transverse. The results of the test, given in Table V, show that copper present in moderate quantities of the order of 2 per cent. has a favourable influence on the toughness of grey cast iron. The test does not always give results that can be duplicated, but this is to be expected from the nature of the test, since it lies between a fatigue test and a true impact test.

The two sets of bars, A235-237 and A265-267, which show a decrease in impact value with the addition of copper, are both low total-carbon irons. Examination of their microstructure has revealed that the graphite exists in mixed areas of supercooled and flake graphite. It has been shown by Norbury and Morgan[16] that a mixture of supercooled and flake graphite in low total carbon irons gives rise to low and erratic impact values. It has not been determined whether the formation of patches of supercooled graphite in low total carbon irons is a characteristic of copper additions; whether it is due to reheating of the melt, or whether, as is probable, at any rate in the case of the series A235-237, it is due to steel dissolving in the melt during manufacture. Even should this prove to be due directly to the copper addition, it is unlikely to prove a serious handicap to the use of copper, as it apparently occurs only when the total carbon content has been lowered to the neighbourhood of 2.5 per cent.

It will be noticed that the considerable influence of copper on the impact value is enhanced by the simultaneous presence of chromium or of high manganese.

The mechanical results show in general that while copper additions cause an improvement in the quality of cast iron, particularly in the toughness, yet the best results are obtained by the substitution of copper for silicon or by the simultaneous presence of copper and chromium or of copper with a high manganese content. It is possible to estimate from a study of the test-bar fractures that the graphitising effect of copper is about equivalent to that of one-third of the quantity of silicon. This means that the chilling effect caused by reducing the silicon content by 0.5 per cent. could be counterbalanced by adding 1.5 per cent. of copper. It may therefore be estimated that simultaneous addition of 1.0 per cent. copper, together with 1.4 per cent. manganese or with 0.3 per cent. chromium should not affect the chill properties of an iron.

Precipitation Hardening of Grey Cast Iron Containing Copper

Heat-treatment tests have been carried out on the irons of the series A235-239 with the object of inducing precipitation hardening. The influence on the hardness of prolonged heat-treatment at 450 deg. C. and of successive treatments of one hour each at rising temperatures is shown in Table VI.

The results indicate that in iron **A236** with 1.70 per cent. copper, an increase of about 30 points in hardness is obtained. This is far less than is possible with the copper-containing mild steels and would not normally warrant the expense of the treatment.

To check the possible effect of a solution treatment prior to the precipitation treatment and of a longer time at higher precipitation temperature, it was decided to carry out further tests on A236:—

Treatment.	Brinell hardness number.	Average.
As cast	263, 262, 262, 260, 252, 262, 256	260
Tempered 4 hrs. at 530 deg. C.	268, 260, 257, 255, 252	258
Normalised 1 hr. at 850 deg. C.	236, 246, 241	241
Normalised and tempered as above . .	257, 260, 263	260

These tests were taken with a 10 mm. ball and 3,000 kg. load. The difference in hardness between the as-cast specimen and the figures for the similar state in Table VI are due to the fact that the specimens, through shortage of material, were taken from close to the ends of the bars. It will be seen that there is no increase in hardness following the tempering of the as-cast material, while the precipitation hardening of about 20 points Brinell following the solution treatment is just sufficient to compensate for the inevitable drop in combined carbon which occurs during the solution treatment.

It is concluded that the precipitation hardening possible in copper-containing pearlitic grey cast iron is insufficient to be of practical use.

Malleablising of Copper Cast Iron

Although no attempt has been made to investigate the effect of copper on malleable iron, yet it was thought worth while to attempt to determine the influence of copper on the breakdown of primary carbide during annealing. Accordingly the 0.4 in. bars of series A210-214 and A215-219 were heated in an electric tube furnace for a period of seven hours at a temperature of 900 deg. C. After cooling in the furnace the fractures of the bars were as follow:—

A210	White	A215	White.
A211	White	A216	Mottled (20 per cent. white).
A212	Black	A217	Black.
A213	White	A218	Mottled (10 per cent. white).
A214	White	A219	White.

This indicates that copper in small quantities accelerates the annealing of blackheart malleable and that the maximum effect is obtained in the region of 3.5 per cent. copper.

Dilatometer Tests on Copper-Containing Cast Irons

Dilatometer tests were taken with a Chevenard thermal analyser on specimens machined from the broken halves of the repeated impact specimens of the irons A230–A234. In all cases there is a large expansion at the *Ar* point, owing to graphitisation. This results in a permanent expansion of the specimen. Table VII gives the critical points and the values of these permanent expansions.

TABLE VII.—*Critical Points and Values of Permanent Expansion of Copper Cast Irons.*

Specimen no.	Cu Per cent.	Ac point heating. Deg. C.	*Ar* point cooling. Deg. C.	Permanent expansion. Per cent.
A230	Nil	785	685	0.280
A231	1.25	785	665	0.355
A232	3.07	775–785	670–660	0.395
A233	5.41	795–830	715–705	0.330
A234	5.79	830–890	735–700	0.230

A230 shows definite periods of stationary temperature at the critical points, and this is the case with A231. The other irons, however, show the critical points occurring over a range of temperatures. In the first specimen there is a contraction at the Ac point. With A231 there is merely a halt in the expansion. A232 continues to expand through the critical range, though the rate of expansion is less at this point. Specimen A233 gives a halt of the same type as in A231, while A234 resembles A230 in showing the usual contraction. The graphitising influence of copper as seen from the permanent expansion figures is in good agreement with that shown by the malleablising tests.

Electrical Resistance of Grey Cast Iron Containing Copper

The electrical resistance of several sets of bars was determined on the repeated impact pieces before the notches were cut. The results were not sufficient to enable any break at the solubility limit to be detected, but the general conclusion was reached that the addition of copper lowers the resistivity of cast iron.

SECOND PORTION OF THE INVESTIGATION

It was felt at this stage that most of the useful information had been obtained from the materials so far made, and that the information then available was sufficient to give a clear idea of the general effects of adding copper to cast iron Further work was therefore directed to determining the influence of smaller quantities of copper on a smaller range of irons more comparable with those in general engineering use.

Addition of Copper to Cupola-Melted Irons

By the courtesy of one of the members of the B.C.I.R.A. the author was able to make additions of copper to cupola-melted metal. The metal was tapped from the cupola into 5-cwt. ladles, from each of which a quantity of 1 cwt. was tapped into a handshank containing the alloying addition. From each shank so treated was cast a set of bars comprising one bar each of 0.6, 0.875, 1.2 and 2.2 in. dia., all 21 in. long. The moulds were of green-sand. The analyses of the bars are given in Table VIII, while the mechanical results are in Table IX.

TABLE VIII.—*Composition of Cupola-Melted Copper Cast Irons.*

No.	T.C. Per cent.	Si Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.	Cr. Per cent.	Cu. Per cent.
1	3·29	1·94	1·27	0·121	0·41	0·15	0·02
2	—	—	—	—	—	—	0·24
3	—	—	—	—	—	—	0·55
4	3·25	1·99	1·28	0·128	0·41	0·16	0·58
5	—	—	—	—	—	—	0·87
6	—	—	—	—	—	—	0·96
7	3·29	1·91	1·26	0·126	0·41	0·14	1·25
8	—	—	—	—	—	—	1·41

Addition of Copper to Crucible-Melted Metal

A series of melts was arranged to cover the range of compositions from 2.7 to 3.5 per cent.

Table IX.—*Mechanical Properties of Cupola-Melted Cast Irons.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.				Tensile strength. Tons per sq. in.	Brinell hardness. 10/3000.	Repeated impact blows
		2 2 in.	1.2 in.	0.875 in.	0.6 in.			
1	1,340	22.5	27.5	25.9	31.4	16.10	227	—
2	1,330	22.0	29.5	20.9F	24.3	15.42	223	—
3	1,330	21.6F	31.0	28.1	28.9	17.24	230	—
4	1,330	22.2	29.7	20.0F	21.4F	13.06F	238	2,769
5	1,340	22.6	30.6	27.8	23.6F	15.44	241	5,781
6	1,250	22.4	31.8	20.1F	24.0F	15.38	237	3,060
7	1,330	21.5	27.9	27.3	29.0	14.98	236	2,987
8	1,310	23.9	28.3	30.7	31.7	14.62	239	—

F = Flaw.

total carbon and from 1.00 to 3.00 per cent. silicon with phosphorus contents of 0.3 and of 0.6 per cent. The metal was melted in an oil-fired crucible furnace, sufficient metal was taken into a shank to pour a set of bars of 0.6 to 1.2 in. diameter and also a fluidity test, a small wedge chill test, and a Jolley K-shrinkage test from the base metal. All the moulds were in dry-sand. One per cent. of copper was then added to the metal in the furnace and without reheating a further set of castings was made. A further 1 per cent. of copper was added to the furnace metal, making 2 per cent. in all. and another set of castings was poured. Finally, and still without reheating, a final 1 per cent. of copper to make 3 per cent. was added to the furnace and the final castings were poured. It was thus possible from each melt to obtain four sets of castings containing respectively 0, 1, 2 and 3 per cent. of copper. The temperature was taken at each pouring by means of a disappearing filament optical pyrometer which was frequently checked against a platinum—platinum-rhodium immersion pyrometer. It was possible to cast a fluidity test only on the first and third pourings, that is, with 0 and 2 per cent. of copper.

Throughout this series of tests the bars cast were 21 in. long. They were broken in transverse, however, on the centres laid down in the new standard B.S.I. specification; that is, the 1.2-in. bar on 18-in. centres, the 0.875-in. bar on 12-in. centres and the 0.6-in. bar on 9-in. centres. It was thus possible to obtain two results on each 0.875-in. bar and three tests on each 0.6-in. bar. The results on these bars are given as the average of the two or of the three results respectively, subject to the fact that fractures showing flaws were omitted from the averages.

The results of the mechanical tests, together with the analyses, are given in Tables X to XXV.

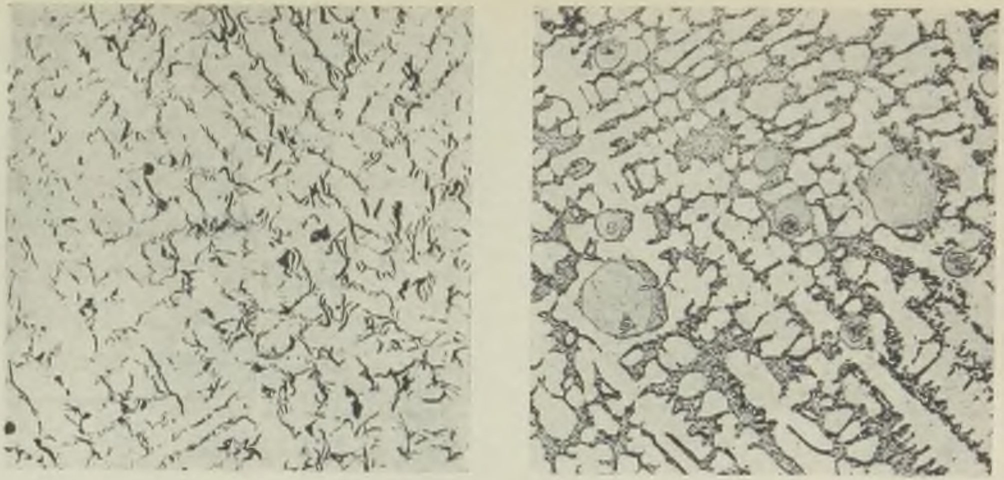

FIG. 3.—SPECIMEN A228.

FIG. 4.—SPECIMEN A229.

Structures of 1.2-in. bars showing the effect of primary copper in causing graphite refinement. Unetched. × 50.

Table X.—*Composition of Crucible-Melted Copper Cast Irons (Set A).*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
9	2.72	1.04	1.68	3.03	0.70	0.30	Nil
10	2.71	0.55	2.16	—	—	—	0.99
11	2.70	1.15	1.55	—	—	—	1.77
12	2.70	0.72	1.98	2.93	0.66	0.29	2.44

Table XI.—*Mechanical Properties of Crucible-Melted Copper Cast Irons (Set A).*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
9	1,410	23.5F	28.0	28.5	16.80	240	1,619
10	1,420	27.8	32.9	33.8	18.14	255	2,212
11	1,430	26.3	30.3	31.0	19.08	255	2,816
12	1,340	25.6F	29.0	30.4	17.98	263	1,640

F = Flaw.

Table XII.—*Composition of Crucible-Melted Copper Cast Irons (Set B).*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
13	3.02	1.00	2.02	2.73	0.81	0.70	Nil
14	2.99	0.70	2.29	—		—	1.08
15	2.85	0.68	2.17	—		—	1.84
16	2.88	0.78	2.10	2.58	0.78	0.61	3.03

F = Flaw.

Table XIII.—*Mechanical Properties of Crucible-Melted Copper Cast Irons (Set B).*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
13	1,320	23.8	30.3	30.4	12.96	231	669
14	1,300	26.2	29.3	30.9	14.86	246	978
15	1,260	24.2	27.6	27.1	11.80	247	632
16	1,250	18.1F	27.7	28.4	11.82	260	280

F = Flaw.

Table XIV.—*Composition of Set C.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
17	3.28	0.74	2.54	1.97	0.61	0.31	Nil
18	3.41	1.00	2.41	—	—	—	0.90
19	3.17	0.91	2.26	—	—	—	1.69
20	3.17	0.88	2.29	1.94	0.60	0.30	2.32

Table XV.—*Mechanical Properties of Set C.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
17	1,340	26.2	30.7	31.9	16.00	208	2,346
18	1,310	25.6	31.4	31.0	15.34	214	3,760
19	1,310	25.6	29.9F	33.3	16.78	225	2,650
20	1,310	29.1	33.8	33.9	17.68	241	1,980

F = Flaw.

Table XVI.—*Composition of Set D.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
21	3.25	0.85	2.40	1.98	0.45	0.59	0.08
22	3.24	0.85	2.39	—	—	—	0.70
23	3.29	0.84	2.45	—	—	—	1.35
24	3.23	0.87	2.36	1.98	0.49	0.58	1.70

Table XVII.—*Mechanical Properties of Set D.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000 on 1.2 in.
		1.2 in.	0.875 in.	0.6 in.		
21	1,250	23·3	24·1	31·5	11·84	219
22	1,230	23.2	18.4F	29.7	5.90F	222
23	1,250	22.7	26.8	33.3	9.82	231
24	1,230	17.4F	15.6F	22.3	10.20	217

F = Flaw.

Table XVIII.—*Composition of Set E.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
25	3.32	0.91	2.41	0.79	0.44	0.30	Nil
26	3.40	1.07	2.33	—	—	—	0.6
27	3.35	1.10	2.25	—	—	—	1.95
28	3.27	0.99	2.28	0.76	0.40	0.29	2.65

TABLE XIX.—*Mechanical Properties of Set E.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
25	1,320	25.4	35.4	—	14.42	190	831
26	1,310	26.1	30.3	33.9	14.06	209	1,734
27	1,320	27.1	28.2	33.8	14.66	229	1,810
28	1,330	29.1	26.9F	28.7	16.46	234	2,893

F = Flaw.

TABLE XX.—*Composition of Set F.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
29	3.23	0.89	2.34	1.25	0.54	0.33	Nil
30	3.13	0.81	2.32	—	—	—	0.82
31	3.13	0.82	2.31	—	—	—	1.78
32	3.09	0.84	2.25	1.17	0.46	0.32	2.43

TABLE XXI.—*Mechanical Properties of Set F.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
29	1,420	28.5	28.3	25.4	13.84	216	982
30	1,420	22.9F	23.9	33.6	12.42F	222	938
31	1,410	21.0F	28.5	29.7	16.10	236	1,449
32	1,380	24.2	30.3	26.9	15.20	232	1,699

F = Flaw.

TABLE XXII.—*Composition of Set G.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
33	3.00	1.15	1.85	1.25	0.34	0.63	Nil
34	2.96	1.05	1.91	—	—	—	0.88
35	2.93	1.00	1.93	—	—	—	1.54
36	2.90	1.02	1.88	1.19	0.23	0.63	1.97

TABLE XXIII.—*Mechanical Properties of Set G.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
33	1,360	31.1	32.0	32.8	14.10	224	1,316
34	1,370	26.3F	26.8F	30.4	14.66	227	1,612
35	1,370	25.9F	26.2F	29.8	14.78	231	925
36	1,350	17.9F	30.4	31.8	14.90	236	1,597

F = Flaw.

TABLE XXIV.—*Composition of Set H.*

No.	T.C.	C.C.	G.C.	Si.	Mn.	P.	Cu.
37	3.33	0.97	2.36	1.24	0.45	0.29	Nil
38	3.27	1.00	2.27	—	—	—	0.99
39	3.22	0.86	2.36	—	—	—	1.80
40	3.21	0.92	2.29	1.16	0.45	0.30	2.27

TABLE XXV.—*Mechanical Properties of Set H.*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.	Repeated impact blows.
		1.2 in.	0.875 in.	0.6 in.			
37	1,400	26.9	28.8	34.4	16.24	210	1,907
38	1,370	28.6	33.8	32.9	17.40	226	2,559
39	1,340	25.1F	27.6	30.8	15.96	226	1,727
40	1,320	22.4F	28.9	—	15.60F	231	1,701

F = Flaw.

In all the tests recorded in this report, the transverse results are given as transverse rupture stress or modulus of rupture, calculated by the usual formula: T.R.S. = $\frac{WL}{0.392d^3}$, where L is the distance between centres, W is the load in tons and d is the average diameter of the bar at the fracture. The hardness tests were taken on a flat ground on the side of the 1.2-in. bar close to the fracture. The tensile tests were taken on half of the 1.2-in. bar after breaking in transverse, these test-pieces being machined to 0.798 in. diameter. The repeated impact is of the Krupp-Stanton type and the specimen was taken from the centre portion of the 0.875-in. bar after the two transverse tests.

Influence of Copper on Mechanical Properties

The results of the mechanical tests recorded in the Tables above confirm the results of the first part of the report, in that the influence of copper on the transverse strength of cast iron is slight, but generally favourable. The tensile strengths are usually increased to a small extent by the addition of copper, while the repeated impact value shows a marked improvement with the first 1 to 2 per cent. of copper.

Influence of Copper on Hardness

The hardness test results show a definite increase in hardness with the addition of copper. This amounts on an average to an increase of 11 points hardness for the first 1 per cent. of copper and an increase of 21 points of hardness for the first 2 per cent.

Influence of Copper on Chill

The results from the chill wedges and from examination of the test-bars, which by their variation in section constitute a chill test, show that within the range of copper content studied in this portion of the report, copper acts as a graphitising agent. A study of the chill test results shows that copper as a graphitiser is approximately one-third as powerful as silicon. This is supported to some extent by the experiments on combined additions of copper with chromium and of copper with manganese, which will be reported later.

Influence of Copper on Fluidity

The fluidity test used was the spiral with a horn gate. In some cases the results of the fluidity tests were spoiled by differences in temperature of the metal when poured. This was the case with sets B, C and H. With the other

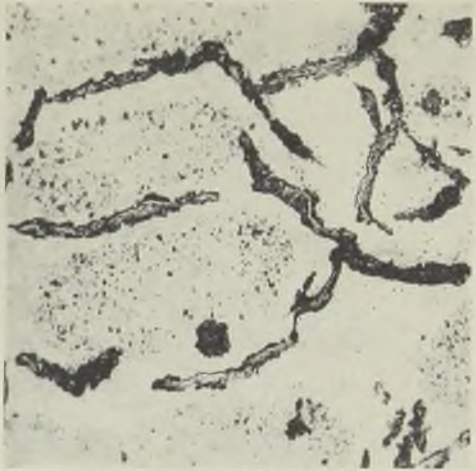

Fig. 5.—Specimen A228.

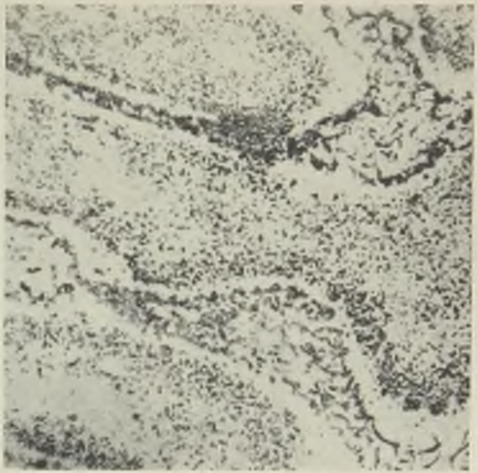

Fig. 6.—Specimen A229.

Etched with 1 per cent. iodine in alcohol to show the distribution of secondary copper. × 500.

sets, however, it was possible to obtain casting temperatures not differing by more than 10 deg. C. The results were:—

Set E.—Both fluidities of the same length.

Sets D and G.—Fluidity greater after copper addition.

Set F.—Fluidity greater before copper addition.

In the case of Set A, the fluidity was greater before the copper addition in spite of a temperature difference of 20 deg. C. in favour of the addition. These results have no exact relation to composition or to absolute casting temperature, except that the two cases D and G, where the fluidity is greater with copper, are irons of 0.6 per cent. phosphorus, while the others have 0.3 per cent. Also, the two sets A and F, which show less fluidity with copper, were cast at a comparatively high temperature.

TABLE XXVI.—*Composition of Copper-Chromium Cast Irons (Set Cu, Cr).*

No.	T.C.	C.C.	G.C.	Si.	Mn.	S.	P.	Cr.	Cu.
41	3.05	0.96	2.09	1.68	0.47	0.035	0.037	Nil	Nil
42	3.15	1.07	2.08	—	—	—	—	0.24	1.04
43	3.16	0.96	2.20	—	—	—	—	0.43	1.77
44	3.07	0.95	2.12	1.62	0.42	—	0.034	0.61	2.65

TABLE XXVII.—*Mechanical Properties of Copper-Chromium Cast Irons (Set Cu, Cr).*

No.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.
	1.2 in.	0.875 in.	0.6 in.		
41	27.2	28.3	27.8	15.6	198
42	34.0	33.9	33.6	17.1	223
43	31.7	34.2	32.6	18.8	241
44	32.4	34.6	34.6	18.4	265

Influence of Copper on Shrinkage

The Jolley K-test showed little variation with copper additions. A study of the whole series, however, leads to the conclusion that the first addition of copper decreases porosity, with the second addition the shrinkage is not markedly different from that shown by the base iron itself, though there is a tendency for the shrinkage to appear as a sink on the surface rather than as porosity. With the final addition of copper there is a recurrence of porosity, accompanied by sinking.

Combined Additions of Copper with other Alloys

It was shown in the first part of this Paper that combined additions of copper with manganese and of copper with chromium have a pronounced influence on the quality of cast iron. It was decided, therefore, to make some experimental melts in which a copper addition would be combined with an addition of each of the chilling elements chromium, manganese and molybdenum, in such a manner as to balance the effect on the chill. These irons were made in the same manner as the copper irons just reported.

Table XXVIII.—*Composition of the Copper-Manganese Cast Irons (Set Cu, Mn).*

No.	T.C.	C.C.	G.C.	Si.	Mn.	S.	P.	Cu.
45	3.07	0.84	2.23	1.92	0.56	0.029	0.034	0.03
46	3.07	1.01	2.06	—	2.02	—	—	1.12
47	3.07	1.12	1.95	—	3.60	—	—	2.37
48	3.07	1.14	1.93	1.75	4.88	0.025	0.043	3.36

Table XXIX.—*Mechanical Properties of the Copper-Manjanese Cast Irons (Set Cu, Mn).*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.
		1.2 in.	0.875 in.	0.6 in.		
45	1.375	23.8	26.4	25.7	14.2	205
46	1,355	26.4	26.2	31.7	16.8	237
47	1,320	27.0	33.0	30.5	17.2	293
48	1,305	25.2	24.1	17.6	15.5	347

It was, unfortunately, not possible to take temperatures at the time when the bars from this melt were poured. The fluidity test shows that the metal was more fluid before the addition of alloys, but this was almost certainly due to a temperature difference. The four chill wedges show that the first alloy addition gave a slight increase in chill depth. On the second addition the chill was the same as for the base metal, while for the third addition the chill was slightly reduced.

The pouring temperatures of this series of bars were taken with a platinum—platinum-rhodium immersion thermocouple. The fluidity tests, as would be expected from the temperatures, showed that the metal was less fluid after alloy addition. The chill wedges showed a constant degree of chill, indicating that this property remained substantially constant. It will be noted, however, that the figures for the combined carbon content of the 1.2-in. bar showed a continued rise with increase in alloy content. The mechanical properties show a marked improvement with the first two alloy additions, but there is a falling off in properties other than hardness with the final alloy addition, which has led to the formation of a partially martensitic structure.

Copper-Molybdenum Additions

The casting temperatures of this series were also taken with the immersion pyrometer. The fluidity tests show the metal is much more fluid before the alloy addition. The chill wedges show an increase in chill with increasing alloy content. indicating that the molybdenum to copper ratio was too high to keep this property constant. The first alloy addition does not give the increase in strength that would be expected from the 0.96 per cent. molybdenum present. The iron No. 51 has a tensile strength of 23 tons per sq. in. when the molybdenum content has risen to 1.89 per cent. The final metal No. 52 was martensitic in structure and unmachinable.

A further set of irons has been made by additions of copper and molybdenum to the same cupola metal used for the first series, Nos. 1 to 8. The bars were cast in green-sand moulds.

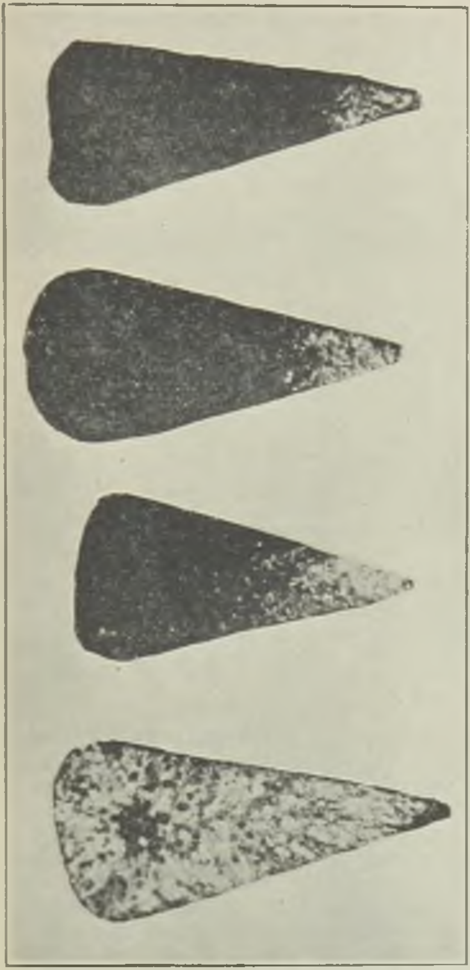

FIG. 7.—FRACTURES OF THE WEDGE TEST-PIECES FROM SERIES F (TABLES XX AND XXI) SHOWING THE INFLUENCE OF COPPER IN DECREASING CHILL. COPPER CONTENTS FROM LEFT TO RIGHT: NIL; 0.82 PER CENT.; 1.78 PER CENT., AND 2.43 PER CENT.

These results show, of course, the effect of increasing molybdenum content on a material of approximately constant copper content. They show that good strength results can be obtained by the addition and indicate that the simultaneous use of copper would enable molybdenum additions to be used without influencing the chilling properties of an existing foundry mixture.

The combined addition of copper with one of the chilling elements gives an easy method by which a foundry can make alloy additions to an ordinary good class iron without appreciably altering its casting characteristics and without being put to the necessity of adjusting the cupola charge to maintain a constant chill. Combined additions of copper and manganese give a rather large bulk of addition which, however, dissolves with surprising ease in fairly hot metal. The resulting alloy shows an increase in strength and hardness compared with the original metal; especially is this the case in respect of the hardness if sufficient alloy is added to

Table XXX.—*Composition of the Copper-Molybdenum Cast Irons (Set Cu, Mo).*

No.	T.C.	C.C.	G.C.	Si.	Mn.	S.	P.	Mo.	Cu.
49	3.23	1.05	2.18	1.69	0.55	0.042	0.038	Nil	0.02
50	3.10	1.10	2.00	—	—	—	—	0.96	0.77
51	3.01	1.54	1.47	—	—	—	—	1.89	1.85
52	2.78	1.60	1.18	1.54	0.49	0.036	0.031	2.85	3.18

Table XXXI.—*Mechanical Properties of Copper-Molybdenum Cast Irons (Set Cu, Mo).*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.			Tensile strength. Tons per sq. in.	Brinell hardness. 10/3000.
		1.2 in.	0.875 in.	0.6 in.		
49	1,280	26.6	26.8	24.5	14.4	198
50	1,240	22.3	31.1	35.8	16.4	240
51	1,260	39.5	29.0	40.3	23.0	298
52	1,240	38.3	35.5	31.9	*	409

* Test-piece not machinable.

bring the material towards the martensitic structure which is so hard as generally to be considered unmachinable.

The combined addition of copper and chromium is less in bulk than the copper + manganese addition, since chromium is a more powerful chilling agent than manganese. The addition is quite readily made, providing that the ferro-chromium is finely crushed. For a given copper content or for a given tensile increase, this addition is cheaper than the copper + manganese addition. It gives rise to increase in strength and hardness, the strength increase being of the same order as in the copper + manganese addition (comparison being made on the basis of the copper contents) while for the same strength increase the hardness rise is less pronounced, although still considerable. The mechanical properties of these irons are very good and there is no doubt that a combined addition of copper and chromium constitutes an effective and comparatively cheap method of

TABLE XXXII.—*Composition of Cupola-Melted Copper-Molybdenum Cast Irons (Set Cupola Cu, Mo).*

No.	T.C.	Si.	Mn.	S.	P.	Cr.	Mo.	Cu.
7	3.29	1.91	1.26	0.126	0.41	0.14	Nil	1.25
53	3.02	1.76	1.12	—	0.40	0.14	0.22	1.32
54	3.03	1.76	1.06	—	0.40	0.15	0.40	1.05
55	3.05	1.76	1.04	—	0.39	0.14	0.68	1.31

TABLE XXXIII.—*Mechanical Properties of the Irons Shown in Table XXXII (Set Cupola Cu, Mo).*

No.	Casting temp. Deg. C.	Transverse rupture stress. Tons per sq. in.				Tensile strength. Tons per sq. in.	Brinell hardness, 10/3000.
		2.2 in.	1.2 in.	0.875 in.	0.6 in.		
7	1,330	21.5	27.9	27.3	29.0	14.98	236
53	1,330	21.2F	31.2F	31.1F	19.5F	15.70	237
54	1,330	28.5	33.7	26.4F	31.5	17.28	255
55	1,330	26.6F	33.9	36.2	39.2	18.40	264

F = Flaw in fracture.

improving the strength and hardness of cast iron.

Microstructure of the 1.2-in. Bars

The microstructures of the irons mentioned in this section of the Paper show that, so far as copper alone is concerned, there is no effect on the microstructure beyond a refining action on the pearlite of the iron and to some slight extent on the graphite size. It was mentioned earlier in the Paper that no new constituent is introduced into the structure by copper, until the secondary copper begins to separate at 3.5 per cent. copper. The irons in this portion of the Paper do not exceed that figure.

The copper-chromium series show a definite refining of pearlite and graphite with increasing alloy content, and in the final bar of the series, No. 44, there is a little eutectic carbide present in the very broken fan shapes reminiscent of the appearance of chromium carbide in austenitic irons. The copper-manganese series show a refinement of pearlite following the first alloy addition. The second alloy addition gives an almost emulsified pearlite with areas, about 20 per cent. of the total, consisting of martensite. There are also present some massive carbides in occasional lumps. The final alloy addition of this series (Bar No. 48) contains a little more massive carbide in a mixed matrix consisting of about equal parts of very fine pearlite and martensite. The martensite in this bar is more acicular in type and finer than in the previous bar (No. 47), where the needles showed a tendency to have rounded edges.

The copper-molybdenum series (Irons 49-52) show that the first addition refines the pearlite and also produces some areas of ferrite containing rounded particles of carbide. As has been noted before in molybdenum irons, an increase in alloy content causes these areas to increase at the expense of the pearlite, while at the same time the carbide inclusions become more acicular. The third bar, No. 481, of this series consists almost entirely of this structure and also contains a little eutectic carbide of the fine fan-shaped type. The final bar of this series would be classed as definitely martensitic and the carbide particles are more numerous.

CONCLUSIONS

(1) Under normal casting conditions, the liquid solubility of copper in grey cast iron is about 5.5 per cent. Beyond this percentage, visible globules of primary copper are present. The equilibrium solid solubility has not been determined, but under normal casting conditions grey iron is capable of dissolving 3.5 per cent. of copper without the appearance of free copper in the microstructure. Above this percentage the free copper is present as dispersed microscopic particles termed secondary copper. These solubility limits are little affected by rate of cooling or by composition, except that the presence of nickel increases the solubility. In quantities less than 3.5 per cent. copper in grey cast iron behaves as if in solution, and this solution is comparatively stable to heat-treatment.

(2) In quantities up to 3.5 per cent. copper acts as a graphitising agent, being about one-third as powerful as silicon. Further copper beyond this figure reverses the effect and causes increase in chill, the effect being apparently due to dilution. No tendency to decompose the carbide of pearlite has been noticed.

(3) The hardness of grey cast iron is increased by copper dissolving in the matrix, although since copper acts as a graphitising agent it may simultaneously reduce the hardness by causing the decomposition of free cementite. In the absence of graphitising effect the hardness increase is about 10 to 11 points Brinell for each 1 per cent. of copper.

(4) The influence of copper on the transverse strength is only slight, but is favourable. The influence on the tensile strength is more markedly favourable than is the case with the transverse strength. The resistance of grey cast

iron to impact shows improvement with the first 1 to 2 per cent. of copper. In general, the mechanical properties reach their optimum values between 1 and 2 per cent. of copper.

(5) Precipitation hardening of pearlitic grey cast iron gives no results of practical importance

(6) Copper has little influence on the microstructure of cast iron. It causes refinement of the pearlite and of the graphite. Free cementite is decomposed, but no new constituent is introduced into the structure until free copper appears at 3.5 per cent. Copper in excess of the liquid solubility limit is capable of giving rise to supercooled graphite.

(7) Copper in quantities up to 1 per cent. improves grey cast iron from the point of view of shrinkage. With 2 per cent. copper the shrinkage is about the same as in the base metal, while with 3 per cent. the material becomes definitely worse from this point of view.

(8) The combined addition of copper together with one of the chilling elements manganese, chromium or molybdenum, results in improved hardness and strength. Copper with manganese gives a marked hardness increase, copper with chromium gives an all-round improvement, while an addition of copper + molybdenum allows molybdenum to be added to an existing foundry mixture without influencing the chilling properties. Additions of copper + manganese or copper + molybdenum are capable of giving a martensitic structure.

Comparison with other Recent Work

Since this investigation began there have been several contributions to the literature of copper in cast iron. Of these, perhaps the most important is the Paper by Eastwood, Bousu and Eddy[1'] on "Copper and Copper-Manganese Grey Cast Iron." It seems worth while making a comparison of this report with the finding of the present investigation.

(1) *Solubility and Hardness.*—The American report gives no direct consideration to solubility beyond a note that copper is effective

in increasing hardness up to 5.5 per cent., though the rate of hardness increase is less after 3.0 to 3.5 per cent. copper is exceeded.

(2) *Chill.*—It is found by Eastwood, Bousu and Eddy that copper has no influence on the chill of irons containing more than 2.0 per cent. silicon, though there is a very slight tendency to increase the chill of these irons when the copper exceeds 3.0 per cent. With a silicon content of about 1.75 per cent., copper up to 3.0 per cent. reduces chill slightly, after which more copper increases the chill. With a silicon content of 1.25 to 1.50 per cent., copper up to 4.0 per cent. reduces chill markedly, though when the copper exceeds 4.0 per cent., there is a slight increase in chill.

A study of the irons reported in this Paper, with these findings in mind, has not shown any confirmation of this effect of silicon. The reversal of chill noted by both Papers had apparently not previously been published except for a reference by Taniguchi.

(3) *Mechanical Properties.*—The American Paper differs from this present Paper in finding a slight adverse effect of copper on transverse strength, though both are agreed on the influence on the tensile strength.

(4) *Combined Additions.*—Both reports emphasise the good results to be obtained from combined copper and manganese additions, while this report also deals with copper-chromium irons.

This short comparison has noted only the main differences or important similarities between the two reports. In many points of detail they are in agreement. It is probable that many of the points of difference can be attributed to the differences in the tests used and in their interpretation. This, for example, is likely to be the case with the chill tests.

DISCUSSION

Mr. J. A. Reynolds commented that in austenitic cast iron, copper was very useful as a part substitute for nickel, and it behaved in the same way in many respects, but in using high percentages, say, 5 or 5½ per cent. of copper, even with a certain amount of nickel, there was a real danger, especially in machining or grinding thin sections, of work-hardening, and that must be guarded against.

He had found that the redundant scrap from a crucible nickel-alloy iron which contained copper was very useful as an alloy addition—he would not call it an inoculant—to cupola irons of the Ni-Tensyl type. The copper content was fairly constant, and it was a very desirable constituent in the iron. It did not increase machining difficulties, yet it gave a higher Brinell hardness and certainly a better and more even structure. In the higher-silicon ranges—although the effect was not very observable in the lower-silicon ranges—there was equalisation of structure and a slight softening.

Work-Hardening of Austenitic Irons

Mr. A. J. Nicol Smith, B.Sc., replied that the substitution of copper for nickel was coming to the front; it was difficult to say how far one could go in that direction, but he felt that it could definitely be done to a large extent. As Mr. Reynolds had said, it could be done very satisfactorily in an austenitic iron. The work-hardening properties of Mr. Reynolds' austenitic irons might not be dependent on the presence of copper; irons just above the austenite range often hardened considerably under work.

The results mentioned by Mr. Reynolds concerning the use of the scrap as an alloy addition were such as would be expected, and it was interesting to have confirmation from works practice.

Mr. Reynolds added that he had experienced the trouble of work-hardening when using the usual nickel-manganese austenitic non-magnetic iron. Copper seemed to be on the border line, but he would hesitate to express a definite opinion without making further experiments.

Mr. Nicol Smith said it was quite possible that copper was not quite so effective as nickel in forming austenite, so that when the one was substituted for the other the effect might not be absolutely the same. It might be equivalent to lowering the alloy content and thus increasing the liability to work-hardening.

Copper Additions and Economic Operation

Mr. A. J. Shore asked why copper was used at all. Why, he asked, should one sometimes use a copper-nickel-chrome alloy rather than a nickel-chrome alloy? Was it mainly a matter of economics, was the material improved sometimes by the use of copper, or could the same results be achieved by juggling with the nickel and chrome?

Referring to the copper manganese alloys mentioned by the author, he said he supposed the manganese was added in the cupola, so that the base metal was of a high manganese content.

Mr. Nicol Smith said one could juggle with nickel, copper and chrome and obtain a variety of results, depending on what was required. He agreed the ultimate test was one of economics.

The irons were crucible irons, and both the extra manganese and the copper were added to the ladle.

Mr. Shore asked whether the same improvement in mechanical properties would be achieved if one used high-manganese base metal from the cupola.

Mr. Nicol Smith said he did not see why not; he saw no reason to anticipate any bother.

Mr. Shore said that on occasion he had used an iron containing, roughly, carbon 3.4 per cent., silicon 2.25 per cent., phosphorus 1 per cent. manganese 0.5 per cent. and copper 3 per cent., and he asked what was the outstanding property of that iron, or what was the advantage of the copper there. He had an idea that it improved the resistance to corrosion or initial corrosion. The iron was used in connection with petrol pumps.

Corrosion Resistance

Mr. Nicol Smith could not say much about the effect of copper on the corrosion properties of the iron in which it was used; the results of the corrosion tests he had made were so indefinite as to be of very little use. Apart from the question of corrosion, he suggested that the outstanding property of the iron was that it was capable of being cast into a varied range of sections without developing chill edges on the thin sections or soft places in the thick sections; 3 per cent. of copper in an iron containing 2¼ per cent. silicon and 3.4 per cent. carbon would even up the properties throughout the sections very considerably.

The question as to why one sometimes used copper in iron, at other times copper-chromium and at other times nickel-copper-chromium was to some extent one of economics. Many people maintained that alloying was of no real benefit, because one could nearly always obtain with a straight iron properties similar to those of an alloy. But one did not always want to do that; it was very often far better to add a little alloy than to go to the trouble of running a special mixture. However, the question was really one for foundrymen to answer.

Mr. Shore said he was querying the substitution of copper for nickel rather than the reasons for using all the various alloying materials.

Mr. Nicol Smith said he believed that copper was substituted for nickel for economic reasons mainly. The effects of each of them were somewhat different. For example, copper alone did not tend to produce austenitic or martensitic structures, but it seemed able to help nickel in producing those structures.

Cupola Variations Eliminated

Mr. W. B. Sallitt, having congratulated the author on an extremely informative Paper, said that since copper was a graphitiser, it was natural, when adding copper, to reduce the silicon content of the iron to some extent. If this were done, one obtained an appreciable improvement in mechanical properties; whereas by means of simple additions of copper to cast iron, one did not effect much improvement in mechanical properties.

Referring to Table I in the Paper, showing the composition of the experimental bars, he said that in many of the melts there had been an appreciable drop in the carbon content between the first and last test-bar. He suggested that under such conditions chill was apt to be erratic, and he thought due weight should be given to this in any conclusions drawn regarding the effect of copper on chill.

An advantage of using copper was that it seemed to damp out the variation of chill from the cupola during a day's run, a matter of special importance for castings in which the chill had to be controlled very closely. In that connection he mentioned an experience concerning a camshaft, where the chill was controlled so accurately that the cam tips were white (without artificial chills) and the shaft was grey. The effect of reducing the silicon content to about 0.5 per cent. and increasing the copper content to 3 per cent. had been to render the chill of the iron much less subject to fluctuation.

Effect of Copper Dilution

Mr. Nicol Smith said he was inclined to agree that normally, when adding copper to an iron, one would tend to reduce the silicon content to below the original value, since the copper was a graphitiser. But it was very difficult to do that in a research test, and the only way to get at the results was to compare one set with another; it would probably be found then that the combined effect of the reduction of silicon and increase of copper was quite beneficial.

With regard to the losses in total carbon in each of the series of bars of which the compositions were given in Table I, he pointed out that much of that was necessarily due to dilution, since large quantities of copper were added. Undoubtedly, however, some oxidation had taken place. He had never been able to run a cupola all day in order to determine how far the chill varied, but he was glad to have the information given by Mr. Sallitt concerning the damping out of the chill variations.

Mr. Reynolds asked if the variations of chill referred to by Mr. Sallitt were those due to variations in cupola working.

Mr. Sallitt replied that they were.

Shrinkage Properties

Mr. A. Tipper, B.Sc. (Met.), in thanking the author for his Paper, and the British Cast Iron Research Association for having prosecuted the work, said that all the members of the Institute were definitely helped by such a Paper. Although the Paper and the work described covered a wide range of properties, that work could with advantage be extended.

The effect of copper on structure (dealt with under the heading of micro-structure) had been described and correlated with the physical properties, and was now fairly well established. However, another most important point was the effect on the shrinkage properties of the iron, and in that connection he had in mind particularly, castings of widely varying section. He asked whether the shrinkage tests carried out by Mr. Nicol Smith had given any definite indication that copper was really helpful, for it was known that nickel was helpful in this respect. Copper effected a slight refinement of the graphite and of the pearlitic structure, and seemed to be following the same lines as nickel. Was it right to assume that, if a casting was giving trouble with shrinkage, owing to varying section and difficulty of feeding, the addition of copper would help in the production of sound castings?

Commenting on the references made by a previous speaker to the effect of copper additions when making certain castings which were subjected to pressure, he said this seemed to suggest that the effect of the use of copper was to produce a denser iron, though not necessarily stronger than the porous metal.

Heavy Copper Additions Detrimental

MR. NICOL SMITH said he could not add to the statements he had made in the Paper concerning shrinkage properties of irons containing copper. The test he had used was the Jolley K-test. A difficulty, of course, was that any test used for ascertaining shrinkage properties did not necessarily represent the conditions in any one foundry or any one type of casting; the best that one could do in research was to use a standard test and hope that people would be able to draw conclusions from the results. Using the Jolley K-test, he had found that there was a definite improvement from the point of view of shrinkage troubles when copper was added to the iron; when 1 per cent. of copper had been added to an iron it had become more sound, less porous and had shown less tendency to sink than was the case without the copper addition. The effect of using a higher percentage copper, however, seemed to be somewhat retrograde. If one added about 2 per cent. of copper, the shrinkage test results were very little different from those obtained with the base iron, and the results obtained when 3 per cent. of copper was added were definitely worse than those obtained with the original base iron, there being more porosity in the centre of the "K" piece and more sinking at the top. At the same time, he felt, in that connection, that there was definitely a linking up of the effects of copper and silicon, that normally the addition of 3 per cent. of copper would enable the foundryman to reduce the silicon content by practically 1 per cent., and the reduction of the silicon content should have a very definite effect on the shrinkage. In other words, if the addition of copper were balanced by the reduction of silicon content, as it would be normally in foundry practice, he did not think the shrinkage effect would show up nearly so much. Under those conditions, he would suggest, up to 2 per cent. of copper would improve the shrinkage conditions.

An Ancient Iron-Copper Arrow-Head

Mr. S. Simpson mentioned, as a matter of interest, an arrow-head, containing copper, which he had had the opportunity of examining some years ago. It dated back to just about the beginning of the Christian era, and had been found by an ecclesiastic who was an archæologist and not a metallurgist, and would not allow it to be chopped up. However, it had been possible to analyse a quantity of about one-tenth of a gramme, and it was found to contain about 5 per cent. of copper; there was also some tin present. Although he (Mr. Simpson) had since dug on the site on which the arrow-head was found, he had been unable to find any more. He suggested that the early foundrymen who had produced the arrow-head had mixed some bronze with some iron; plenty of bronze spears and arrow-heads had been found, but only the one arrow-head made of iron which contained copper.

Mr. Nicol Smith said that that raised the question as to what would happen if there were pieces of bronze or brass in the copper scrap used in iron. He did not think there could be any doubt that the addition of zinc in the form of brass would not be of any great benefit to the iron, and probably one would have to control the chilling properties carefully if there were very much tin present. Apart from that, however, he did not think there should be very much trouble.

Impact and Fatigue Tests

Mr. G. L. Harbach, commenting on the author's reference to the improvement of impact value as the result of the addition of copper, and the point that the Stanton test lay between a fatigue test and a true impact test, asked whether tests had been made on the new machine which gave a single blow, for his opinion was that the results obtained with the single blow were far less erratic than the results of the Stanton test, and that the single blow test was likely to become popular in testing the properties of cast iron.

Another question he asked was whether, in ascertaining the deflections, the plastic were separated from the elastic deflections in cases where high impact values were obtained, and whether the high impact values were associated with a high proportion of plastic deflection.

Mr. Nicol Smith said that the Research Association hoped to say more in the near future concerning the single blow impact test it had recently developed. He had applied the test to some of the copper irons; he had not the results at hand, but, speaking from memory, the results were on the same lines as those of the repeated impact test. Improvement in impact value was obtained with 1 per cent. of copper, and sometimes with 2 per cent., but beyond 2 per cent. of copper the impact values decreased a little, though, so far as he could remember, they did not drop below the value given by the original iron. He had not reported the results of the single blow test in the Paper, because, in the first place, the test was not recognised by anybody but the Research Association at the moment, and, secondly, the test had been applied to only three groups of irons and not to a complete range.

He had not taken note of the plastic deflection as distinct from the elastic deflection. The figures given in the Paper represented simply the total deflections at fracture.

Mr. A. G. Harrison, commenting that the author had indicated the effects of copper additions to crucible-melted and cupola-melted irons, asked whether he had any data on the effect of adding copper in the furnace charge by means of copper scrap or in some other way, because with some of the other alloys there were marked differences in effect according to whether they were incorporated as ladle additions or melted with the charge.

Mr. Nicol Smith replied that he had no data at all of adding copper in any manner other than he had described in the Paper. But he had added copper as a crucible charge (melting it with the iron), and alternatively he had melted the iron first and had added copper just before pouring, but he could find no difference between the results obtained as between the two methods; and he saw no reason to suppose that there would be any great difference.

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Paper No. 639

THE MODERN MANUFACTURE OF MACHINE-TOOL CASTINGS

By J. BLAKISTON, A.I.Mech.E.

The object of this Paper is to present, in a manner necessarily brief, a survey of present-day practice and developments which are taking place in the production of machinable grey-iron castings for machine tools. Numerous valuable and interesting Papers covering such subjects as camber, densening technique and use of special irons have been written concerning machine-tool castings, indicating the numerous problems encountered and the endeavours made by the foundry to meet the rapid progress in the design and construction of modern machine tools.

Machine-tool castings vary in weight from a few ounces to 50 tons and over, the section varying in thickness from $\frac{3}{16}$ in. to 9 in. and over, with section variation of this order sometimes occurring in the same casting. Most machine-tool castings require to be machined internally in addition to externally, the machined faces of which remain exposed to view in the completed machine and must be free from all forms of defects and blemish. The machined faces not exposed are generally slide-ways, and in addition to being free from any form of defect must be close-grained, possessing good Brinell hardness value to resist wear.

Cast iron possesses many certain, definite advantages which, while making an ideal material to use for the construction of machine tools, preclude the likelihood of its being superseded by any other material, provided full advantage is taken of developments that are constantly taking place in its manipulation. The following are the outstanding properties of cast iron which commend it to the machine-tool manufacturers.

Ease of Casting to any Desired Shape

The various parts of a machine tool may be of extremely complicated shape and the present trend towards cellular construction with diagonal bracing (sometimes called the Allen system) makes the casting process the only economical way of producing these shapes. Taking the cost of the pattern and moulding tackle into consideration, each further unit made from the original pattern is necessarily cheaper. This advantage can be coupled with that of low production cost.

Low Production Cost

The cost of the castings, even when in alloy iron, is rarely more than 20 per cent. of the cost of the finished machine. This aspect should be given serious thought, for when so much time and labour is spent on the subsequent operations on the castings, a small increase in the first cost to produce a superior foundation material is justified.

Rigidity

This property is essential in a machine tool, as the accuracy of the work which it has subsequently to produce depends on its ability to retain its shape when subjected to varying stresses. Cast iron generally can be subjected to a stress equivalent to 80 per cent. of its breaking load without taking permanent set. This property is an advantage in the case of a machine receiving an abnormal violent shock stress, when a breakage may result in place of an undetected deformation or distortion, which would occur in a more ductile material. Attention has also been focused on the advantage of cast iron by the notable failure which has attended any attempt to replace iron castings by steel welded structures for machine-tool frames

Capacity for Absorbing Vibration

This is a very important property of cast iron, and has only recently come to the notice of machine-tool designers, mainly through the introduction of higher speeds occasioned by the use of modern cutting tools. The higher cutting speeds of the modern alloy carbide tool over that of carbon steel tools has resulted in an increase of stress repetitions by as much as twenty times.

The vibration absorption properties of metals can be measured by means of the Foeppl-Pertz machine, and the record traced by this machine gives a very graphic indication of the vibration damping properties of the materials so tested. Fig. 1 shows a record taken from this machine, and Fig. 2 shows the properties of aluminium (which has about the best vibration absorption properties), common cast iron, high-duty cast iron and mild steel. It will be seen from this chart that the stronger the iron, the less is the apparent damping effect. This would indicate that certain castings for machine tools, *e.g.*, trays, legs, supports in compression, should be made from softer cast iron on account of their extensive damping effect. This property has been dealt with in considerable detail in a Paper* read by Smalley.

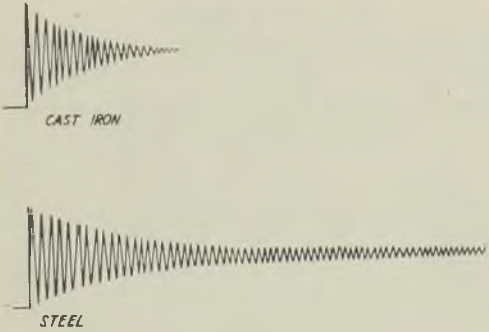

Fig. 1.—Foeppl-Pertz Diagram.

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* "Gear Castings with Special Reference to Cast Iron," "Foundry Trade Journal," July 22, 1937.

Low Coefficient of Friction

Cast iron is one of the few materials which forms a good bearing with itself in its natural or untreated form. This can be attributed mainly to the presence of graphite flakes. For bearing surfaces subject to high pressures, the introduction of nickel and chromium is found to assist materially.

The above are only a few of the advantages of cast iron. It is not proposed to detail such properties as machinability with high Brinell value, ability to take a fine finish, resistance to corrosion, etc., all of which are valuable properties of cast iron in the construction of machine tools.

Three Grades

Cast iron as used in machine-tool construction can be divided conveniently into three grades:—

TABLE I.—*Typical Percentage Compositions of Cast Iron Used in Machine-Tool Castings.*

	1.	2.	3.
Total carbon	3.3 to 3.5	3.0 to 3.2	2.9
Silicon* ..	1.1 ,, 2.5	0.9 ,, 2.25	2.0
Manganese ..	0.6 ,, 0.8	0.6 ,, 1.0	0.8
Sulphur ..	0.10	0.10	0.09
Phosphorus..	1.0	0.70	0.15
Nickel ..	—	—	1.2†

* Depending on section. † "Ni-Tensyl."

(1) General engineering cast iron (straight pig and scrap mixture, giving 1.0 per cent. phosphorus); (2) high-duty steel or refined iron mixture (medium phosphorus); and (3) low total-carbon alloy cast iron. Typical compositions of these three types are shown in Table I.

Properties of Machine-Tool Castings

The following is a brief description of the various properties to be expected from these irons.

(1) *General Engineering Irons (Phosphoric).*—This class of metal covers the type of iron used for machine-tool castings over a long period of

years, and, although termed phosphoric, is not to be confused with the higher phosphorus metal of the light casting industries.

Fig. 3 shows a typical photomicrograph of this class of iron. It will be noted that the graphite is medium-coarse in flake formation, with the matrix mainly pearlitic and the phosphide present as large areas in a coarse network. This class of iron still has many adherents, mainly on account of its fluidity and generally good casting properties. A characteristic of this iron is, however, that it tends to show rather open grain in heavy sections, with a low Brinell hardness value of the order of 140. Tensile strength value

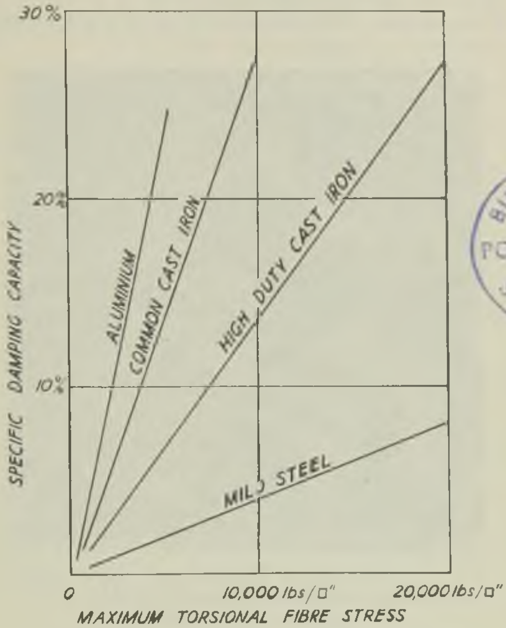

Fig. 2.—Vibration Absorption Capacities.

on separately cast bars, 1.20 in. dia., is of the order of 10 to 14 tons per sq. in.

To obtain a closer grain in heavy sections and so meet the present-day standards set for machine tools, densening is resorted to with reasonable success. The technique of the use of denseners as an aid to the production of machine-tool castings has been dealt with in a Paper by E. Longden. For the smaller medium-light section type of machine-tool castings, this class of metal still offers considerable scope, and good wearing properties are amply demonstrated by the fact that there are many machine tools still in operation after 30 to 40 years' useful life.

FIG. 3.—ORDINARY PHOSPHORIC CAST IRON. ETCHED PICRIC ACID. × 100.

(2) *High-duty Iron.*—A typical microstructure of this class of iron is shown in Fig. 4 at a magnification of 500. It will be noted that the graphite is present as short stubby flakes in rosette formation. The matrix is dense pearlite

with well-distributed small phosphide areas. This structure is taken from the centre of a heavy-section slide of an 8-ton casting, not densened in any way. A Brinell hardness value of 200 was obtained on the thickest section after machining.

The composition of this iron is T.C, 2.80; Si, 1.75; Mn, 0.70; S, 0.07, and P, 0.70 per cent. The carbon content is somewhat lower than is desirable for large castings; with a carbon content of below 3.0 per cent. there is a tendency to irregular camber and contraction, with a corresponding possibility of cracking. The tensile strength of this casting (cast-on test-piece) was 18 tons per sq. in. With high-duty iron densening is seldom resorted to, except to compensate violent changes of section or hot spots which occur through design. With these irons of medium-low carbon content, the presence of phosphorus up to 0.70 per cent., on account of its

FIG. 4.—HIGH-DUTY CAST IRON. ETCHED NITRIC ACID. × 500.

influence on the running properties, is permissible, and the closer appearance which it gives to the metal when machined outweighs its disadvantages.

(3) *Alloy Irons.*—The principal alloys used are nickel and chromium, the latter often being added to general engineering iron to assist in obtaining a satisfactory Brinell hardness value. Nickel is employed to give a combination of uniform structure in varying sections, together with fine grain and good wearing quality in the castings, whilst maintaining good machinability.

Fig. 5.—Alloy Cast Iron. × 500.

Considerable development has taken place in America in the use of alloy castings for machine tools. The silvery characteristic of the cast iron in American tools has often been commented on. The advantages of alloy cast iron for machine-tool castings is rapidly being recognised in this country.

The photomicrograph reproduced in Fig. 5 was taken from a typical modern nickel alloy cast iron as made by the "Ni-Tensyl" process. This iron lends itself particularly to machine-tool production, giving a tensile strength of 22 tons per sq. in. and upwards, with a Brinell hardness of 240 to 280, accompanied by good machining properties. As shown in the photomicrograph, the iron has a dense, fine structure, with fine graphite flakes embedded in an all-pearlitic matrix.

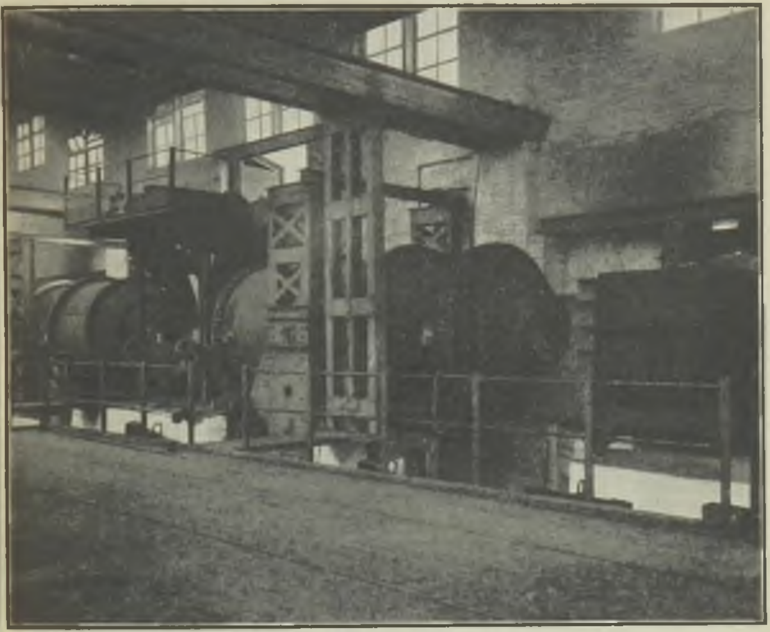

Fig. 6.—Brackelsberg Furnaces.

"Ni-Tensyl" is produced under British Patents 290,267 and 352,510, and is essentially a synthetic iron made up from steel scrap and alloy additions with suitable inoculation. This metal is suitable for a wide range of sections.

Melting Practice

The cupola is still, and is likely to remain, the principal melting unit for machine-tool castings, on account of its low melting cost, flexibility and ease of manipulation. With the introduction of high-duty and alloy irons more exacting furnace control is essential to achieve the required results, or difficulties will be experienced.

High-percentage steel mixtures are used, which tend to be more severe on cupola linings and, therefore, only first-quality furnace bricks and patching material should be used. The author prefers a lining built from bull-head bricks with their noses pointing into the centre of the cupola, and has found an increase in life of 20 per cent. over a lining made from similar bricks in block form Correct air volume and pressure control is essential to ensure clean, hot metal with maximum life.

For the melting of high-duty and alloy irons, coke consumption from an economic point should be a secondary consideration to that of being able to tap the metal at a satisfactory degree of superheat (1,450 to 1,500 deg. C.), and to achieve this the coke ratio is generally higher than the accepted figure of 10 : 1 excluding the bed. It has been found that high-percentage steel mixtures result in a high sulphur pick-up, and care should be taken to use only best-quality coke.

The Rotary Melting Furnace

This has made considerable progress during recent years, and a combination of the rotary and cupola furnace as a melting unit for machine-tool castings approaches an ideal combination, although where a wide range of casting sizes is being produced, the rotary furnace melting unit alone presents some disadvantages.

In the following remarks the type of rotary furnace concerned is the Brackelsberg (Fig. 6), burning pulverised bituminous fuel, which can be described as the long-flame type. This furnace, apart from rotating, tilts to an angle of 45 deg., so that it can be charged from a platform without the use of a charging machine. The rotary furnace is not a method for producing a cheap iron, but a means of producing a stronger metal, and facilitates obtaining iron with a low carbon content and/or desired alloy content. (The addition of alloys to the ladle is, in the opinion of the author, a practice to be deprecated, except for inoculation effects.) When producing machine-tool frame castings, it is inadvisable to attempt to use 100 per cent. scrap with alloy corrections, for, although the composition may be to the desired limits, an iron liable to crack, and with a tendency to hereditary oxidation, is

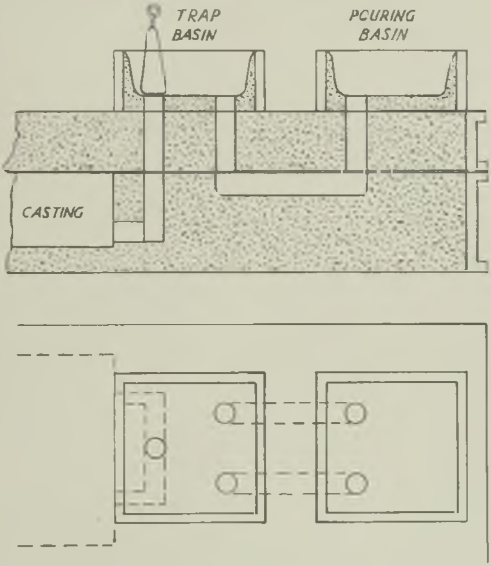

Fig. 7.—Trap Runner.

obtained. When making large castings, a minimum of 30 per cent. pig-iron should be used in the charges, also 30 per cent. of metal melted in a cupola should be added in the ladle to that tapped from the rotary furnace. This general rule should be followed whether duplexing or not.

Rotary Furnace Linings

The monolithic lining for rotary furnaces has presented difficulties to users of this class of melting unit. The general practice has been to reline the furnace entirely with a new lining every 100 to 150 heats with furnaces of 10-ton capacity. The following method has been found very satisfactory for lining this type of furnace when operating intermittently.

The casing is first lined with 4½ in. of common firebrick to form a backing. The furnace is then lined with first-class "ganister" by ramming round a former. This "ganister" is used with a free-moisture content of approximately 5 per cent., and is of the following composition:—

		Per cent.
Silica	SiO_2	86.0
Alumina	Al_2O_3	8.0
Iron oxide ..	Fe_2O_3	1.4
Lime	CaO	0.10
Magnesia	MgO	0.30
Potash	K_2O	0.12
Soda	Na_2O	0.38
Loss on ignition..	—	3.36

It will be seen that the silica content is not as high as is usual for rotary furnace linings.

The greatest wear on the furnace lining takes place during charging, and while the furnace and charge are being heated to the normal operating (melting) temperature, and the higher the silica content of the lining material, the greater the contraction and expansion range, rendering the lining more friable under mechanical shock.

"Ganister" with the stated silica content may not be so refractory for extremely high temperatures, but it will patch more easily, and can be maintained on similar lines to a cupola. A 10-ton furnace lined in this manner has given, up to the time of writing, over 300 heats without a major re-line. This type of lining is "active," meaning that the metal has not the tendency to stick to it and become oxidised.

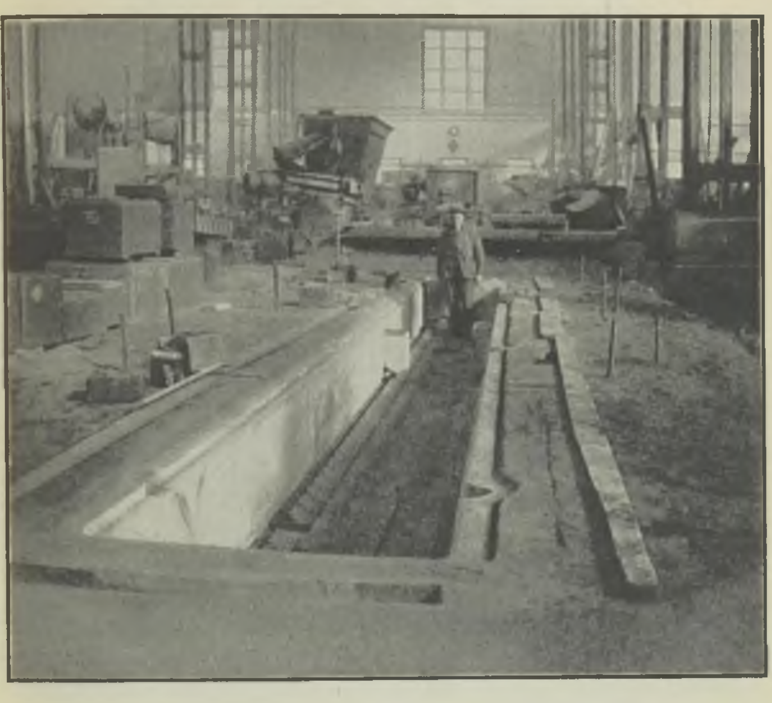

FIG. 8.—MOULD FOR PLANING-MACHINE CASTING.

This property compares with that of an air-furnace bottom which has to be made up with silver sand every twelve or so heats to keep it "active." To maintain this state in the rotary furnace, after every heat when the slag has been drained out, about 2 cwts. of sea sand is thrown in, while the furnace is kept revolving to distribute it evenly. This frits to the lining.

Melting Losses and Gains

Melting losses and gains of the various elements vary for each individual furnace and with the quality of coal used for firing. The greatest loss of silicon and carbon takes place when the metal charge is in a pasty state. At this period of the melt, it is possible to make any carbon additions necessary in the form of petroleum coke. The carbon is charged into the furnace, and the furnace is revolved so that the metal rolls on top of the carbon like a mat. The furnace is not continuously revolved until the metal is quite fluid. Silicon is added 20 min. before tapping, so that it also acts as an inoculant. The average metal losses may be allowed for as below, but these may vary with conditions, as previously stated:—C, −20 per cent.; Si, −28 to 30 per cent.; Mn, −14 per cent.; S, +0.004 per cent.; and P, no change or slight increase.

The following is the comparison of two large planing-machine tables cast from the same pattern, one from cupola melted metal and the other from rotary furnace metal. The physical tests were similar, both giving 17.0 tons per sq. in., with a Brinell hardness figure of 200 on the heavy section after machining. The metal was perfectly close at the bottom of deep T-slots. With low total-carbon rotary-furnace metal, the silicon range can be higher and to much wider limits, and still maintain close grain in heavy sections. When duplexing is carried out, the iron with the lower silicon content and any

Composition. Per cent.	Cupola metal.	Brackelsberg rotary furnace metal.
T. C	3.40	3.10
Si	1.20	1.5
Mn	0.54	0.80
S	0.117	0.07
P	0.78	0.40

alloy addition is melted in the rotary furnace, and the iron with the higher silicon content is melted in the cupola.

Moulding Methods

Nearly all machine-tool work is of a jobbing nature, and the numbers and size of some of the castings do not permit the general use of mechanical methods of moulding. Two main principles are observed:—Castings must be made with the " ways " to the bottom of the mould, and the casting must be run into the lowest por-

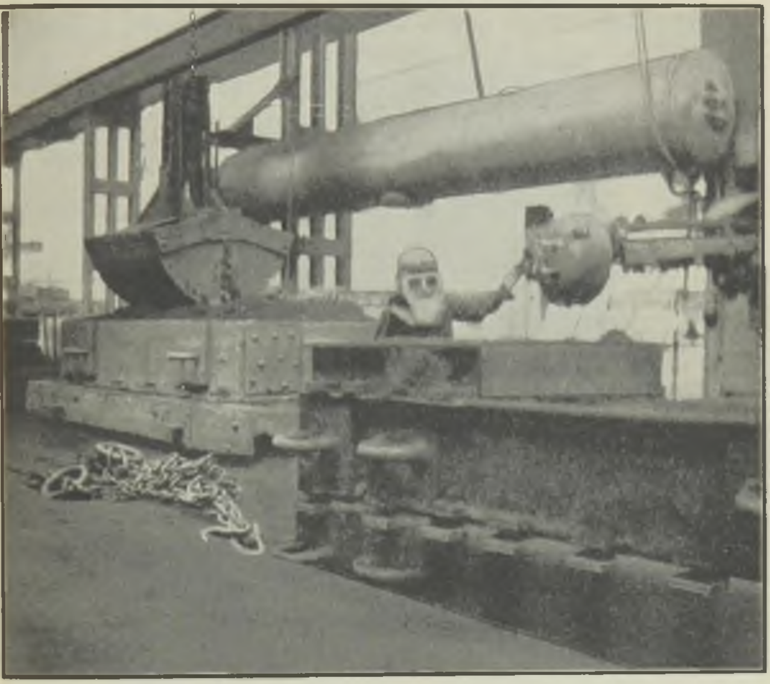

FIG. 9.—SHOCKLESS JARRING MACHINE AND SANDSLINGER.

tion, this being generally direct into the "ways." Metal perforated strainers are used on the smaller moulds, and trap runners are used on larger castings similar in construction to that shown in Fig. 7. In the moulding of large castings, the flats of the "ways" are strickled, the correct camber, which in some cases may be as much as 1½ in., being allowed for during this process. The pattern is then laid down on this bed, and moulding proceeds.

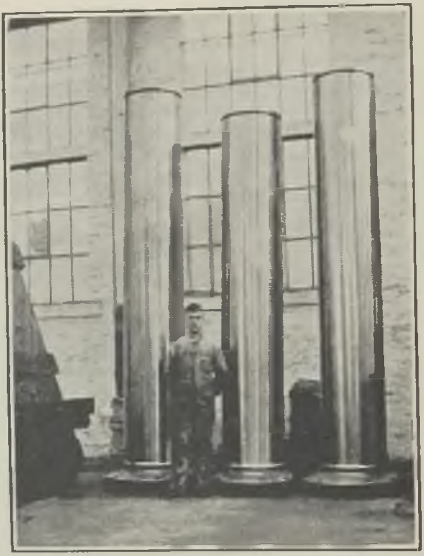

Fig. 10.—Drilling-Machine Sleeves.

Camber on machine-tool castings has been very extensively dealt with by E. Longden in one of his Papers entitled "Camber in Castings." The camber of any large casting should be recorded for future guidance, and even then it may vary with analysis variation. Fig. 8 shows a mould

40 ft. long ready to be cored up. In the background can be seen a travelling Sandslinger used for ramming the mould tops, and also a portable dryer. In a casting of this size, three or four of these dryers would be used simultaneously for its drying. The mechanical ramming aids for making these moulds are practically limited to the Sandslinger and the pneumatic rammer.

On medium routine work, jolting machines can be used to facilitate ramming. Fig. 9 shows an 8-ton shockless jarring machine which is used for preparing drags. The half or block portion is placed on a table and covered with facing sand. The drag is then placed in position and filled with backing sand by means of a grab operated by an overhead crane. After this mould has been jolted, it is turned over and placed under an adjacent Sandslinger, which rams the tops. The completely rammed mould is then passed to the moulders for pattern withdrawal and finishing, the mould being dried *in situ* by means of a portable dryer. Very good production times are achieved by this method, but it is only applicable for certain classes of work.

FIG. 11.—CORE BARREL MACHINE.

Refractory Materials

It is not proposed to discuss sands in this Paper, as these depend on the geographical situation of the foundry, but it has been stated that

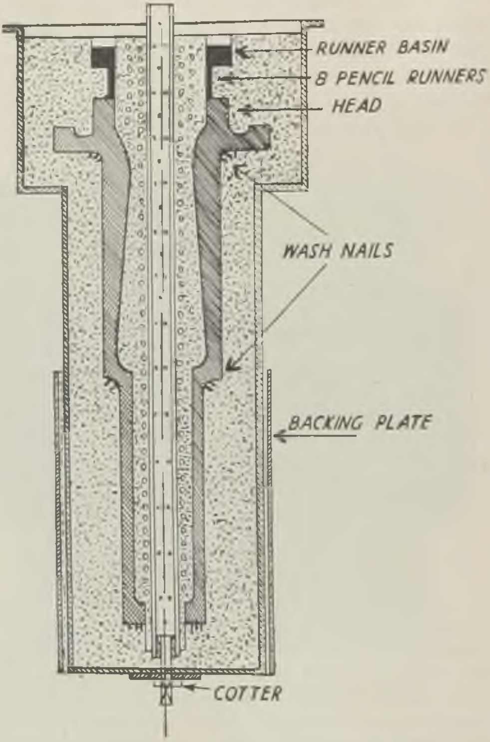

Fig. 12.—Mould for Drill Sleeve.

high-duty and alloy irons require to be poured at a fairly high temperature on account of their short freezing range. This calls for moulding sands that are refractory, or "burning-on," which creates considerable fettling difficulties,

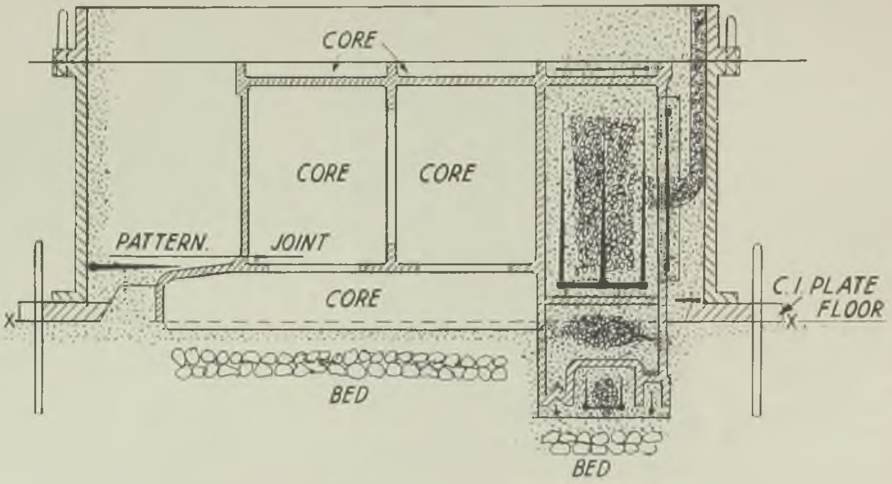

FIG. 13.—MOULD FOR GRINDING-MACHINE BED.

will take place in the heavier sections of the castings.

The following "compo" has been found very resistant to the action of hot metal, and can be applied on the thicker sections of a casting and in the vicinity of the runners:—One barrowful old firebricks; five shovelfuls of fireclay; five shovelfuls of sea sand; four shovelfuls of small coke; one bucketful of common blacking. These are milled, and water is added until the required fineness and degree of moisture for ramming is obtained. It can be let down still further with water and used in the place of loam for strickle work.

Drilling-Machine Sleeves

The following describes in more detail the methods of moulding a typical machine-tool casting, actually drilling-machine sleeves the weight of which may range from 5 cwts. to 12 tons; the largest casting would measure 15 ft. in length and 30 in. in diameter, and such a casting is shown in Fig. 10.

The core is made by means of a strickle sweeping up the loam on a steel barrel. These barrels are turned by means of a machine similar to a lathe headstock. A bar in front of the operator enables rotation of the barrel to be stopped and started at will. This method enables the winding of the straw rope, and the subsequent application of the loam, to be done with considerable rapidity. The barrel is driven by means of a square shaft in which a cotter hole is provided, which is also used for keeping the core barrel from lifting when it is in the casting position in the mould. The square end of this shaft fits the standard collet of a driving head on the core turning machine. This is shown in Fig. 11. The mould is made by jarring the bottom half on a jolting machine, the top half being rammed up by a Sandslinger.

Owing to the design of this type of casting, it is sometimes impossible to obtain a straight drop for the metal, and no matter where the runners are placed the metal will strike on either a shoulder of the mould or the core. Where this strike is likely to take place the mould is studded with metal studs for protection. These moulds are always run from the top by means of pencil runners situated round the core.

No feeding takes place, sufficient head being allowed on the casting for this purpose. Bottom running for this class of work is considered dangerous, as a cleavage line may be caused by the presence of blacking or dust when the metal is rising in the mould. This can be a source of undetected weakness in the casting. When top pouring is used, the surface of the metal is being constantly agitated, and so the possibility of cleavage lines is eliminated. Fig. 12 shows the completed mould in section.

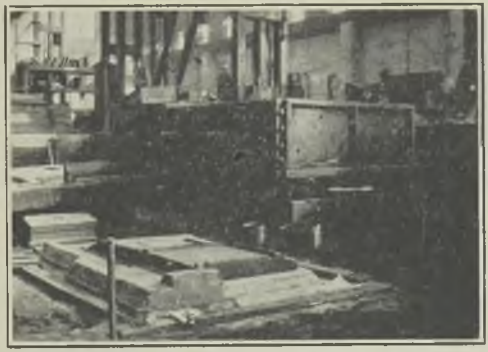

Fig. 14.—Mould Assembly for Grinding-Machine Bed.

Grinding-Machine Bodies

These castings are more or less of a standard type, irrespective of the make of machine, and three standard methods can be used for moulding these castings:—One is by using a plain pattern in the foundry floor surrounded by drawbacks. This, although an expensive method of moulding, does not require much tackle. The second is by means of a three-part box with two joint lines on the patterns. The initial outlay for tackle is considerable, but the whole mould is accessible and can be thoroughly dried in the foundry stove.

The third method which the author proposes to describe is achieved by using patterns with two joint lines similar to that for a three-part box, but in this case the ways to joint (X, X in Fig. 13) are bedded on the foundry floor. The main body of the mould is carried in a box by means of a shaped cast-iron plate 2 in. thick, which fits round the pattern within 2 in. all round. This plate, carrying what may be termed the middle portion, is guided by means of floor stakes. A top part is used, which is located on the middle part by means of pins. The mould is dried *in situ*, and can be assembled as the cores are built up. The intricate core operations round the ways which are built up from the floor are readily accessible, which is of considerable advantage. In this case there are approximately 57 cores. The metal sections are generally on the thin side. Adequate runners must be provided or some of the sections will be chilled and extremely hard to machine. Fig. 14 shows one of these moulds stripped prior to coring up.

Fettling Machine-Tool Castings

Fettling of high-duty and alloy castings presents additional problems over those manufactured from the softer irons. The iron, having a higher tensile strength, naturally requires greater manual effort to chip. Perhaps the most useful mechanical aid to fettling is the swing-frame grinder fitted with a high-speed grinding wheel. This is aided by the pneumatic hammer. Very often large heads and feeders have to be removed and these cannot always be struck off for fear of breaking in. It is usual to drill these risers transversely across the junction of the casting after which they can readily be removed. An improved finish and a subsequent aid to fine fettling on the castings can be obtained by means of a shot-blast plant.

Fig. 15 shows a casting for a 30-ton press body after being sand-blasted. This casting, on account of its thin sections coupled with high tensile strength, weighs only 34 cwt.

Design Considerations

It would not be fitting to conclude this Paper without reference to the design of castings to be manufactured from high-tensile cast iron. It is imperative that an even section be maintained throughout and that no hot-spots are created through the junction of too many ribs at one point. A transverse rib should be broken where it enters a right-angled corner by means

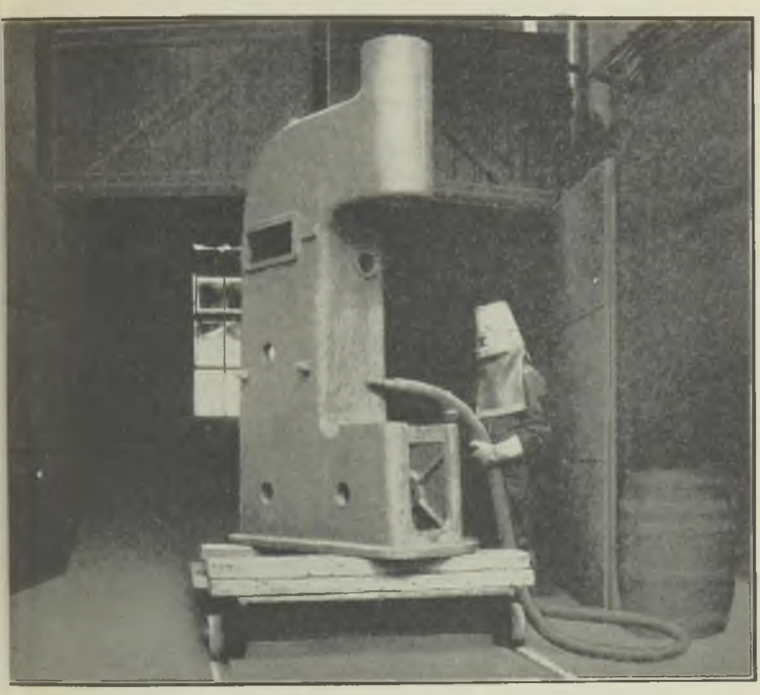

Fig. 15.—Press Body being Sand-blasted.

of a small round core. A casting is not always strengthened by thickening certain sections, as a reduction of tensile strength may take place through " mass effect."

When a draughtsman designs a casting he should also visualise the moulder's parting line and incorporate the necessary taper for stripping in his design. This not only will reduce the moulding cost, but does much to eliminate misshapen castings caused through excessive rapping or uncontrolled pattern taper applied by the patternmaker.

The author wishes to apologise for the briefness of the Paper, which attempts to outline a most comprehensive and difficult type of work, any sub-heading of which offers scope for a detailed treatise. Machine-tool moulding requires constant personal supervision to detail and probably has done much to enable the small jobbing foundry to survive these days of intensive competition on account of its working owner always being on the spot with a practical knowledge of the class of machine-tool casting on which he has specialised.

In conclusion, the author wishes to thank the directors of William Asquith, Limited, and Modern Foundries, Limited, for their permission and facilities for the writing of this Paper, and to Dr. A. B. Everest, of the Mond Nickel Company, and Mr. H. F. Poole, of Keighley Laboratories, for their suggestions and help.

DISCUSSION

Phosphorus Content for Machine-Tool Casting

The discussion was opened by MR. A. J. SHORE, who referred to the table (in the section of the Paper headed " Melting Losses and Gains ") comparing the compositions of cupola metal and Brackelsberg rotary-furnace metal, and pointed out that the phosphorus content of the cupola metal was 0.78 per cent., and the phosphorus content of the rotary-furnace metal was 0.40 per cent. He imagined that, unless borings or some material of that sort, were used in the

Brackelsberg furnace, the base iron was more expensive in that case than in the case of the cupola-melted iron. Yet the physical properties were said to be roughly the same, and he asked whether the example was given in the Paper to damn the rotary furnace, because it did not show up very well on the figures given.

Inoculation by Steel Sheet Additions

Discussing the inoculation of iron, he asked whether the author had had experience of adding steel to the ladle in the form of very thin sheet (not molten steel). It was his experience that as the result of adding 2 per cent. of steel at the bottom of the ladle (using 5 cwts. of iron), there was a definite improvement of the density or soundness of the thick sections, although there did not seem to be any particular reason for that improvement. The material used consisted of clean pressings, the waste from the press shop. It had a certain amount of fat on it, and it had been suggested that perhaps the improvement of properties of the castings was due to the fat " shaking up " the metal in the ladle.

The importance of design seemed so obvious, he continued, that it should not need comment; yet the improvement of design from the point of view of moulding seemed to be the last matter which designers considered. At his works they had really got down to the problem, and by improving the design of castings from the moulding point of view they had been able to achieve at least 25 per cent. increase of production, and to turn out a better job. That meant that previously they had been doing things which were not necessary; they had effected improvement by dispensing with things that were unnecessary, by providing a little more taper here and there, and so on.

Reason for Low Phosphorus Contents

Mr. J. Blakiston, dealing with the comment upon the table showing the compositions of the cupola metal and the Brackelsberg rotary-furnace metal, and the suggestion that the latter metal was more expensive than the former, said that in the instance given it was decided as a safety factor to reduce the phosphorus content of the rotary-furnace metal in order to maintain density at the bottom of deeply-machined Tee slots. It was a question of the founder suiting his methods to the design, and it was a well-known method to reduce the phosphorus content to below 0.5 per cent. He believed there was no increase of cost of the charge; the result desired was achieved by adding steel to the Brackelsberg furnace and carburising it with petroleum coke. Actually one could make a synthetic iron in a rotary furnace by using 100 per cent. steel and carburising it with petroleum coke.

He had never attempted the addition of sheet steel to the ladle, but the reference recalled to his mind a method once adopted by an old foundry foreman who was required to make cast iron which would bend. He had filled a small ladle with foundry sprigs and had poured in hematite iron from the cupola.

Effect of Composition

Mr. F. C. Pearce, commenting on the author's statement that the rotary furnace delivered a better iron than the cupola, asked in what respect it was better. For example, referring to the table showing the compositions of the cupola and the rotary-furnace metals, he asked whether, if the cupola would give a metal having a composition equal to that specified for the Brackelsberg rotary furnace,. the Brackelsberg furnace metal would be any better than the cupola metal. Or was the Brackelsberg furnace metal better merely because it had a lower total carbon content than the cupola metal?

Mr. Blakiston said the question was answered by the fact that a casting from a rotary-furnace iron showed much more even grain in varying sections than did a casting from the cupola iron, as had been proved by breaking up certain castings. There was certainly a greater tendency to produce open iron from the cupola than from the Brackelsberg furnace.

Ladle Additions and Ribbon Turnings

Mr. F. J. Cook (Past-President), discussing the addition of thin steel sheet in the ladle, said he had had to produce very large quantities of machine-tool castings, and for small slides it was the practice in some foundries to use the ribbon turnings from automatic lathes, which turnings were extremely thin and were kept clean—they were usually supplied by the people who took the castings—and there was no doubt that a very definite improvement was effected in the texture and closeness of the metal, and a reduction of sinking in deep parts.

With regard to foundry difficulties arising from the design of the castings, he claimed that a great deal of the trouble experienced was due to the foundrymen themselves, and he asked how many foundrymen could criticise a drawing when it was on the drawing board. It was very easy to be wise after an event; but if the foundryman was to be able to effect improvement in regard to design he must be able to criticise a drawing at its inception. It had been his good fortune for very many years to be able to ensure that no drawing was traced unless he had approved it. In the case of one design of engine, a saving of at least £100 was effected in the production of each individual engine as the result of alteration of the design, without detriment to the efficiency of the job.

Mr. Blakiston, endorsing Mr. Cook's remarks, said he believed the Institute was doing its best to make practical foundrymen realise how essential it was to secure technical training, so that they could understand the points of view of others and could explain their own point of view more graphically than they had been able to do previously.

Value of Phosphorus Content

Mr. P. A. Russell, B.Sc., commented that the analyses the author had given in Table I of irons used in machine-tool castings were representative of practice throughout the country;

but he asked for some further information with regard to phosphorus. In the Type 2 iron in Table I, the phosphorus content was 0.70 per cent., and that agreed with his own practice; he liked low-phosphorus iron for pressure work, but for machine-tool work a proportion of phosphorus was an advantage. In the table given in the Paper to indicate the compositions of cupola metal and Brackelsberg rotary furnace metal, the latter metal had the lower phosphorus content, whereas one would imagine that it could have a higher phosphorus content than the cupola metal. In the case of the cupola, having the higher carbon content, and where there was greater risk of the carbon approaching the eutectic point, there was more of a case for low phosphorus content; in the Brackelsberg furnace metal, in which the carbon and silicon could be controlled very well, he would have thought that one could afford to maintain an even higher phosphorus content than in the Type 2 iron. In machine-tool irons, phosphorus was a valuable constituent; its effect on wear was quite distinct, and when looking at a machine-tool casting which had been in use for some time one could tell whether or not the phosphorus content was high by the way in which the phosphide eutectic stood out.

Fluidity of Inoculated Irons

Whilst endorsing the author's remark that it was difficult to carry out inoculation in small quantities, he would not like to leave the impression that one could not make small quantities of inoculated irons; he had done it in cwts. at a time. It was a question of tapping temperature to start with. If the iron were hot enough it would stand inoculation in small quantities. Incidentally, he said it was his experience that inoculation rendered an iron more fluid; for a given temperature and class of iron, thinner castings could be run in inoculated iron than in straight iron.

Discussing the trap runner illustrated in Fig. 7 of the Paper, he said he would have thought that it was rather dangerous to use. If the runners were well organised, and the diameter of the downright from the pouring basin were greater than the downright into the casting—there were also different levels, and so on, to be considered—it might be all right. But in the trap runner illustrated there seemed to be very grave risk of the metal running out of the trap basin at a greater speed than that at which it could enter from the pouring basin, so that the slag would be carried into the casting. He would have thought that a scheme with a tangential arrangement would have been more effective. The trap runner illustrated occupied much room.

Limit of Phosphorus Content

Mr. Blakiston, referring to the table showing the compositions of cupola metal and the Brackelsberg rotary furnace metal, said that in fact the cupola-melted sample was taken from a casting supplied from an outside source, and the Brackelsberg-furnace-melted sample was taken from a similar casting he had made. There was no definite attempt to match the analyses, but he endorsed Mr. Russell's statement that there was a higher phosphorus margin in the Brackelsberg furnace metal than in the cupola metal. It paid always to maintain the phosphorus content as high as one dared without running into the bugbear of all machine-tool casting moulders, *i.e.*, open Tee slots. Not only did it give the casting a superior finish, but it also enabled the machine shops to use high cutting speeds without plucking.

With regard to inoculation, he said that foundry managers very often had to make the best of the plant they had available, and when he had mentioned 10 cwts. as the minimum weight for inoculation, he had meant that it was more or less a safe weight to run commercially with the plant that was probably available. With the necessary plant and with superheated iron, no doubt one could achieve good results with much smaller quantities of metal.

Trap Runners

As to the trap runner illustrated in Fig. 7, he said the first entry from the pouring basin to the trap basin was achieved by means of a double runner, so that it provided double the area of that of the runner into the casting. That afforded a sufficient margin of safety, and there was no possibility of the metal from the trap basin carrying the slag into the casting. The proof of the pudding was in the eating, and the volume of dirt precipitated in the trap basin was surprising. He was observing the different results obtained with different cupola cokes; and when using cokes of very similar analyses, there were definite variations in the dirt precipitation when making similar castings through the trap runner. He hoped to collect further data on that subject.

Dangers of Ladle Additions

Mr. Reynolds said that, in spite of the references made to the successful results accruing from using steel turnings or pieces of thin steel sheet in the ladle and pouring metal on to them, he was opposed to that practice as against the more normal and constitutional methods. He would like to know what advantageous effect the steel turnings or sheet could have, as against steel which was added either in the cupola direct or (where the quantities were small) steel which was melted in the crucible, with or without ferro-alloys, and added to the ladle in order to strengthen the iron. The addition of steel turnings and the pouring of hot metal over them seemed to be rather a hit-and-miss business, for there seemed to be danger of the turnings floating up, becoming entrapped in the runner and, therefore, into the casting. He could foresee many disadvantages arising from that practice as against the more normal practices of alloying in the cupola or by means of ladle additions.

Mr. Blakiston replied that he, too, was very much against ladle additions unless they were necessary for inoculation. The correct method of making additions was to make them on the charging platform, in weighed amounts. There was always a tendency to produce a " plum-pudding " effect with ladle additions, and there was also the chilling effect on the metal.

Ladle Additions Upheld

Mr. D. Sharpe was thoroughly in agreement with the practice of using thin steel sheets at the bottom of the ladle; it was common practice in a number of foundries where they required to stiffen up iron for a few castings. The thin sheets were placed at the bottom of the ladle, or fed into the metal in ladle, and the mixture was then poured. That method was giving satisfactory results every day. It was worthy of note that the practice was so common, despite the common agreement that additions should be made through the melting medium.

Mr. V. C. Faulkner (Past-President) asked what percentage of steel sheet could be added to the ladle. A figure of 2 per cent. had been mentioned, and he asked whether that represented the economic limit.

Mr. Sharpe said he would not like to give a definite figure. At his own works the matter was left entirely to the judgment of the foreman and in some cases to the man responsible for making the job. The practice was rule-of-thumb, as were many others. But in the light castings trade it was a common practice to use an unqualified quantity, being left to the judgment of the man responsible for the job.

Selected Additions Essential

Mr. F. J. Cook agreed that, if one had to deal with a sufficient quantity of a mixture, it was better to make additions in the usual way—either by making alloys and adding them to the ladle or, better still, by putting the additions through the melt. But perhaps there was some misapprehension with regard to the addition of turnings to the ladle. He did not mean that the ordinary shaving turnings were used, but the turnings which came from the lathes in the form of ribbons, about 1-in. or 1½-in. wide and only a few thousandths of an inch thick. They were added in definite quantities—1½ per cent. was added in 2-cwt. ladles. The practice was adopted in cases where a few castings of a certain composition were required in the course of a day's run. The turnings were red hot, as the result of the heat at the bottom of the ladle, before the metal came on to the top of them, and there was no question that very good results were obtained regularly.

Limiting Factors

Mr. A. J. Shore added that the addition made to the ladle was carefully weighed and was perfectly free from rust, though it had some fat on it. The strips were 1-in. or 1½-in. wide, and they were thin. They were used for special jobs, where one required to be quite certain that the ladle contained the correct metal. If a small amount were added in the cupola, it might be missed, whereas one could be certain that it was in the ladle if it were added there. The amount used was, roughly, 2 per cent., and he reckoned that 2 per cent. added in that way was as good as 5 or 7 per cent. added in the cupola. He did not know why, but it worked out in that way.

An Historic Practice

Mr. A. Harley (Past-President) recalled that, when watching the casting in the moulding shops at Coalbrookdale about 40 years ago, he had noticed an old man about 70 years of age dropping thin sheet steel very carefully into a big ladle of metal. In reply to questions, the old man had said that better castings were made as a result; and that was in fact the case, for the castings were excellent. Further, the old man stated that his father and his grandfather had followed the same practice. Therefore, the practice of adding sheet steel to cast iron in the ladle had been followed for generations at Coalbrookdale. The method might not be the most scientific, but Mr. Harley believed it was far better than the method of putting small quantities through the cupola. A quantity of 2 or 3 per cent. could be added quite easily. The old moulders of the past had realised, by observation, that for certain classes of work cupola metal was rather too grey and might be inclined to draw, and their method of adding sheet steel gave the metal a closer grain.

Running Long Plane Beds

Mr. A. Marshall, referring to the plane bed illustrated in the Paper, asked for Mr. Blakiston's opinion about running from one end, and whether there was a maximum length that could be run from one end. If the casting were run from both ends, one ladle was standing, and the temperature was dropping.

Trap basins in his experience were successful, and collected a considerable amount of slag which otherwise would enter the castings.

Dealing further with the pouring of machine beds, he suggested that where they were poured from both ends, there was at some points a tendency to slight oxidation and for particles to be picked up, producing porosity in the castings at those points. With regard to design, he said that where two ribs met, there was naturally a certain amount of porosity. He had tried chill nails, but the hot metal seemed to nip them off.

A Fourteen Feet Limit

Mr. Blakiston replied that the plane bed of which a photograph was shown in the Paper was 40 ft. long. It was necessary to run the metal along the bottom on chills, to counteract any tendency to draw created by the cross ribbing of the casting. A distance of 20 ft. was a long way to run metal on chills, but it was achieved successfully.

He was against pouring long castings from both ends; where the two streams of metal met there was always a tendency, not for a cold lap, but for a deposit of oxidised matter. When that matter existed in the metal, there was increased tendency to pick up blacking or skim the sides of the mould, and patches of "gas-holing."

The limit of length for running from one end successfully was about 14 ft.

In the Brackelsberg furnace practically any temperature could be achieved up to the temperature at which the lining was injured. The metal must be fairly hot when producing high-duty cast irons. But the lower the temperature at which one could cast successfully, the longer the life of the refractories; the hotter the metal, the shorter the life of the lining.

Dealing with the question of porous patches in ribbed castings, he said that it paid to slip in a little core between ribs and corners at such places, even if only of ½-in. diameter; if one could not do that, a small steel bar could be used.

Mr. V. C. Faulkner suggested that those interested in the addition of thin sheet steel to the ladle might study the American Exchange Paper presented two years ago by Mr. Judson. That Paper was very valuable; the author was mixing in the liquid form two categories of metal in which some auto-inoculation had taken place.

SAND-BLASTING AS APPLIED TO THE VITREOUS ENAMELLING PROCESS

Paper No. 640

By H. WHITAKER, M.Sc.

Sand-blasting is a process whereby grains of abrasive are thrown forcibly against the articles to be cleaned or treated. " Blasting " would be a better general term to describe the process, as nowadays sand is very little used, in this country, at any rate. The abrasive, generally crushed iron grit, is impelled against the articles being treated either by a stream of compressed air or from the blades of a wheel, rotating at high speed.

History

The original patents are said to have been taken out by Tilghman in 1870, when the process was used for obscuring glass. It was first applied to the metal trades in this country in Sheffield and Derby, about 1896, when it was used for cleaning castings, sand being the abrasive used. It was carried out in the open air, no precautions being taken regarding dust. About the year 1900, attempts were made to confine the process to an enclosed chamber, and crushed iron grit was introduced as the abrasive.

Object of Blasting

The object of blasting prior to vitreous enamelling is threefold:—(1) To remove the hard " skin," which is of a different nature from the rest of the metal and does not enamel well; (2) to remove all surface impurities, such as sand, blacking and the oxide formed during annealing; and (3) to roughen the surface and thereby cause a " bond " which enables the enamel to grip the metal. For cast iron no other method of cleaning has been found so effective, and it may also be applied to the heavier gauges of sheet steel.

It is vitally important that the blasting be done thoroughly and efficiently, because very many enamelling troubles can be traced to faulty blasting; for example, lack of care on the part of the operator, or the presence of oil or water in the compressed air.

Choice of Plant

When the prospective purchaser of blasting plant knows the type of goods he is to handle, and the quantity per hour, the suppliers have little difficulty in advising as to the best type to instal. When, however, the user himself—an enameller working for the trade, say—has not this exact knowledge (as the work may vary from a knob weighing an ounce to a heavy pan weighing up to a ton), then the choice of plant requires careful consideration.

Assuming the class of work to be known, the type of plant is largely settled by the output required; for example, on light castings (stove grates, etc.) the different types would turn out approximately:—Cabinet, 1 cwt.; room, 2 cwts.; and rotary table, 6 to 8 cwts. per hour per man (operator only). It is best to select blasting equipment on the cost per unit cleaned, because low running costs can easily outweigh an apparently high capital expenditure. Assuming a daily output of 25 tons, a saving of £100 in purchase price can be wiped out in two months if the operating costs are 2s. per ton higher than they might be. Moreover, after that there would be a loss of £100 every two months.

OUTPUT OF PLANT

This depends on (*a*) air pressure employed; (*b*) air capacity; (*c*) bore and type of nozzle; (*d*) nature of abrasive; and (*e*) type of plant.

(a) Air Pressure

Difference of opinion still exists as to the best pressure for vitreous enamelling. A pressure of 50 to 55 lbs. per sq. in. at the nozzle appears to be generally used in this country, although this may rise to 70 to 80 lbs. or fall as low as 30 to 35 lbs. Probably the last range is the absolute minimum for giving a satisfactory bond for the enamel, and the higher pressures are used with the object of obtaining a greater output. It should be borne in mind, however, that the power required to compress air increases rapidly with the pressure; for example, to produce 100 cub. ft. free air per minute at 30 lbs. pressure, 12 h.p. are required, whilst for the same amount at 60 lbs. pressure 18 h.p. are required. Few users of compressed air have an accurate idea of what it costs. It has been estimated that a plant with three $\frac{1}{4}$ in. nozzles costs about 2s. 6d. per hr. for compressed air, or over £300 per year.

(b) Air Capacity

The air consumption depends solely on the pressure and the bore of nozzle, and as the latter increases through wear, the compressor should be well on top of its work, say 20 per cent. above the demand of a new nozzle. To obviate stoppages due to breakdowns, repairs, etc., it is better to have two or more medium-sized compressors than one large one.

(c) Bore and Type of Nozzle

The wear of nozzles should be carefully controlled. A $\frac{7}{16}$-in. bore nozzle will absorb 205 cub. ft. free air per minute to operate it at 60 lbs. pressure, but when the jet is worn to $\frac{1}{2}$-in. bore 270 cub. ft. are used at the same pressure, *i.e.*, an increase of over 30 per cent. Nozzles of bore varying from $\frac{5}{16}$ to $\frac{7}{16}$ in. are generally used for vitreous enamelling, the most usual being $\frac{3}{8}$ in. They are usually made of chilled cast iron and last 6 to 8 hours. The use of "long-life" nozzles made of special alloys such as boron-carbide or tungsten-carbide is steadily increasing. They have a life of from 1,000 to 2,000 hrs. with careful use. The saving in their use is due not only to the bore remaining practically constant, but also to the time saved through not having to change them so frequently. It is necessary to keep a control on the nozzle-holder washers, as if these be allowed to wear too much, the outer cover of the nozzle becomes damaged beyond repair.

(d) Nature of Abrasive

In this country the use of crushed chilled white iron grit is now practically universal, because of the following reasons:—

(1) The risk of silicosis is greatly reduced.

(2) Although more expensive in first cost, it has from 10 to 20 times the life of silica.

(3) It is estimated that 1 ton of iron grit will do the work of 16 tons of silica.

(4) Very much less dust is formed, which reduces the problem of its disposal.

(5) Nozzles last longer with iron grit than with quartz.

Claims have been made that silica is better for certain purposes, *e.g.*, for acid-resisting enamels, but these seem difficult to substantiate. In the case of hollow articles where there is a possibility of some abrasive being left inside, there might be some advantage in using silica. The chemical composition of crushed iron grit of British manufacture is approximately as follows:—C.C, 3.1; Gr, nil; Si, 1.8; Mn, 0.4; S, 0.1; P, 1.1; Cr, 0.15 per cent. The Firth-Diamond hardness of such grit varies between 750 and 880. Hardness, however, is not the only desirable quality, and the manufacturers, by keeping the production under close technical control, can strike a balance between hardness and "toughness."

(e) Type of Plant

There are five types of plant in common use: (1) room; (2) cabinet; (3) rotary table; (4) barrel; (5) airless type, and their respective (A) advantages and (B) disadvantages are as follow:—

(1) *Room*:—

(A) The "universal" unit, as it will take any size of casting. It has greater flexibility of operation than the cabinet.

(B) High initial cost; excavation necessary; occupies large floor space; requires large dust equipment, and operator must be inside room.

(2) *Cabinet*:—

(A) Operator can work outside; small initial cost and floor space, also exhaust equipment.

(B) Smaller output, due to restricted manipulation of nozzle and vision of work. It cannot handle large castings.

(3) *Rotary Table*:—

(A) High output; will handle wide variety of flat castings, both large and small. The operator can work outside; no excavation is required, and it takes less floor space than room.

(B) Practically constant maintenance required. One type is only suitable for flat work, therefore another kind of plant is necessary (*e.g.*, cabinet) to look after edges. In another type, however, edges up to 1 in. are being satisfactorily cleaned. Requires large compressor as several nozzles are operating simultaneously.

(4) *Tumbling Barrel*:—

(A) Very economical, simple and robust. Operator can work outside.

(B) Only suitable for fairly small work, which can be tumbled without risk of breakage. As very few enamelling plants have sufficient work of this kind to keep the barrel running to capacity, this type is not often installed.

(5) *Airless Type*:—

(A) No compressed air is required, therefore cost of motor, compressor, receiver, piping, etc., is saved; also no trouble due to oil and water in air. No excavation; small floor space; lower power costs, compared with room or rotary table; no rusting of abrasive; the operator can work outside, and the work is more thoroughly cleaned than in any other type.

(B) Initial cost relatively high, also cost of maintenance.

In addition to its application to the barrel type, airless blasting is now being applied to the rotary table, with satisfactory results. By adjusting the angle of blast, vertical surfaces or edges can be cleaned. The airless type will clean four times the area cleaned by the pressure type in the same time, with an expenditure of one-tenth the horsepower. The chief reason for its high output is the large amount of grit which is flung on the work, being eight or nine times as much as in the pressure type, in the same time. It may be difficult to compare the actual velocity of the grit as it strikes the work, in the two types, but the cutting action in the airless type is at least equal to that obtained at 60 lbs. pressure in the pressure type. An average load of 3 to 4 cwts. of light castings is satisfactorily cleaned for vitreous enamelling in about 15 min., in the "Tumblast" machine. It should be made clear that the airless-type is not suitable for every class of work, but for work for which it is suitable it shows advantages both as regards quality and cost over any other type of which the author has had experience.

Operating Troubles

The chief troubles in the pressure type are due to water and oil in the compressed air supply.

Water.—It has been estimated that with a $\frac{3}{8}$-in. nozzle operating at 80 lbs. pressure, the amount of moisture carried in with the air per hr. is about $\frac{3}{4}$ gall. The air is heated while being compressed, which enables it to carry more water in the form of vapour. If moisture travels as far as the pressure chamber before condensing, it causes the abrasive to congeal and results in the apparatus becoming "clogged," also it is driven into the castings and causes rusting if they are allowed to stand. To prevent this trouble inter-coolers and after-coolers are employed, to cool the air and cause condensation near the compressor. Main pipe-lines should have a slight fall, with drain taps at the ends of the lines. All branch connections should be taken from the top of the main line, and it is advisable to fit a centrifugal type of separator immediately before the pressure unit. In some cases it is found advantageous to heat the air just before it enters the apparatus, generally by a gas jet, in order to vaporise any remaining traces of moisture. To keep down the temperature it is advisable to use a two-stage compressor, at any rate for the higher pressures.

Oil.—As this does not vaporise so readily as water it is not generally present to such a great extent, but if it gets through to the castings it causes far more trouble than water, because the enamel " crawls " and will not adhere. The compressor makers have introduced several modifications to overcome this trouble. The compressor should be double-acting, so arranged that a point on the piston rod does not enter both cylinder gland and crank chamber gland, thereby preventing the oil being carried forward. There should be an air gap between cylinder and crank case. Slightly tapered pistons and forced-feed lubrication (in place of the old splash method) have also assisted in this direction. The auxiliary oil feed to the top of the piston should be kept to an absolute minimum, 3 drops per min. for 1,000 cub. ft. air being ample. Oil can be removed from the main pipe-line by the use of cocoa-mat filters.

Silicosis

This disease is contracted through penetration to the lungs of dusts containing silica. To damage the lungs, the particles must be less than $\frac{1}{100}$ mm. in diameter, in other words they are invisible to the naked eye, and they must be inhaled over a considerable period. Although the almost universal use of iron grit has very greatly reduced the silicosis risk, it is still present, and it is difficult to convince sand-blast operators that it is the invisible particles which cause the trouble.

It has been calculated that there may be up to 3,000 million such particles per cub. ft. of air in a sand-blast room, and the risk of silicosis exists with anything above, say, 10 million. To guard against this, the most stringent care should be taken that helmets and protective clothing be kept in good condition and not left lying about when not in use. Also exhaust systems should be kept in perfect order, and leakages stopped. Workers in the vicinity, apart from the operators, should realise that they are not immune from danger, and should take precautions accordingly.

Further Developments

As a user of blasting plant, the writer respectfully suggests a few directions in which the manufacturers might improve their service to the enamelling industry:—

(1) *Pressure Plants.*—Pressure apparatus should be made more accessible, so that stoppages due to damp shot, etc., can be more quickly rectified. It should also be stronger and more robust, to withstand the rough usage to which it is subjected.

(2) *Airless Plants.*—There are certain parts which vitally affect the performance of the apparatus and research should be carried out with a view to giving longer life to these components, *e.g.*, by making them of special alloys.

(3) *Iron Grit.*—Research might be carried out using varying air pressures and grades of grit, with a view to utilisation of some of the grades not at present in common use for enamelling. A test should be evolved (*e.g.*, microscopic, or connected with " pick-up " of enamel) to ascertain the degree of " pitting " best suited to take enamel.

In conclusion, the writer wishes to express his indebtedness to the various suppliers of blasting equipment, who have given willing assistance in the compilation of this short Paper.

DISCUSSION

Air Pressures

The discussion was opened by MR. W. TODD (Vice-President, Institute of Vitreous Enamellers), who, commenting on the reference in the Paper to the air pressures used for sand-blasting for vitreous enamelling, it being stated that a pressure of 50 to 55 lbs. per sq. in. at the nozzle appeared to be generally used in this country, although it might fall as low as 30 to 35 lbs. per sq. in., said he was not aware of any vitreous enameller using pressures as low as the latter range for shot-blasting castings nowadays; such pressures were used for ordinary cleaning, but not where vitreous enamelling was concerned. In the old days a pressure of 30 lbs. per sq. in. was used for cleaning castings such as baths and similar sanitary ware to which the dusting process was applied; but even there it was found advantageous to increase the pressure to 40 to 45 lbs. per sq. in.

He suggested that a good deal of space was wasted on the type of rotary tables incorporating a series of circular spaces, as compared with the type of table on which the entire table area was utilised. He supported the author's observations concerning the use of nozzles made of tungsten-carbide and similar alloys.

Plant Selection

Discussing the selection of the most suitable type of plant to use, according to the types of ware produced, he said the percentage of breakages would increase seriously if certain types of castings, particularly those with projecting lugs or sharp corners, were dealt with in the tumbling barrel, and he suggested that in mechanised plants such castings should be dealt with on the slat conveyor or rotary table equipment.

Angular Chilled Grit Preferred

The introduction of the angular chilled iron grit was advantageous not only from the point of view of output, but also from that of the health of the operators; slowly but surely the danger of the operators contracting silicosis had been removed. Some people claimed, however, that the admixture of silica sand to the shot helped to keep the shot clean. He agreed that there was a great deal of room for investigation concerning the cleaning of shot. It was not sufficient merely to pass it through a sieve, either a revolving or a flat sieve; "black specking" was a bugbear to the enameller, and it was important to solve that problem, which was possibly related to blasting.

With a view to reducing wear on the machine due to the blast, a good deal had been done in the direction of using alloy steels; he had obtained good results with a malleable iron blade as against a cast-iron blade or impeller.

Suitable Blast Pressures

Mr. Whitaker replied that for several years he had used successfully an air pressure not exceeding 35 lbs. per sq. in. for blasting castings for vitreous enamelling; although that pressure seemed to produce good results, the pressure used at his works nowadays was nearer 60 lbs. per sq. in. He believed that a pressure of 35 lbs. was sufficient to give the necessary bond for vitreous enamelling, but that pressure did not give anything like the production attained with higher pressures; he agreed that 50 to 60 lbs. was the best pressure for vitreous enamelling. Castings for vitreous enamelling should be able to withstand a pressure of 60 lbs., otherwise there was something wrong with them. It was a very different matter simply to clean castings of, say, malleable iron or other material, on the one hand, and on the other hand to prepare castings for enamelling, for in the latter case there must be a definite pitting of the surface, and a much more thorough cleaning was necessary.

He agreed that a good deal of space appeared to be wasted where the small tables were used in the rotary plant. Obviously, if there were any spaces which were not covered by work, wear would result and maintenance costs would be increased.

He did not consider that the mixing of iron grit and sand was worth while, owing to the large amount of dust arising from the use of the sand. No sand had been used at his works during the last ten years; they had not found the slightest use for sand since grit was introduced.

Table Wear

Mr. Reynolds said it was the experience in a number of works that the wear on the rotary table plant of the compressor type was very great, and he asked whether the wear on the plant was also excessive where the Wheelabrator type was used.

In the preparation of castings for stove enamelling and galvanising, he was using round shot at a pressure of 25 to 30 lbs. per sq. in. Whilst no doubt angular shot was necessary in order to produce a key on the surface of a casting for vitreous enamelling, he had found that round shot was much better than angular shot for preparing castings for stove enamelling or galvanising, not from the point of view of speed of operation, but from the point of view of wear on the plant, the wear being very small and the results quite satisfactory so far as the finish on the castings was concerned.

Mr. Whitaker said he could not give the experience with regard to wear on the Wheelabrator type of machine table, for he did not think that a table plant had been in use for more than a couple of years or so in this country. But, from his experience of the barrel type of plant, he suggested that the wear on the table plant would be fairly heavy.

The Keying Theory

Mr. J. W. Gardom (Convenor of the I.B.F. Technical Committee, and Vice-President of the Institute of Vitreous Enamellers), commenting upon the author's statement that one of the objects of blasting prior to vitreous enamelling was to roughen the surface and thereby cause a "bond," said there seemed to be a suggestion that, as the result of using grit, small cavities were created into which the enamel would run and become keyed to the metal. He personally could not see it.

Again, he did not think it was true to say that the use of steel grit was universal for blasting and that sand and flint were entirely out of business, and he suggested that, particularly for deep section work, flint was probably better than steel grit from the point of view of the cleanliness of the casting, because there was not quite so much loss of velocity when using flint as when using steel grit; where there was appreciable loss of velocity, the carbon deposit on the casting would not be removed.

In asking Mr. Whitaker to amplify his remarks concerning the striking of a balance between the hardness and toughness of the grit used, he said he did not think that the toughness entered into the problem, but that it was hardness that mattered. He felt that the more the grit could be made to break up, the better was the keying, and it was economical to throw the material away as soon as it was used.

As to the suggestion that pressure apparatus might be made more robust and more accessible, he said that always the plant manufacturers were told that their plants were not good enough; it would be well if buyers would remember that it cost money to make a plant good enough.

Types and Sizes of Grit

Dealing with a suggestion that users were tied to the use of only two types of grit, he said there were plenty of other types, and perhaps the reference was to two sizes.

Mr. Whitaker said he had referred to two grades. The sizes he used were 14's and 16's.

Mr. Gardom repeated that there were plenty of others available, and, if Mr. Whitaker had tried them, he would like to know the results. He also asked for a rough figure representing the cost of sand-blasting castings for vitreous enamelling, or the proportion represented by sand-blasting in the total cost of vitreous enamelling.

As to Mr. Whitaker's statement that he had used successfully air pressures down to 35 lbs. per sq. in., he asked whether the size of grit used was varied with the air pressure or whether the 14's and 16's were used indiscriminately, or whether allowance was made for the fact that much of the grit was broken up so that he was not actually using 14's and 16's when the air pressure was 35 lbs.

In a reference to the "bogey" of waste space on the rotary table, he said he could not appreciate the argument. The whole idea of any conveyor was to get certain work past a certain spot in a certain time, within which time the work was to be done; if the work were not coming out completely finished, the table was slowed down, whereas if it were coming out too well—which was impossible from the point of view of the founder—the table was speeded up. So that it was merely a question of time.

Continental Preference for Round Shot

On the Continent recently he had visited a vitreous enamelling plant where round shot was used for sand-blasting, with extremely good results. There seemed to be a definite change-over to round shot there; therefore, he asked whether Mr. Whitaker had had experience of its use, and particularly, what results were achieved with the different sizes of round shot on castings for vitreous enamelling.

Even though Mr. Whitaker had said that there were only two sizes of shot, it would be interesting to know which of the two he had found to give the better results.

A Key Bond Essential

Mr. Whitaker, dealing with the criticism of the statement that one of the purposes of blasting was to roughen the surface and thereby create a " bond " between the enamel and metal, said he was under the impression that a bond was necessary, that there must be small dendrites or " fingers " of enamel which provided mechanical adhesion between the enamel and the iron. It could easily be confirmed by trying to enamel castings which had not been sand-blasted; if one used even perfectly clean castings which had not a bond, one would quickly experience trouble. Not only was a bond necessary for cast iron, but also for steel sheets, and he believed that was one of the reasons for pickling.

Use of Flint

With regard to grit *versus* flint, he had mentioned in the Paper that the use of flint was still advocated for certain purposes. For example, he had heard that it was used by people who were enamelling large tanks because, if any of the abrasive were left inside, it was better that that abrasive should be flint rather than steel grit. His works, however, were producing a large quantity of hollow articles, and they did not intend to go back to the use of flint.

He had expected criticism of his reference to " striking a balance " between the hardness and toughness of the abrasive, but he did not think that the user of grit wanted it to break up immediately it was put to use. That breaking up might be good for the grit suppliers, but not for the users, who wanted it to give a certain life; if it were to break up to dust immediately it was applied, the users would experience considerable trouble. He was not quite sure if " toughness " was the correct word to use, and how it was related to the tensile or the crushing strength, but he wanted grit which would stand up to the blow without immediately disintegrating into dust.

It was true that the robustness and strength which could be achieved in a plant must depend on cost, and it would not be fair to beat down suppliers in price and still expect them to produce very strong plant.

Restriction of Sizes Problem

The grades of grit in common use in the vitreous enamelling industry were 14's and 16's, which two sizes represented, he estimated, about 90 per cent. of the total amount used in the industry. How far the 14's and 16's were used in order to follow the fashion and how far they were used because they were considered the best sizes, he could not say, and that was why he had suggested that either the British Cast Iron Research Association or the National Physical Laboratory or some other body should carry out fundamental research on sand-blasting, using the various grades of grit. He suggested that the investigators might start with 1 sq. ft. of iron or steel of uniform composition, using a long-life nozzle, and constant air pressure, blast for a certain length of time, and ascertain how much was removed. He believed the Germans had carried out research on those lines, but he was not aware that such work had been done in this country.

He believed a large firm of stove makers had tried different sizes of grit and had concluded that the 14's and 16's were the best.

He would prefer to avoid the question of costs for obvious reasons, but sand-blasting represented one of the major items of cost in vitreous enamelling, and he could give Mr. Gardom some information on that point privately. When working at a pressure of 35 lbs. per sq. in. he had used the same grade of grit as he was using at present at the higher pressure.

He had had no experience of the rotary table as applied to the airless type of plant; but it was true of all types of blasting plant that blasting parts of the plant rather than the goods was an expensive matter. With regard to round shot, he had always been under the impression that it had merely a peening action and did not give the " bite " into the surface of the metal which, he contended, was required for vitreous enamelling.

Pickling Proposed

Mr. J. J. McClelland commented on the statement in the Paper that no other method of cleaning had been found so effective as blasting for cast iron which was intended for vitreous enamelling, and asked whether there was any objection, other than that of cost, to the use of the pickling process, which was applied to castings for galvanising, tinning, etc., in order to ensure that the surfaces were sufficiently clean to enable the coatings to adhere.

Mr. Whitaker said he was often asked for advice as to the preparation of castings prior to blasting, and it was generally sufficient to give them a good fettling and to grind off any " knobs and excrescences," but it was not necessary to grind all over. When enamellers asked for castings with a smooth skin they did not mean dead smooth, as obviously blasting would roughen such a surface, but a clean surface, as free as possible from sand, etc. He did not think the pickling of castings prior to enamelling was a practical proposition. He was aware that it was applied to sheet steel; but he believed it was not applied to cast iron because the latter might be porous, so that acid might soak in and salts would form and give trouble later in the enamelling process.

Control in Grit Manufacture

Mr. J. H. Cooper suggested that the reason why shot was sometimes broken into smaller pieces immediately it was used was that the makers produced it from a quality of metal which was entirely unsuitable, in order to reduce their costs. If they used metal containing more than, say, 2½ per cent. of silicon—which was present in many machinery castings—and made shot in the usual way, by allowing the metal to trickle down a lander, blow it with a steam jet to fall into a tank of water and then take the large particles through a sieve and a crusher, it would not be suitable, as it would be composed practically, not of chilled white iron, but of iron which was grey and sometimes even contained graphite. Thus the user, instead of roughening the surface of his casting, would be defeating his object by covering the surface with graphite, which he had seen in some of the larger pieces of shot which he had broken and examined. He asked whether some of the black spots which appeared regularly on enamel could be the result of applying a deposit to the surface of the casting instead of cleaning it.

Mr. Whitaker said he did not think that was a very vital matter; he had watched the production of shot very carefully, and did not think that very much grey iron got through.

Mr. Cooper pointed out that the depth of chill or hardness in any metal was determined by the composition of the metal; that applied to small or large particles, without exception. If one used a metal having less than or more than a certain range of silicon, a 1-in. or $\frac{3}{8}$-in. test-bar or shot would show no chill, but simply a blackening. Various irons were used in the cupola, and sometimes a small proportion of steel scrap was used. Without wishing to suggest that the German practice was better than British—indeed, he believed the reverse was the truth—he said the tendency in Germany was to use more round shot, because they exercised more care in the selection of their raw materials, and they tested the shot by hammering it on an anvil; it would not fly to pieces on impact unless it was almost grey.

Mr. V. C. Faulkner (Past-President), who presided, suggested that the adhesion of enamel to iron might be regarded as due to a chemical reaction between the enamel and the iron. Sand-blasting increased the surface area of the casting, and so provided a better opportunity for the chemical reactions to take place.

On the motion of Mr. F. J. Cook (Past-President), seconded by Mr. D. Sharpe, a hearty vote of thanks was accorded the authors of the various Papers presented to the conference, and tribute was paid particularly to the authors of Exchange Papers from overseas.

PAPERS PRESENTED TO BRANCHES

Scottish Branch

EQUIPPING OF A FETTLING SHOP*

Paper No. 641

By JOHN CAMERON, Junior
(Associate Member)

Before setting out to discuss the various means of converting the product of the moulding shop into a saleable article, it would be of interest perhaps to follow the various steps which led to the complete re-equipment of a fettling shop dealing with almost all varieties of light castings. These castings include rainwater pipes and gutters; soil, drain and underground water pipes and their attendant connections; various small castings for the general engineering trade, and finally castings for marine-valve gear up to four tons in weight. The last two classes of casting are supplied both in what is called " ordinary " cast iron and Meehanite high-duty cast iron.

Before the lean years of 1930 to 1934, the fettling shop of Cameron and Roberton dealt with a daily output of approximately 32 tons of castings. This total consisted, to a very large extent, of heavy drain and water pipes; these pipes are easily and quickly cleaned of sand, while any fettling takes the form of smoothing down the face of the runner and little else, a very simple job requiring no plant whatever; second, came the pipe connections, and lastly the jobbing castings. Only the last two categories require any proper fettling.

During the depression, naturally, there was no difficulty in dealing with the volume of work on hand, but all this time the company had

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* The author was awarded a Diploma for this Paper.

been developing a very extensive trade in drainpipe connections and special castings, and in 1933 were added the special Meehanite castings. As the trade in pipes had declined, the tonnage output appeared low, but actually the shop was fully engaged, due to the more complex work being handled.

When business began to pick up again in 1934, the management suddenly realised that there was a very acute bottle-neck in the fettling shop, and although the moulding shops were delivering about 140 tons of castings per week to be fettled, it was only by working considerable overtime that the resulting fettled castings could be handed over to the despatch department in the same period, and this in spite of the fact that there was a cast on only five days per week.

This state of affairs was almost entirely due to the increased quantities of connections of the type shown in Fig. 1, so, as there were no signs of a reversion to the earlier preponderance of heavy pipes, actually the contrary being the case. the management proceeded to re-equip the shop to tackle economically the new types of castings being produced.

Any fettling shop can be split into two well-divided sections:—(1) That dealing with cleaning the casting and (2) that dealing with the removal of fins, flashes, gates, runners, etc., and it is proposed to deal with them in that order.

Rumblers

Among foundries producing castings for the building trade, the commonest method of cleaning castings is by rumbling, or revolving the castings in a drum-shaped receptacle, in close contact with hard iron stars of a suitable size. Rumblers vary considerably in design, the two most popular being that with a hollow trunnion for dust-exhaust purposes, and that where the trunnions are solid, and dust exhaust takes place from an enclosing hood.

The advantages of rumbling are that it produces an adequate finish on most classes of casting, the plant is relatively cheap, and power and maintenance costs are low, with the result that cleaning costs per ton are low. The disadvantages of rumbling are that, broadly speaking, it cannot produce a finish sufficiently good for enamelling in a sufficiently short space of time. Secondly, it is an extremely noisy process, so much so that it is always advisable to have the rumblers in a separate shop from the fettlers. Thirdly, there is always present the possibility of broken castings.

Elaborating on these last two points, where the rumblers can be installed in a shop by themselves, the hollow trunnion type is generally used, but where they must be in the fettling shop proper, the solid trunnion type enclosed in a wooden or sheet metal hood is advisable, due to the fact that this enclosing hood silences the noise to a very considerable extent. As regards broken castings, this is almost entirely due to the skill of the rumbler loader; a good man will rarely lose a single casting, but cases are known where an inexperienced man has broken 50 per cent. of the rumbler's load.

The time necessary to clean the castings depends entirely on the finish required. From twenty minutes to half an hour should remove all loose sand, and from 45 minutes to an hour and a half should produce a good smooth skin, though castings which have to be painted without further cleaning are often rumbled for two hours.

Shot-Blasting

Where a satisfactory finish cannot be obtained by rumbling, sand-blasting or shot-blasting is the most common method of securing a clean finish. There are three distinct types of sand blast installations: (1) the rotary-table type for flat castings such as are used in the fitted goods trade; (2) the combination tumbling barrel and blast jet type, sometimes called the " Tumblast," generally used on small engineering castings, and (3) the larger cabinet sets employing either ex ternally or internally operated nozzles, and suitable for cleaning castings too large to be handled by either of the two former methods.

As an abrasive, sand has been almost entirely superseded in recent years by chilled iron shot, due to the much more efficient cleaning with shot, and also to the risk of the operator contracting silicosis when using sand.

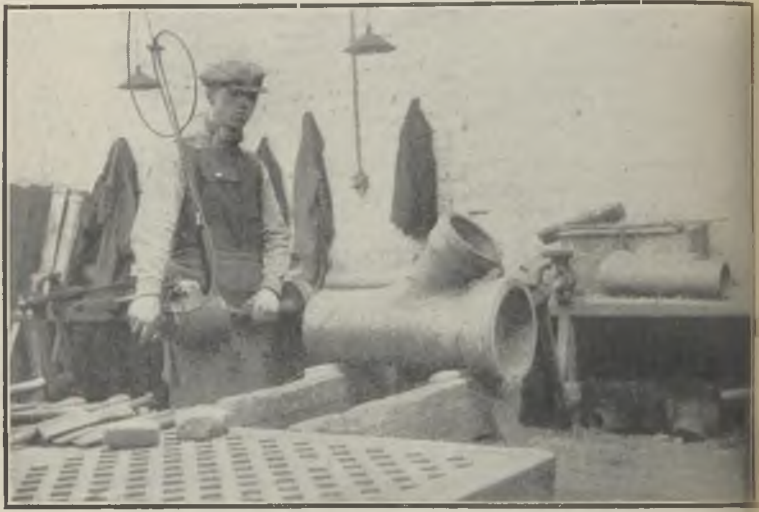

FIG. 1.—TYPE OF CAST-IRON PIPE CONNECTION, INCREASING DEMAND FOR WHICH LED TO A FETTLING-SHOP REORGANISATION.

Shot-blasting or sand-blasting is, however, a fairly expensive process, but it is the most widely used method of securing a finish sufficiently clean for enamelling. It is also necessary for cleaning castings such as motor cylinder blocks, which will subsequently be in close contact with lubricating fluids. The principal disadvantage of shot-blasting is the large amount of horse-power required to maintain the required pressure of air at the nozzle or nozzles, and the heavy maintenance charges. The figures for power are so well known that there is no point in repeating them here, but the cost of compressed air may be taken to be between 1¾d. and 3d. per thousand cub. ft., depending both on the size of the installation and the pressure employed. A representative figure for total cleaning cost, that is inclusive of power, maintenance, abrasives, labour and depreciation, may be taken as between 8s. and 9s. per ton.

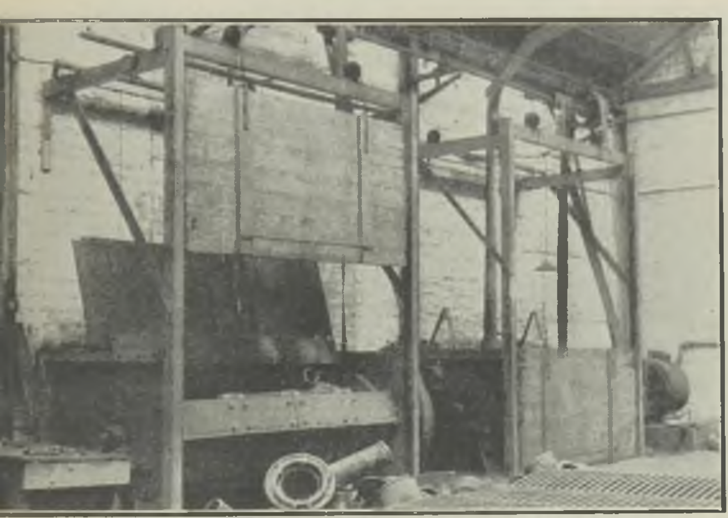

Fig. 2.—Two of the Solid-trunnion Rumblers with Built-in Dust Hoods.

Shot-Slinging Machines

The most recent development in the cleaning field is that type of machine using centrifugal force to impart to the abrasive the energy necessary for removing the sand or scale. In this class both the Wheelabrator and the Sand Wizard are widely advertised, the difference between the two makes being in the design of the impeller head; in one case it is rather like the impeller of a centrifugal pump, and in the other case has two blades and resembles the Sandslinger.

Originally, the Wheelabrator type of machine was only available in the Tumblast style, but now both this and the rotary table styles are on the market. So far, the system does not seem to have been applied to cabinet sets, and it is doubtful if it will be possible to adapt it for this purpose, but the author would be the last person to say that it was impossible. It is clear, therefore, that up to the present, centrifugal cleaning can only be applied to small castings, but there appears to be no doubt that the finish produced is excellent and quite as good as that obtained by shot-blasting.

The outstanding advantages of this type of machine are the relatively low power and maintenance costs when compared to compressed-air installations, and most foundrymen will have seen a recent advertisement which claims a cleaning cost of 28.374d. per ton. When depreciation has been added to this figure, the full cost would appear to be around 3s. 6d. per ton based on an 8-hour day, or 2s. 10d. per ton taking advantage of working a 23-hour day. When this figure is compared with the cleaning cost by the compressed-air method, there is little wonder that these machines have developed so rapidly.

Hydraulic Cleaning

A further cleaning method which has received a little publicity recently is the " Hydroblast " system. Here, a jet of high-pressure water is directed on to the casting to be cleaned, and, due to the sand mixing with the water, an action comparable to sand-blasting is set up, the difference being that the water carries the abrasive and there is a complete absence of dust. This system appears only to have been applied in the United States, and originally was restricted to heavy castings, but members will recollect that Dr. A. B. Everest stated in his recent Paper on American developments that this type of cleaning had also been applied to small engineering castings. It would appear on the face of things that where there is ample room available and an abundance of water, this method merits very considerable attention for medium-sized and large engineering castings.

Fig. 3.—The Brushing Tables on which Heavy and Bulky Castings are Hand-Cleaned.

Of the various methods, briefly dealt with above, available to-day for cleaning castings, rumbling was chosen for the new shop because (1) it is the cheapest; (2) a sand-blast finish is not required on the majority of the castings produced, and (3) the water system was not considered.

Four rumblers, two of which are shown in Fig. 2, were installed, of the solid trunnion type with built-in dust hoods, as they had to run in the same shop as the dressers. Two are 7 ft. long and 31 in. across the flats, and ten-sided; one is 4 ft. long and 25 in. across the flats and hexagonal, and the fourth—a small one—is 3 ft. long and 24 in. across the flats, and octagonal.

The two larger rumblers are driven by a 9-h.p. motor, and the two small ones by a 5-h.p. motor. In the large rumblers, soil-pipe and drain-pipe connections are cleaned, the two classes being kept separate as far as possible due to the risk of the lighter soil connections being damaged by the heavier drain pipes. It takes, on an average, half an hour to clean a batch of castings satisfactorily, and nine batches per rumbler are handled daily. The two smaller rumblers tackle various other types of castings, a complete load of the same type being put through at a time.

Pipes of all descriptions are not rumbled, but cleaned by hand. The heavy underground and drain pipes in 9 ft. and 6 ft. lengths are built up in a bank, sockets all the one way, and as the runner mark on the socket is chipped smooth, the pipes run along a pair of rails to the brushers, who clean them inside and out with wire brushes. A large brushing table deals with the dust question during this operation.

Heavy and bulky drain connections, too large to rumble, are also cleaned by hand, but on three brushing tables 8 ft. square, shown in Fig. 3. This cleaning down by hand is always the dirtiest and most objectionable part of the work in a fettling shop, and the provision of these tables has made a most remarkable improvement in the atmosphere of the whole shop; it is always clear and healthy, and the walls and windows maintain their cleanliness for much longer periods.

Dust Extraction Plant

A dust extraction plant was installed at the same time. Dust is extracted in all from five brushing tables, four rumblers, and four double-ended floor grinders. The fan is of ample capacity, driven by a 21-h.p. motor, and capable of maintaining a negative pressure of 2 in. water gauge with the whole number of suction points in use and the dust collector sleeves clean. The collector itself is of the dry type, and consists of 48 canvas sleeves 12 in. dia. by 9 ft. 6 in. long. A small gauge is fitted to the fan staging, and when the negative pressure rises to 1 in. water gauge, the sleeves of the collector are shaken and cleaned.

FIG. 4.—DOUBLE-ENDED FLOOR GRINDING MACHINES FOR DEALING WITH SMALLER CONNECTIONS.

The rumblers are completely enclosed by hoods made from ordinary tongued and grooved board-ing. Care is taken to see that all joints are really tight so as to maintain a good suction. The journals are outside the hoods, out of the worst sand and dust, and are easily accessible for lubrication and other attention. As previously mentioned, these hoods act as excellent silencers for the rumblers when these are in motion. The brushing tables are very strongly built, the tops being half solid, half heavy grating; the sides and cleaning doors fit very closely, and the area open to suction is approximately 7 sq. ft. The floor grinders are fitted with special combined wheel guards and exhaust hoods; heavy matter falls directly to the bottom of the container, which has a large cleaning door, and dust exhaust takes place from about halfway up the hood. On one occasion when a very fine sand was required for moulding purposes, silt from the dust collector was proposed as a possibility. On analysis, however, this silt proved to be almost 75 per cent. metallic.

Fettling of Castings

Much work is still done by the hand hammer, chisel and file, and for intricate work it is difficult to see that they will ever be displaced. On medium-sized castings and heavy work, the pneumatic chisel has by now penetrated even into the most conservative shops, and probably there now exists no man who will maintain that he can beat a pneumatic chisel by hand. The pneumatic tool is also extremely useful when used with long chisel bars for digging cores out of larger castings.

Quite separate from this type of fettling appliance are the grinding machines. There must be very few shops where some types of casting cannot be quickly and neatly finished by this means. These machines are divided into two classes:—(1) Normal speed, operating at around 5,000 s.f.p.m., and (2) high speed, operating at around 9,000 s.f.p.m. The first class of machine uses vitrified bonded wheels, and the second class Bakelite bonded wheels. Almost any combination of grit and hardness is obtainable in either type of wheel, generally a softer wheel being used on hard materials, and a harder wheel on soft and ordinary irons. The high-speed machines must be exceptionally strongly built, and are claimed to remove metal at twice the speed of normal-speed machines.

In this class of machines also enter the swing-frame grinders. These are generally suspended from their centre of gravity by a block and tackle, and are popular on medium-sized castings, as the wheel is brought to the job, not *vice-versa*. They are made both in normal-speed and high-speed types.

Yet another class of grinder is the small portable type operated either from compressed air or electrically. The compressed-air models are available working either on the turbine or the reciprocating principle; the turbine type would appear to have the advantage due to simplicity of working parts and the high spindle-speeds obtainable. Compressed-air grinders also have the advantage that, if accidentally stalled by an inexperienced operator, there is no armature to burn out. The electric grinders were for a long time handicapped by the difficulty of securing a sufficiently high spindle-speed. This has now been overcome to a considerable extent by the introduction of the high-cycle type of machine in which almost any speed may be attained; this machine is also less susceptible to armature trouble, and represents a great advance on the older type of machine. A wheel 6 in. by 1 in. seems to be one of the handiest sizes. These machines are useful in most shops for finishing operations, particularly on the inner surfaces of cylindrical castings. In the fettling shop already described almost all of these aids to manual labour are found in one form or other.

The smaller connections, after being rumbled, are passed to a set of three double-ended normal-speed floor grinders (Fig. 4). Two machines have 16 in. by 2 in. wheels and one has 18 in. by 2 in. wheels. The smaller castings are dealt with on the smaller wheels, leaving the larger machine to tackle the drain connections. These grinders are driven by 4-h.p. and 5-h.p. motors respectively, which are installed within their bases and completely closed in. The drive from the motor to the grinding spindle is by vee belt and is particularly good. This arrangement has the advantage of doing away entirely with overhead shafting and belting, giving the fettler complete freedom around his machine, and in the case of removal the complete unit may be lifted from the ground and set down again ready for operation with a minimum of disturbance.

Grinding Speeds and Work Tables

The spindle speed of the smaller units is 1,200 r.p.m., giving a grinding speed of 5,000 s.f.p.m. at 16 in. dia. The larger machine has a two-speed pulley, so that the spindle may be run either at 1,050 or 1,200 r.p.m.; the slower speed is used for a new wheel and it is stepped up to the higher speed when the wheel wears down below 16 in. dia. A fourth machine with 16 in. by 2 in. wheels handles small flat castings. The wheels, incidentally, are about 31 in. apart, giving comfortable room for two operators. The grinding wheels used are on the hard side—the result of much experimental work as regards grit and grade. Owing to the fact that most of the castings handled are made very accurately to pattern, there is no necessity for removing a large amount of metal; consequently, life is of more importance than free-cutting properties. The harder stone also maintains its shape better and requires dressing less frequently. For good fettling on such a grinder, too much stress cannot be laid on the necessity of having sturdy work-rests of ample size and capable of accurate adjustment. It has been personal experience that most work-rests are far too light and quite incapable of withstanding the very severe conditions found in most foundries. The method of attaching these rests to the body casting of the grinder is often also open to criticism.

Small Tools for Finishing

From these floor grinders, the castings are passed on to benches, where any finishing necessary is done by hand. The pneumatic chisel has been tried repeatedly for this work, but there is insufficient mass in the casting to offer reasonable resistance to the hammer. A considerable number of the heavier castings, which are cleaned on the square brushing tables, such as inspection pipes, are fettled by hand hammer and chisel and finished by a portable electric grinder using a 6 in. by 1 in. stone. This grinder is hung on a compensating spring, leaving the operator free to direct the stone without having to waste energy holding the weight of the machine. Two pneumatic grinders of the turbine type are also used continuously, both on this work and some of the jobbing castings.

The bulk of the jobbing castings are dealt with by a special squad using pneumatic chisels, hand tools, small pneumatic grinders and also a swing-frame high-speed grinder, depending on the size and shape of the casting in question. As in most other jobbing foundries, they are liable to get almost anything to fettle, from a coal cutter casing in Meehanite with a strength of 25 tons per sq. in., through feed-water heaters and marine slide valves, to small diesel-engine cylinder blocks, so naturally they require a pretty complete kit of tools.

Fettling Meehanite Castings

The high-duty Meehanite castings raised some very interesting points as regards fettling. The moulding practice with these castings is more akin to steelfoundry practice than iron, and, as a result, there are sometimes heavy risers to remove. Although these are considerably smaller and fewer in number than on a steel casting, they often are quite a problem. On small castings, these risers may sometimes be knocked off by a shrewd blow from a heavy hammer; this practice, however, is dangerous and may lead to a casting being spoiled due to the riser breaking in unless considerable care be exercised. Where it is inadvisable to use this method, the riser is cut round at the neck with either a pneumatic chisel or a metal saw to such a depth as to make breaking safe, while on the heavier castings, two or more holes are drilled in the neck instead of cutting.

Whatever method of removing the riser proper be used the casting is always left with the stub, which must be fettled flat; this frequently entails the removal of a considerable weight of metal and is an expensive business, so tests were carried out with hand chisel, pneumatic chisel, portable grinder and the swing-frame high-speed grinder to find out the most economical. The swing-frame grinder won in a canter from the pneumatic chisel (the other two being a long way behind), and has proved itself a most versatile instrument, being very well balanced and capable of working in any position. The wheel is 16 in. by 2 in., running at a speed of 9,000 s.f.p.m. The bond is Bakelite, and the grit and grade are chosen to give the freest cutting possible combined with reasonable life. In this instance, rapid removal of metal is of prime importance, and on a series of heavy castings, stubs 4 in. square and ⅜ in. thick were consistently ground flat in seven minutes; this represents a rate of removal of metal of over ¼ lb. per minute.

In conclusion the author would like to thank those members of the staff of Cameron & Roberton, Limited, who have assisted in the preparation of this Paper.

London Branch

TRENDS OF CONTINENTAL STEELFOUNDRY PRACTICE*

Paper No. 642

By P. C. FASSOTTE (Brussels) (Member)

This Paper is not a thesis, but rather an attempt to give a broad idea of opinions and general tendencies prevailing amongst the steelfounders on the Continent, and of the directions in which they are striving to solve the ever-present problems of greater efficiency and better products. Its only ambition is that it aims at being objective, although it is not easy, with such a subject, to avoid altogether subjective interpretations. A French critic said of a novel that it is " a piece of life seen through a temperament." An endeavour, however, will be made briefly to describe the trend of things on the Continent without allowing personal opinions to intrude.

Two Main Groups

If orderly minds, possessing the habit of classification, analyse the working conditions of Continental steelfoundries, they will be strongly tempted to divide them into two main groups. They will find in Belgium and large parts of France an important body of steelfoundries, quite a number of which produce tonnages upwards of 1,000 tons a month, and some exceeding 2,000 tons, which rely solely on natural moulding sands as a moulding medium. On the very doorstep of these foundries, or within a cheap rail freightage, exist deposits of sand peculiarly suited to the steelfoundry and, quite logically, the foundries in these districts have concentrated on the use of this material. They have done so to the exclusion of any other. In the whole of

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* The Author was awarded a Diploma for this Paper

Belgium and Northern France, "compo" is unknown in the steelfoundries, and it is not even used for castings upwards of 50 tons.

Influence of Local Conditions

Having once started with the local raw material, they soon perceived that its quality enabled them to develop a practice of casting steel in green-sand moulds, and to their credit it may be said that they have exploited this possibility in a full measure. In this group, there are to-day steelfoundries using the green-sand process exclusively, others where dry-sand moulding is practised can be considered as exceptional.

Fully to develop the possibilities of their green-sand practice, these foundries were naturally attracted by the use of the small acid converter, with its concomitant of quickly repeated heats, small ladles, lip pouring and shanking. They were fairly well situated for obtaining raw materials for their converter plants, the freights on hematite from the North-East Coast being reasonable and the Customs duties, at any rate in Belgium, quite nominal. The Franco-Belgian group of steelfounders may therefore be broadly characterised by its use of sand as a moulding material, the development of an extensive green-sand practice and the intensive use of the acid converter.

German Practice

The opposite school was developed in Germany. The moulding sands available were not of the same high standard, and the quarries were mostly situated a long distance from the metallurgical centres. Reliance, therefore, had to be placed on synthetic materials, and in the preparation and use of moulding compositions, the German foundries have achieved a remarkable measure of success. With characteristic thoroughness they set themselves the task of producing from chamotte—by calcining it at high temperature, crushing and grading it—an exceedingly fine base for a moulding composition.

The material has a high refractoriness and the care lavished on its manufacture ensures that high standard of *regularity* which is perhaps the foremost quality of any moulding medium.

The bonding clays used impart generally to this chamotte composition a greater strength than is found in similar materials used in Great Britain, the speed of moulding being thereby accelerated and the need of mould repairs reduced. Similar care has been devoted to the production of mould washes, with the result that some German foundries are producing castings of startling cleanliness with the use of composition. Green-sand moulding in this material is, however, not practical. Another factor gives the German foundries a different aspect from the Franco-Belgian. In Germany converters are somewhat handicapped, particularly so since the war. Probably the main reason is the difficulty of procuring hematite of the right type. Whereas the English steel foundries can in normal times obtain hematite with a maximum phosphorus as low as 0.02 and, on an average, 0.03 per cent., the German steelfounder cannot obtain at a reasonable figure a hematite with less phosphorus than 0.08 per cent. Everything favoured, therefore, the basic open-hearth furnace, and later the introduction and development of electric furnaces.

The German foundries can be considered as typified by the use of basic steel, synthetic moulding materials and dry-sand practice. Other countries in Europe followed either one or the other of the two main tendencies, according to their local conditions and the respective facilities for obtaining one or the other set of raw materials at an economic figure.

Diffusion of Practice

However, this broad division of Continental steelfoundries into two groups must not be considered as absolute. The two schools have reacted on each other, or rather there has been a phenomenon of osmose, of interpenetration between the two practices. Whilst in Belgium and

Northern France sand is still being used to the exclusion of "compo," even for the heaviest castings, in Central France, Switzerland, Holland and other countries, synthetic preparations are used to a fair extent. In Germany the movement has been in the other direction, namely moulding sand has found its way into most foundries, at any rate for the production of the lighter work. One foundry produces all castings with wall thicknesses of $\frac{7}{8}$ in. in sand; another limits the use of sand to castings below three tons in weight, but all German informants agree that the progressive use of natural sands is a feature of recent steelfoundry practice in Germany.

Phosphorus Control by Mixed Process Installation

Inside the Franco-Belgian group another tendency, not less noteworthy, has made itself felt. The typical Franco-Belgian foundries of a few years ago were equipped with converters. Some of the large foundries had also one or more basic open-hearth furnaces of relatively small capacity, usually between 8 and 15 tons. This combination of converters and small basic open-hearth furnaces was always considered as a fortunate one, as by judicious transfer of scrap produced by the two processes, the tendency for the average phosphorus to rise was held in check, and the supply of suitable scrap for the converter thereby facilitated. The converter remained the backbone of the steel supply, however, and the whole trend of thought was directed towards exploiting to the full the elasticity of the converter process, its ability to cope with varying quantitative needs, and the peculiar suitability of its steel to the requirements of a green-sand floor. With those considerations uppermost in their minds, and looking on the converter essentially as a tool for intensive production, the Franco-Belgian steelfoundries on the whole have somewhat neglected the other possi bilities of the acid converter.

Slow Development of Soda-Ash Process

For instance, as a body, they have definitely been slower than their British colleagues in standardising the soda-ash process, which has done so much to rehabilitate the acid converter. Many of them have not credited the converter with being able to cope, at any rate to some extent, with the new requirements of the customer in alloy steels. For instance, there is no parallel on the Continent for that important British steelfoundry which is producing, with converters only, the largest proportion of its castings in alloy steels (of the manganese-carbon. chromium-carbon, and nickel-chromium varieties).

It is somewhat curious to reflect that, whereas it could be said that the acid converter has its natural home in Belgium and Northern France, to-day the possibilities of the converter seem more highly esteemed in Great Britain than anywhere else. It is in Britain that are found to-day some of the most confirmed protagonists of the converter, and also some of the most able exponents of its practice.

Electric Furnaces and Alloy Production

When, during the last ten years, a growing demand arose for alloy steel castings, the electric furnace received a sudden impetus in Belgium and France. In Germany most foundries were already relying on the basic arc furnace, and the same still applies to Italy and Switzerland. In the Franco-Belgian group there have been numerous instances, particularly during the last five years, of the installation of basic arc furnaces. The induction furnace also made its appearance, and quite a number of foundries in every country have now installed them. It is considered by some as the furnace of the future for the steelfoundry. Some of these installations are quite large; one which was visited recently has four furnaces, another has three—a 5-cwt., a 10-cwt. and a 15-cwt. unit; and a third has two 10-cwt. and one 3-ton units.

New Induction Furnace Practice

While on the subject of induction furnaces, it is interesting to note that efforts to develop a refining process have met with a very fair measure of success. Crucibles are lined to-day with a basic refractory, twenty-five to thirty heats per lining being common practice. Thin basic slags are produced, particles of which are actually drawn into the metal itself by the vortex caused by the eddy currents. The calorific input is increased to the maximum during the refining. These slags are easily removed, and, if necessary, renewed. Their momentary partial immersion in the steel is said to be without effect on the cleanliness of the metal. It is further said that phosphorus has been removed with three consecutive slags to the extent of leaving only a remnant of 0.005 per cent., but no figures for extra current consumption were available.

Unusual Duplexing Practice

Another somewhat exceptional practice in relation to arc furnaces may also be of passing interest. A Continental foundry is using a basic electric furnace for producing its steel, but transfers a part of the metal to a small acid electric, and works it again with an acid finishing slag. They resort to this costly operation with the sole view of imparting to the metal the better life associated with acid steel. The object in this case is to produce more easily small steel castings in green sand. It was, at the time, the only instance of this peculiar duplex process which had ever been brought to the author's notice. On further inquiries it was found that not only basic electric, but also cheaper basic open-hearth steel is transferred in Germany to either an acid arc furnace or an acid induction furnace for the same purpose, and that this duplexing is a fairly regular practice.

Outlets for Alloy Steel Castings

To-day the basic arc furnace and the induction furnace are producing the large majority of alloy steel castings on the Continent. One should mention, however, that for the 12 per cent. manganese steel castings, many foundries rely on the converter, though others have a distinct preference for the arc furnace. The increase in use of alloy steel castings has been exceedingly rapid. For instance, a foundry of world reputation, catering exclusively for outside customers, is turning out now an average of 30 per cent. of its production in alloy steel. Drawing offices in engineering works seem to have become conscious of the higher demands which can be made upon alloy castings. Specifications containing nickel, chromium and molybdenum, which ten years ago were an exception, are now regularly received, and steam-turbine castings, for instance, are frequently ordered in 2 or 3 per cent. nickel steel.

The chemical, cellulose, artificial-silk, brewing and other industries have developed a very strong demand for non-corrosive steels. The foundries which have been preparing themselves to meet this new demand are quite numerous. Alloy castings with 25 per cent. of nickel and even more are being produced as a matter of routine. Alloy steel castings are being ordered on repetition lines. An order recently received by one foundry was for 400 sets of small castings in 18 : 8 steel, weighing a total of 8 tons. The average weight was no more than 9 lbs. The castings are intended for dairy plants and some of them are likely to tax the ability of the supplier to the utmost. High-chromium steel castings are ordered for wearing purposes, particularly for working in high temperatures. The low-chromium steels or manganese-chromium steels are demanded for a variety of purposes, amongst others for connecting rods and crankshafts for large internal-combustion engines and compressors. Where high physical tests are required, and particularly shock-resisting tests, the steelfounder offers a large choice of materials in the nickel-chromium range. Molybdenum steels for high-pressure steam ducts, austenitic steels for the chemical and other industries, and chromium-tungsten steels which retain strength at high temperatures together with wearing qualities—all these the steelfounder supplies now in ever increasing quantities.

Certain sources of work for the steelfoundries have dried up. In Belgium, for instance, welded constructions have ousted high permeability steel castings almost entirely, although this is not the case in Germany. New fields, however, have been tapped; as an instance, underframes for tenders and carriages cast complete with axle-box guides and accessories, which a number of railways have standardised. Previously, these parts were constructed or welded. The problem of making these underframes has entailed a good deal of research and large outlays on equipment, yet a fair number of foundries are to-day in a position to supply them, and deliver them in the finished machined state.

Laboratory Facilities

All these specialised requirements have considerably altered the conditions of technical management. In the days when straight carbon steels only were produced the laboratory played a very minor *rôle* and sometimes was non-existent. To-day the highly-trained metallurgist has come to the fore. In fact, he has become inevitable. His staff has been increased, and his equipment brought into line with the accrued importance of his work. Some steelfoundry laboratories which have been visited in recent months can be said to be equal in every respect to the best encountered in the heavy steel industry. Research work has become a feature of these laboratories. Customers call in the steelfoundry metallurgist to help to solve their own special problems. Whereas, in the past, the laboratories were used merely as a check on products and raw materials, to-day the problems of non-metallic inclusions, grain size, heat-treatment, wear, corrosion, and strength at high temperatures have become as familiar to some steelfoundry staffs as to the makers of alloy steels in rolled and forged conditions.

What is true for the laboratory is equally so for the heat-treatment shop. The old grate-fired annealing stove has given way to modern furnaces with equilibrated temperatures capable of reaching and maintaining any temperature up to 1,150 deg. C. Quenching tanks with coolers and dipping tackle have been installed, equal to those found in forges and stamping shops. The growing importance of the scientific side of management, both as regards personnel and plants, is one of the outstanding developments which have taken place in the steelfoundries.

Acceptance Tests

A subject connected with the laboratory work is that of physical tests. It is not surprising, since the same tendency prevails everywhere, that physical tests have become more stringent, and that private customers more and more insist on test-pieces being attached to the castings. Physical tests have been required for many years by the national buying authorities, such as the Admiralty, War Office, mercantile marine, railways, etc. To-day a large number of private engineering works are in turn requiring tests for the castings they buy. The more noteworthy development has been that of the shock tests of the Izod, Charpy and Mesnager types. New types of test-pieces have been introduced recently, but discussion is still raging in every country as to the best type of test-piece for shock purposes.

What is striking is the increased number of specifications calling for a shock test. It has led the foundries to overhaul not only their steelmaking, but to give more attention to the question of heat-treatment. Some daring practices have been evolved, such as that of a particular foundry which does not hesitate to water-quench all castings subject to shock tests provided the carbon remains in the neighbourhood of 0.2 per cent.

The yield-point is stressed by customers far more than the ultimate strength, particularly in Germany. It is now well known that a high yield-point at elevated temperatures is facilitated by a molybdenum addition, and molybdenum steel is specified for all castings for high-pressure steam, certain castings for the chemical industry, etc. These castings are regularly tested for their resistance to creep, the usual test prescribed being from 25 to 35 hours and the limit of creep accepted 5/10,000 of the test-piece per hour.

X-Ray Testing

The other move which is definitely interesting is the attention being paid to X-ray testing. It is felt by many foundries on the Continent that, whether they like it or not, the time is near when they will have to agree to X-ray testing. A move has been made in that direction by some of the defence ministries. Light-alloy castings for aircraft have been subjected to X-ray testing as a routine test for some considerable time, but in certain countries this has been extended to all steel castings entering into the manufacture of aircraft or aircraft engines. The X-ray test has also been imposed definitely for a number of castings supplied to admiralties.

The view has been repeatedly expressed by foundrymen that the X-ray test is bound to become more and more in request, and it must be admitted that the very nature of a steel casting gives a peculiar importance to this test.

Curiously enough, most foundries look upon this development with a good deal of equanimity. They are of the opinion that, however troublesome it may be to have to undergo an extra test, and one capable of revealing hidden defects, this test will bring to their notice deficiencies in their practice and will therefore prove helpful in the long run. The more progressive consider that they should forestall the imposition of the test and themselves use the X-ray apparatus as an instrument for routine control. They hold the view that it is up to them, as steelfounders, to deliver as perfect a product as possible, and that any test capable of showing up hitherto unknown defects is likely finally to help the industry.

They point out that in the manufacture of welded articles it has already become a practice to supply, when required, a complete photograph of every weld in a job, and that nothing done by the welding industry has done more to create confidence among the buyers than the development of this practice. The objection of the steelfounder, therefore, is not one of principle. What is feared is the fact that, the time taken for testing with the present X-ray apparatus being lengthy, if the test is applied to a large number of castings, both space and time will be taken up, which will constitute an impediment to production. The maximum capacity of X-ray apparatus that seems practical in a foundry is either of 200 or 300 kilovolt capacity. Beyond this figure manufacturers hesitate to go, as the plant might become dangerous in inexperienced hands. If, with plants of this capacity, it were possible to obtain pictures by direct illumination, say through a section of a few inches of steel, the plant would undoubtedly receive a very much wider application for routine tests than is the case. Sections up to 4 in. can be examined by the X-ray apparatus, but only by means of a photographic plate, and the process lasts for hours.

In spite of this limitation, it is felt that the X-ray plant, owing to its ability to reveal defects or weaknesses which could not be discovered by any other means than destruction, is bound to play an increasingly important part in the acceptance of steel castings. Several foundries on the Continent are already equipped with X-ray apparatus at the present moment. Over a dozen of X-ray apparatus are functioning, on the other hand, in light-alloy and other foundries.

Sand Preparation and Handling

In the moulding shops there have been no developments of very striking importance, except, perhaps, the general tendency of improving the sand-preparation plants, and to solve at the same time the problems of transport connected with sand. In many foundries, due to the layout of the shop, the cost of handling the sand from the knocking-out place back to the moulding floor, after having passed through the sand preparation plant, is a more costly operation than the actual preparation of the sand. Comprehensive sand preparation and transport plants have been built or are contemplated everywhere.

The Sandslinger has made far less progress in the steelfoundries than in the ironfoundries. For some unexplained reasons, this machine is not made such extensive use of in the Continental foundries as in those of Great Britain.

Moulding Machines

With regard to moulding machines, the Franco-Belgian founder has definitely very little use for the turnover machine; he prefers a straight-jar and lift or pressure machine, which with his strongly-bonded sands are quite satisfactory. With "compo" or the leaner sands used by the German founder, this is not the case and a preference for the turnover machine is almost general throughout the German foundries. Oil sands are used on the whole very sparingly, and only for castings of thin sections and complicated design. Often, however, outside cores in oil sand are fitted into "compo" moulds to facilitate contraction and to avoid hot tears. Composite moulds made partly of "compo" and partly of moulding sand are also resorted to in many instances.

Fettling-Shop Developments

In the fettling-shop, the Bakelite-type grinding wheel driven at constant peripheral speed has become fairly general. The shot-slinging type of cleaning plant has made its appearance in many foundries and is watched with interest by the whole of the foundry community. The fact that a certain amount of competition has appeared between makers is considered as likely to prove helpful to popularise this method of cleaning. On the other hand, cleaning steel castings by means of a high-pressure water jet seems to have caused disappointment. With the pressure of 50 atmospheres used in this machine, the power consumption is appreciable. Special problems arise connected with water supply and disposal of sludge, but most of the criticism is directed to the fact that the efficiency of the machine drops considerably when core irons or core supports are met by the stream of water. It is generally felt that this machine may prove of greater boon to the ironfounder than to the steelfounder.

Riser Removal

An increasing use is being made of machines for removing, with an oxygen burner, risers the bases of which are in the shape of segments. Special machinery has been put on the market for this purpose, whereby the burner is automatically guided along a given radius. More noteworthy is the increasing use of power-driven machines carrying inserted teeth. Machines are nowadays used by the steelfoundries the general design of which reminds one of a horizontal borer, but with a massive head-stock of square section, at the end of which is provided a saw with universal movements. In one foundry eight of these machines are standing in a row and are used for cutting off any type of riser having a flat base. One of the machines in this row has a cutting capacity of 13 in., and when inspected was actually removing a circular head with a section of approximately 20 in. The operation was naturally made in four cuts. This machine is particularly valuable when castings have to be supplied with a rough-machined base. It would appear that, from the point of view of cost, it has its advantages, since the particular foundry has almost done away with the oxygen burner for removing heads. They claim that this type of saw is a cheaper proposition provided a number of saws can be looked after by a single operator.

The author hopes that this brief survey has left the impression which was intended to be conveyed, namely, that the Continental foundries are also alive to the need of moving with the requirements of the time. An industry is a live body, not a static institution. The steelfoundry industry is moving fast and tries hard to do its share in the general progress of engineering.

Employer-Federation Activities

With association and price-fixing problems still looming in the minds of steel-castings manufacturers, it may be interesting to know in what way Continental countries have been meeting the emergency which arose during the last depression, when selling prices went below production costs. In Spain, prior to the tragic events of the last two years, an association of steelfoundries functioned for a few years. The basis of the understanding was not one of tonnage quota, but merely an undertaking to quote minimum prices for all classes of work. A number of members of this association expressed themselves fully satisfied with its method of operation and no discordant voice was heard.

In France the Syndicat Général des Fondeurs, which groups the foundries of all metals, was formed as far back as 1920. It is more concerned with establishing standardised selling conditions regarding estimating costs, packing, transport guarantees, patterns, replacements and payment conditions than with fixing new prices. In Belgium a timid attempt has been made towards the establishment of a price policy, but only as far as the home railways are concerned. Such an association existed already before the War, was revived after the War, and, later on, dropped. About a year ago, this association with limited scope was brought to life once more. Thirteen main foundries belong to it. The method of division of the work is somewhat involved; it takes into account both selling price and tonnage, as some castings are worth considerably more per ton than others. There seems little likelihood of the understanding being extended to general work.

In Germany there was created, five years ago, an organisation, in many respects similar to the British association, called the Verein Deutscher Stahlformgiessereien, with its head office in Düsseldorf. The various classes of castings are carefully tabulated, and the German counterpart of what some British steelfounders call their "Bible" contains 101 pages starting with "Abdechplatten" and finishing with "Zylinder Verbindungen für Lokomotieven." A carefully compiled index refers to minimum prices which must not be underquoted. Categories of prices are mentioned according to weight. Penalties are foreseen if the minimum prices are not respected, but foundries are at liberty to quote higher figures. No arrangement exists regarding a division of tonnage on a quota basis, but it is interesting to note that the price arrangement applies equally to straight carbon steel and alloy steels. Percentage increases are naturally foreseen for the latter. For certain specialities, however, mostly to be delivered in sets like Pilger rolls or locomotive parts, there are separate understandings.

The various firms having received the inquiry, send their estimated figures to the association office in Düsseldorf, and after an examination of the estimates, it is the association which decides which price has to be quoted. Only then is a final price submitted to the customer.

Another association is functioning in Germany, namely the Stahlräder Verband. It is composed of eight or ten of the principal steelfoundries of the Reich, and is dealing with the sale of wheel centres, mine-tub wheels, and complete wheels and axles. The members of this association each have a right to a given percentage of the tonnage available. The invoices are actually sent to the association itself, which in turn invoices up to the customers, receives the product of the sale and pays the supplier. Both these associations seem to work to the entire satisfaction of the members. They have introduced orderliness in the market, and the customers themselves appear to have accepted the position ungrudgingly.

Acknowledgments

The author wishes to express his sincere thanks to all the Continental steelfounders who, during the past few months, by the frank discussion of their problems and their readiness to give information, have made it possible to give this, at any rate, true picture. In this connection mention must be made of Mr. Buerger, of Schaffhausen; Mr. Schweizer, of Saarbruchen; Mr. Jacques Henricot; Mr. Michaux, of Peugeot, and especially of Dr. Resow, of Krupps. The others are too numerous to mention, but to all of them is due the author's personal appreciation of their help.

DISCUSSION

Origin of "Green" Sand

Mr. V. C. Faulkner (Past-President of the Institute) asked whether in Belgium steel castings were being used for jobs for which, in England, malleable would be used. He believed that for railway switch work, for instance, there was a difference of practice as between the two countries. Bearing in mind references made to North-East Coast hematite, he asked whether it was still the custom of the Franco-Belgian group of founders to import iron from England or whether they had a local substitute.

Discussing sands, he said he had been told by Dr. Werner, who had lectured to the Branch on a previous occasion, that near his works at Düsseldorf there was some green-coloured sand and that that was definitely the origin of the expression "green sand." He believed also that Dr. Werner was using that local green sand in his steelfoundry. There was also a green-coloured sand available in England.

Probably the finest metallurgical laboratory in Europe was the old steelfoundry at Le Creusot, where there was a range of open-hearth furnaces having capacities varying from 5 tons up to about 25 tons. That installation was supplemented by a converter plant, a crucible plant and the electric furnaces which he had had the privilege of installing there. He asked whether the crucible process was still being used on the Continent; he believed it was used very extensively in one of the very large works until quite recently.

A year or two ago, he continued, there had been very considerable discussions in Australia as to whether the product of the converter was good enough for their best type of acceptance specifications. Therefore, he wondered whether the converter steel was universally accepted throughout the Continent as being of the highest class.

Metallic Losses

With regard to metallic losses, he asked whether they were of the same order in France as in England; he was under the impression, he said, that they were distinctly higher on the Continent than here.

As to the manufacture of manganese steel, he believed the governing conditions on the Continent should be much the same as in England, *i.e.*, they would use the electric furnace if there were an abundance of manganese steel scrap available. Another question was whether any progress had been made on the Continent with the use of electric furnaces for the heat-treatment of steel castings, for the newest steel foundry in Great Britain had adopted that process.

Finally, he asked whether a machine known as the Speed muller had made its appearance on the Continent; it had already found its way from America into Australia. Using the principle of centrifugal force, the Speed muller had 2-ft. diameter rubber-covered balls running round at about 90 r.p.m., the centrifugal force forcing the balls against the muller pan, which was rather like a milk basin. The apparatus was stated to prepare sand very rapidly without crushing the grains, at something of the order of 10 cub. ft. per minute.

Steel or Malleable Applications

Mr. Fassotte replied that he knew nothing of the Speed muller, and therefore, could not give a considered opinion with regard to it. Dealing with the question of steel castings *versus* malleable iron in Belgium, he said that malleable had not made the same strides in Belgium and France as in Germany or in this country. The reason probably was that the Belgian steel-foundries, having specialised largely on repetition work in green-sand moulds, had always been able to produce a casting which would compete economically with malleable. Automobile works in France, for instance, relied on steel castings to a far greater extent than in this country, in spite of the fact that the malleable foundries had developed the manufacture of blackheart malleable; they were producing in steel a large number of motor-car castings which in Great Britain and certainly in the United States would be made in malleable.

The Belgian steelfounder had a preference for English hematite. He had alternative sources of supply, however; it was available from several sources, including a Dutch blast furnace organisation, and occasionally a French hematite was used in Belgian foundries. The bulk of the supplies, however, still came from this country.

Mr. Fassotte said that he knew the green-coloured sand referred to by Mr. Faulkner as being produced at Düsseldorf; in Belgium also there were some green-coloured moulding sands, and one pipe foundry was using such a sand exclusively. Another type of sand, also green in colour, was used largely for the making of manganese steel castings, for it was practically devoid of oxide of iron.

There might be some crucible furnaces in use still in Belgium, but he knew of none either in Belgium or Northern France.

Mr. Fassotte said he felt it was beyond the scope of his Paper to give a personal opinion on the question as to whether the product of the converter was good enough to be used in castings to the highest specifications. It would be somewhat invidious, he added, to make a comparison between converter practice on the Continent and in Great Britain. Metallic losses in the converter varied from works to works on the Continent, just as in this country.

Mr. Faulkner suggested that they varied from 12 to 18 per cent., roughly.

Mr. Fassotte replied that, in practice, the losses varied from 13 per cent. to almost anything. However, he was of the opinion that some of the best practices were found in this country. He was aware of only a single instance of the use of an electric resistance furnace for the heat-treatment of castings. The annealing furnaces usually used were fired by stoker grates, by pulverised fuel, or by oil.

He agreed that the availability of manganese steel scrap governed the choice of process, and added that the induction furnace was being used considerably nowadays for the production of manganese steel as well as the basic arc furnace.

Critical Sections for Green-Sand Practice

Mr. J. Deschamps asked what was the critical thickness up to which castings were made in green sand on the Continent, for he believed that in this country the attempts at green-sand moulding had been limited to relatively thin castings up to now. Commenting on Mr. Fassotte's rather casual reference to lip pouring, Mr. Deschamps asked why that method of pouring was more prevalent on the Continent than here. As to the extensive use of chamotte in Germany, he said he could never understand what took place during the calcination of chamotte; he understood that it was a kind of siliceous clay, that it was not a carbonate and was not supposed to lose any weight on being calcined; he wondered why it was calcined.

Refining in the Induction Furnace

Discussing the author's references to the refining of steel in high-frequency induction furnaces, and the very important matter of the effect of the slags during the refining, Mr. Deschamps had in mind the Perrin process, which was used extensively in the Ugine plant in France and was very promising. By the use of molten synthetic slags one was able to remove practically the whole of the phosphorus content of any given steel, and he mentioned its application to converter steel in practice, where the chief difficulty was due to the presence of phosphorus. It seemed to him that one could apply that process of intimate mixture of the steel with molten synthetic slags of a highly basic and oxidising nature in a ladle; it appeared to be more or less instantaneous, and should enable one to produce in a ladle the sort of reaction which Mr. Fassotte had mentioned as taking place in the crucible of the high-frequency furnace, where slags were used for refining.

Bogie Under-Frames

Coming to the work of some of the French steelfoundries, particularly the production of bogie under-frames for sleeping cars, tenders and bogie carriages generally, representing the most intricate type of steel casting, Mr. Deschamps said he had seen a number of those frames made on the Continent and had been astounded by the quality and the efficiency. He had seen those big frames, about 8 ft. long, 5 ft. wide and 2 ft. deep, full of cores, and with thicknesses of $\frac{7}{8}$ in. or even less, in a single casting, coming out of the moulds without any cracks; they were not made in green sand, but in a special type of sand mixed with manganese dioxide. The process was quite new and was full of possibilities, and he believed it would come to this country in due course. Discussing the theory of it, he said that if an ordinary oil-sand core were used, the linseed oil in it became oxidised and gave a substantial bond to the sand, but enabling it to col-lapse under contraction stresses when the oil burned away. In the case of a fairly thick core, there was oxidation only at the skin; one could not expect the oxygen of the atmosphere to have more than a superficial action. On the other hand, if there were mixed intimately with the sand and linseed oil a certain amount of manganese dioxide, which latter, when the sand was hot, yielded very easily one atom of oxygen, the linseed oil in the very heart of the core became oxidised. Thus, there was the possibility of using less linseed oil and of increasing the collapsibility of the sand under contraction stresses.

Riser Removal

The developments in connection with the removal of the risers by means of disc saws were very interesting, but he wondered whether the greatest drawback was the very high cost of maintenance of the saws. In his experience the cost of upkeep of the saws seemed to be terrific, and he asked whether they had inverted teeth or whether they were solid saws.

As to the heat-treatment of steel castings in the electric furnace, he asked what tonnage of steel castings could be dealt with economically in that furnace; if the current could be supplied at sufficiently low cost, one should be able to avoid some of the problems of the oxidation and scaling of castings and of distortion through lack of uniform heating in the annealing oven.

It was not at all difficult to satisfy the Australian authorities that properly-made converter steel would meet their specifications. Some foundries in this country, operating only the converter process, were making steel castings which met very easily the requirements of all existing specifications for plain carbon steel castings.

Speed in Casting Green-Sand Moulds

Mr. Fassotte said that when he had referred to the use of natural moulding sand in Germany he had mentioned that opinions varied considerably with regard to the limitations of that sand. The same was true also with regard to the limitations of green-sand moulding; every foundry had a different view from others concerning the extent to which green-sand moulding could be carried on and the extent to which it was worth while carrying on with it. The rule generally followed by Belgian foundries was not to worry so much about the weight or wall thicknesses of castings, but to cast a green-sand mould on the same day as that on which the mould was made; very rarely was a green-sand mould left over night. That fact would indicate probably more definitely than anything else the general opinion about the limitations of green sand. He had in mind a foundry which was producing large gear segments, weighing 5 cwt. each, in green-sand moulds, although the wall thicknesses must have been two or three inches; there was no hesitation about producing those castings in green sand, provided that they were cast on the day the moulds were made. Green sand was used essentially for repetition work—machine-moulded and small hand-moulded work.

Reasons for Lip Pouring

The reason why lip pouring was used to such a large extent in Continental steelfoundries was because of their adoption of their green-sand practice. Obviously the green-sand mould was not so strong as a dry mould, and must be dealt with carefully. Lip pouring was more gentle in its action and was, therefore, preferred in many foundries for casting green-sand moulds. Exactly the same consideration applied to shank pouring. The use of shanks entailed inevitably considerable loss of metal, and careful records tended to show that the losses could be as high as 5 per cent. of the total weight of metal; yet for a number of castings it was worth while to put up with that loss solely to enable advantage to be taken of the gentle action of shank pouring.

He could not give a full explanation as to why chamotte was calcined at a very high temperature, unless it be that the main reason was the same as that of the maker of firebricks, who calcined his material first in order to eliminate as far as possible the initial contraction.

Slag Reactivity

With regard to the reactivity of slags used in the basic induction furnace, Mr. Fassotte said he had mentioned particularly that the slags were kept very thin, obviously with a view to speeding up the reactions. He had been present quite recently at the end of an operation carried on in a large induction furnace where a de-phosphorising slag was used in the last instance; the period between the moment of generating the slag and the moment at which the slag was skimmed off was only 3 minutes, a fact which indicated a very rapid reaction. There was some measure of similarity between this refining in an induction furnace and the Perrin process to which Mr. Deschamps had alluded.

Manganese Dioxide in Cores

The use of manganese dioxide for making collapsible cores and moulds was not extensive, so far as he was aware; he would not be dogmatic as to the extent to which it was used, but he had heard of only one foundry which was using it. Many of the under-frames for bogies, mentioned by Mr. Deschamps, indeed the majority of them, were made in plain greensand moulds. He had tried to ensure that his Paper would be as non-controversial as possible, and it was not for him to express an opinion on the matter, but it was a fact that most foundries preferred to make those under-frames in electric steel. He had no personal experience of the manganese-dioxide sand mixture, but he understood that it was necessary to take certain precautions with regard to the making of the coreboxes, and special precautions had also to be taken concerning the temperatures at which the material was rammed.

Disc Sawing Machines

All the disc saw machines which he had seen in operation recently were very rigidly built, in order to prevent vibration of the saw; the square section of the headstock measured about 12 in. per side. Even so, there was a certain amount of vibration in a particularly heavy job which he had seen. But the experience of the users of that machine was entirely favourable. He supposed that the main cause of breakage of the saws or of the teeth of the saws was lack of rigidity of the machine, and the construction of the modern tools was such that this main objection was actually overcome.

Replying to Mr. Deschamps' question concerning annealing in electric furnaces, he said that the main problem was that of price of fuel. It seemed to him doubtful that the electric furnace could meet the competition of other methods of firing unless a continuous furnace were used. High cost of fuel was a terrific handicap in the economic operation of any furnace used intermittently, whereas for continuous the higher priced fuels might be considered. It was a very open question whether it would ever be practicable to use a continuous furnace fired by a fuel so expensive as electricity in a steelfoundry, which had to anneal castings of widely different sections.

X-Ray Examination

Mr. W. B. Lake, J.P. (Vice-President of the Institute), asked to what extent the X-ray process of examination was used by those firms which had installed it. Did they use it merely on trial castings, or did some firms actually X-ray all the important castings they produced?

The reference in the Paper to the quenching of steel castings in order to obtain reduced grain size recalled to his mind a conversation he had had with Héroult many years ago, when investigating the electric furnace. Héroult had been the first man to tell Mr. Lake that if a steel casting were to be made as good as a forging, it must be quenched and that the carbon must be 0.3 per cent.

In asking for a little more explanation of the machine used for sawing-off the heads, etc., from castings, Mr. Lake said he had not quite gathered the principle on which they worked. Did the headstock itself carry the saw, or did the headstock carry a big chuck, and was the saw run on separate bearings?

Finally, Mr. Lake bore testimony to the great interest which Mr. Fassotte's Paper had created. He had made up his mind that he must be present when the Paper was presented, even if it meant driving home in the fog at night. He hoped he would not be regarded as impertinent in saying that he had never met any other visitor from the Continent who had been able to express himself so well as Mr. Fassotte had done in the English language.

MR. FASSOTTE said that, to his knowledge, only one type of steel casting was produced where each individual casting had to be subjected to X-ray examination, namely, certain castings produced for aircraft in a particular country. In foundries generally where X-ray apparatus was installed, it was not applied to every individual casting, if for no other reason that at present the process was so slow. The penetration of X-rays through steel was such that with an apparatus of 200 or 300 kilo-volts, one could get a direct reading for only a very small thickness; the exposure of photographic plates, as said, was slow.

MR. LAKE said that by X-rays one could examine steel to a depth of about 3 in.

MR. FASSOTTE agreed that that could be done by means of photographs, but not by direct reading. It was the practice to examine light alloys, such as those of aluminium, by X-rays visually, but that was not the case with steel castings, and the fact that the process was so slow was perhaps the greatest impediment to its development.

With regard to the machine used for sawing off the heads, etc., of castings, Mr. Fassotte remarked jocularly that the fact that he had not made his meaning clear in the Paper did not quite fit in with the compliment that Mr. Lake had paid him concerning his ability to use the English language. The machine, he said, had a massive headstock, about 12 inches square, which slid up and down a column, and at the end of the headstock there was a circular saw driven by a motor. The casting to be dealt with was placed on a baseplate, and remained fixed throughout the operation, and the saw came down to the job. The saw was fixed horizontally, vertically or on the slant, for cutting off the head, according to its position on the casting.

Mr. C. H. Kain (Past Branch-President) asked to what extent the Sesci furnace was used in Continental steel foundries.

Mr. Fassotte replied that one did not like to talk about one's own babies, but the furnace was being used regularly for the production of steel castings, though to a limited extent.

Mould Bonds

A Speaker asked whether Mr. Fassotte knew of any foundry using a green sand with a mixture other than water, which latter evaporated.

Mr. Fassotte said he had not seen that.

Mr. Lake commented that the practice was very common in the earliest days of green sand.

Mr. Fassotte said that silicate of soda was being used in connection with some cores and moulds, but that was no longer a green sand.

Mr. Lake recalled that a green sand which had been marketed as a proprietary article had been bonded with creosote.

Mr. Fassotte said that organic bonds of the sulphite type were used extensively in coremaking, but hardly ever in moulds.

The "Fischer Process"

Dr. A. B. Everest asked if Mr. Fassotte could enlighten him by information concerning the "Fischer process," for he had heard much about its use for making steel castings in the United States during a recent visit there. Apparently the American naval authorities were very keen on the process, which he was told had originated on the Continent, apparently in Switzerland.

With regard to hydraulic fettling and the statement by Mr. Fassotte that a pressure of 50 atmospheres was required, the Branch-President said that obviously tremendous pressure was necessary for removing the sand which was burned on to steel castings; but the figure of 50 atmospheres was probably higher than was used in the case of cast iron, and he asked for a comparable figure applying to iron castings.

Mr. Fassotte said he believed that the use of the term "Fischer process" was not quite correct, even though it might be used in the States. The Fischer foundry at Schaffhausen was a very fine foundry indeed, with a very good reputation, its products being known all over the world. He would not imagine that the Fischer people used just one particular process; they certainly possessed a very wide experience, and he presumed that the so-called "Fischer process" was rather a general practice operated under that firm's guidance by licence.

Dr. A. B. Everest said he had gathered that it was something of that sort.

Mr. Fassotte added that there was a foundry in Italy, several in the States, and there might be others, working under the advice of the Fischer steel foundry. Presumably that fact was the origin of the expression "Fischer process."

Apparently he had not made himself clear in his reference to the use of a pressure of 50 atmospheres for the hydraulic fettling of steel castings; the same pressure was used on steel as on iron. The criticism levelled against this machine by the industry was that in the cleaning of steel castings, where core irons opposed themselves to the jet of water, the efficiency of the machine was reduced tremendously; probably the same objection did not apply to iron castings.

Vote of Thanks

Mr. V. C. Faulkner, proposing a hearty vote of thanks to Mr. Fassotte for his Paper, said that it contained a wealth of interesting and utilisible information. In addition to the facility with which Mr. Fassotte had used the English language, a facility which Mr. Lake eulogised, the meeting must have also appreciated his profound knowledge of English practice. The members of the Branch and of the Institute were deeply indebted to him for having travelled from Belgium in order to present the Paper. The fact that he had so wide a knowledge of British practice had enabled him to give just the information most acceptable, and all members would look forward to the opportunity of studying the Paper again. He felt sure that no vote of thanks was ever better merited than that which he proposed to Mr. Fassotte.

Mr. H. Winterton (Immediate Past-President of the Institute), seconding the vote of thanks, said that never before had the members of the Institute been favoured by a lecture from a Continental visitor delivered in such excellent English and conveying so many English thoughts.

Commenting upon the point raised by Mr. Deschamps, as to why the German founders heated their chamotte, Mr. Winterton said that presumably they did so for the same reason that the manufacturer of compositions in this country heated his silica, *i.e.*, to reduce the danger of shrinkage and to increase the refractoriness.

Mr. C. W. Bigg (President of the Institute) supported the vote of thanks, which was accorded with enthusiasm.

Mr. Fassotte, in a brief response, said that the reception accorded him was another example of the numerous kindnesses to which his English friends had accustomed him.

Scottish Branch

HIGH DUTY IRON*

Paper No. 643

Some Experiments with the Rocking Arc Furnace

By B. MacDOUGALL (Associate Member)

It should be clearly understood that the conclusions reached in this Paper are taken from the results obtained up to the present only. Further experiments have still to be carried out to fill in obvious gaps and to finish certain series of experiments, and it is hoped at a later date to be able to complete this study.

The experiments were commenced with a view to ascertaining the conditions governing the production of cast irons unalloyed and alloyed, from an electric furnace, which would give either all or several of the properties listed below in the highest degree:—(1) Soundness; (2) machinability; (3) ultimate strength; (4) resistance to impact; (5) resistance to wear, and (6) resistance to volume changes and distortion under heat influences.

The most important of these properties is undoubtedly soundness, since a casting becomes valueless unless it be free from shrinkage defects, blowholes, slag inclusions, cracks, etc. Similarly, with machinability, unless a casting be free from hard spots and be sufficiently low in hardness value to allow of easy machining, its usefulness for general engineering work is negligible.

The first of these properties depends to a greater or less extent on practical foundry technique which, by giving proper attention to gates, sprays, risers, condition of sand, method of casting, casting temperature, etc., should

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* The Author was awarded a Diploma for this Paper.

with ordinary care result in a sound product. The second, on the other hand, depends on the chemical analysis of the metal and the thermal condition, *i.e.*, casting temperature, metal thickness and method of production, whether green-sand, dry-sand or chill casting. The correct balance of these conditions with metal analyses should produce an easily machinable casting. Since the thermal condition is of such great importance, it should here be pointed out that throughout this Paper all the results are taken from British Standard Specification 1.2 in. diameter bars, 21 in. long, which were machined for tensile test without any heat-treatment to 0.65 in. diameter, *i.e.*, $\frac{1}{3}$ sq. in. area. These bars were produced in oil-sand cores 3 in. square which were inserted into a 6 in. diameter tube and rammed with a backing sand, three tests being taken per experimental heat of 300 lbs.

Assuming the properties of soundness and machinability, high-grade cast iron has commonly been defined on the basis of strength property, since there is a broad relationship existing between this property, growth and wear. This statement is made in its broadest sense, since any feature of composition, constitution or treatment which influences one or other of these related properties is likely to have a similar effect on the remaining properties. For example, much has been written on growth and irons with low silicon content. Assuming the machining property, tensile strength and wear are also compatible with low silicon. Similarly, with low total carbon, it is known that the tensile strength is improved, while wear and growth are not impaired, but in some cases are even improved. In these experiments, therefore, high-duty iron will be considered solely from the point of view of improving the tensile strength, it being assumed that the other properties, *i.e.*, wear and growth, are related.

The Furnace

The furnace (Fig. 1) installed for these and subsequent experiments is of the single-phase

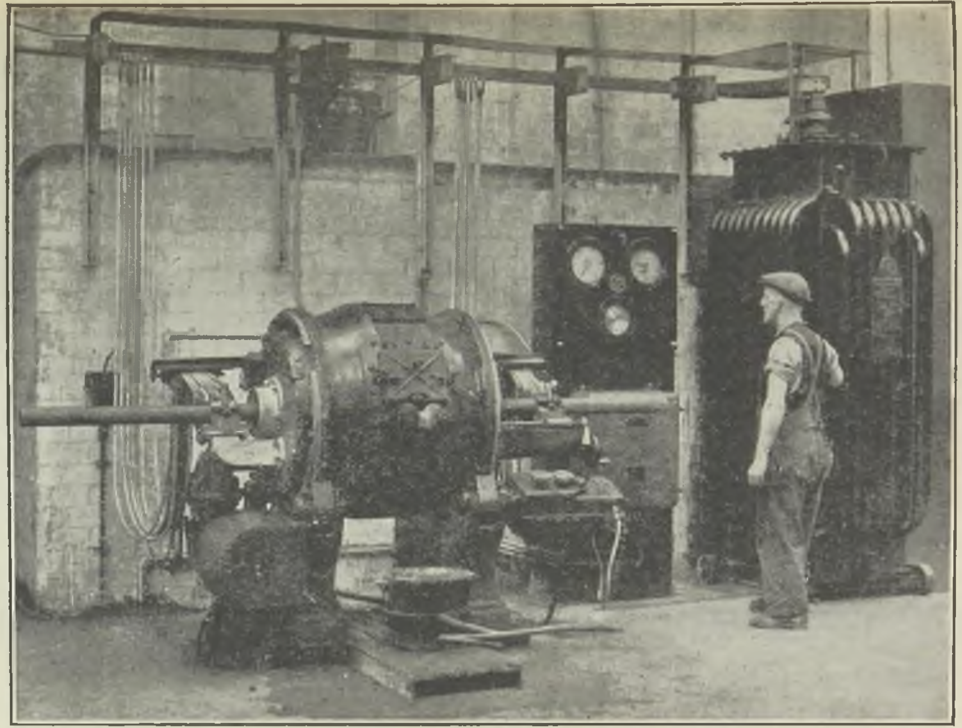

Fig. 1.—Rocking Electric-Arc Furnace in which the Experiments were carried out.

rocking arc type of rated capacity 350 lbs. cold charge and 500 lbs. liquid charge and a power input of 125 kw. It has a horizontal cylindrical body, on the axis of which enter two graphite electrodes. This cylindrical body is lined with rammed sillimanite, although it is agreed that for grey-iron melting this is not the best. This body is arranged to rock through a varying angle about its horizontal axis, an ingenious automatic rocking control device being supplied to facilitate operation. By means of this device, rocking can be maintained at a definite angle between 20 and 260 deg. or arranged to increase through varying angles at fixed periods.

The advantages of rocking are longer lining life and quicker melting, due to the fact that the metal is in direct contact with practically the whole of the lining during the molten state, thus absorbing heat from the lining, and maintaining a uniform heat balance between the metal and lining. The factors contributing to the selection of an electric furnace for the production of high-duty iron may be summed up as follows:—

(1) Uniformity and control of chemical analysis. No sulphur or carbon pick-up.

(2) Ability to give high degree of superheat.

(3) Ease with which alloy additions can be made.

(4) Only small quantities about 1,000 lbs. of metal required at one time on any day.

It is not proposed to enter into the cost of operating this type of furnace for two reasons. Firstly it is beyond the scope of this Paper, and secondly, since the furnace has been operating intermittently, and under varying conditions, it has not yet been found possible to estimate accurately what the cost will be on a production basis.

Effect of Superheating Ordinary Cupola Irons in the Electric Furnace

It has been claimed of superheating that it refines the graphite, and at least three theories have been put forward explaining this. Piwowarsky[1] states that the degree of superheating temperatures attained by the molten metal determines the percentage and fineness of the graphite in it. Osann,[2] on the other hand, seems rather inclined to think that refining is due to the following mechanism. As the iron remains a long time liquid in the electric furnace, " kish " or hyper-eutectic graphite has the opportunity to get out of the alloy, graphitisation then taking place at the true stable eutectic temperature, when cooling down in the mould, resulting in fine graphite. Hannemann[3] evolved the nuclei theory by saying that if one remelts pig-iron this does not result in all the graphite germs or nuclei being dissolved. Nuclei remain behind in the liquid iron and form the starting point for crystallisation of the graphite in the solidified state, which crystallisation is based on the dissociation of the cementite. When the iron is superheated, the nuclei are dissolved and crystallisation of the graphite results in a fine-grained form. In view of these theories and claims for superheated iron, several heats were tried transferring cupola-melted metal to the electric furnace and superheating to 1,600 deg. C. or over, without further addition; test-bars were taken before and after this treatment, and Table I shows the results obtained.

On studying these results, one is forced to conclude that there is definitely an improvement, especially in the tensile strength, which is increased from 7 to 38 per cent., the greatest improvement being shown on the highest carbon content iron. However, one is forced to conclude that this improvement is due possibly more to the effect on the analyses than any effect on graphite. As will be observed in all three cases, the total carbon has been decreased by

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[1] Piwowarsky: "Progress in Production of High-Test Iron," Trans. American Foundrymen's Association, Vol. 34, 1926.

[2] Osann: "The Manufacture of High-Quality Cast Iron," "Foundry Trade Journal," December 20, 1928.

[3] Hannemann: "Stahl und Eisen," 1927, Vol. 47, p. 693.

TABLE I.—*Effect of Superheating Cupola-Melted Iron in an Electric Furnace.*

Heat No.	6		47		48	
	Cupola melted.	Super-heated.	Cupola melted.	Super-heated.	Cupola melted.	Super-heated.
T.C per cent.	3.65	3.53	3.46	3.36	3.48	3.34
Si ,, ,, ...	1.89	1.92	1.23	1.16	1.85	1.67
P ,, ,, ...	0.25 max.	0.25 max.	0.25 max.	0.25 max.	0.25 max.	0.25 max.
S ,, ,, ...	0.1 ,,	0.1 ,,	0.1 ,,	0.1 ,,	0.1 ,,	0.1 ,,
Tensile, tons per sq. in. ..	9.0	12.4	15.1	16.2	12.9	14.8

3 to 4 per cent. of the original content, which might justify Osann's theory, but the silicon in two of the heats has also dropped about 10 per cent., suggesting oxidation.

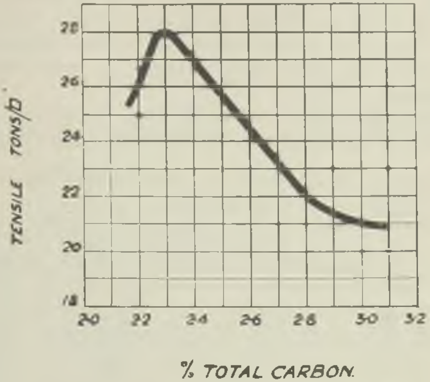

Fig. 8.—Synthetic Unalloyed Iron—Effect of Total Carbon on Tensile Strength.

The graphite structures were examined and Fig. 2, which shows the cupola-melted iron from heat No. 47 at a magnification of 100, reveals a large quantity of evenly-distributed, medium-sized graphite flakes. Fig. 3 shows this same heat after superheating in the electric furnace.

Table II.—*Synthetic Ordinary Irons.*

Heat No.	33	34
T.C per cent.	3.67	3.44
Si ,, ,,	1.72	1.34
P ,, ,,	0.1 max.	0.1 max.
S ,, ,,	0.1 ,,	0.1 ,,
Tensile, tons per sq. in.	10	17.3

The graphite structure shows no improvement; if anything the flakes appear slightly larger than in Fig. 2. [For photomicrographs see page 455 *et seq.*]

Fig. 4 shows the higher silicon content iron as received from the cupola (Heat No. 48) and here the graphite structure is very little different from Fig. 2, the flakes being, if anything, larger. Fig. 5 shows the same iron as Fig. 4 after superheating in the electric furnace, and like Fig. 3 this shows no improvement; if anything the flakes are coarser, but more evenly dispersed.

From the examination of these structures one is forced to conclude that, under the circumstances described, superheating has failed to refine the graphite. Concerning Hannemann's nuclei theory it was decided to run two heats by melting steel, carburising this, and then adding the necessary silicon and manganese, so that the analyses would be almost similar to heats Nos. 47 and 48. By so doing, it was argued that there would be no existing nuclei to form the starting for crystallisation of the graphite, and a fine graphite structure should therefore result. Table II shows the results obtained.

TABLE III.—*Comparison of Cupola-Melted Iron with Synthetic Iron.*

Heat No. ..	Synthetic. 33	Cupola melted. 6	Synthetic. 34	Cupola melted. 47
T.C per cent. ..	3.67	3.65	3.44	3.46
Si ,, ,, ..	1.72	1.89	1.34	1.23
P ,, ,, ..	0.1 max.	0.25 max.	0.1 max.	0.25 max.
S ,, ,, ..	0.1 max.	0.1 max.	0.1 max.	0.1 max.
Tensile, tons per sq. in. ..	10.0	9.0	17.3	15.1

A comparison between these irons and the superheated cupola-melted irons is shown in Table III.

It will be agreed that there is a very slight improvement with the synthetic irons over the direct cupola-melted irons, and Fig. 6 shows the graphite structure of heat No. 33 which, if anything, is even coarser than the superheated cupola-melted iron of same analysis, *i.e.*, heat No. 48 (Fig. 5). Fig. 7 shows the graphite structure of heat No. 34, which, compared with the superheated cupola-melted iron of same analysis, *i.e.*, heat No. 47 (Fig. 3), appears even coarser structure.

Low Total-Carbon Irons

Although the foregoing experiments have shown slight improvement in physical tests over the ordinary cupola-melted irons, the results obtained are not, by any means, what it was originally set out to attain. The next line of attack left open, therefore, in the production of high-duty cast iron is, of course, the low total-carbon series. By this method, a smaller quantity of graphite should result, both by virtue of the lower total carbon and of the increased combined carbon and it is said that with the smaller quantity of graphite the individual flakes are smaller. The method employed to produce this low total-carbon iron was by using all steel charges, carburising to the desired amount and

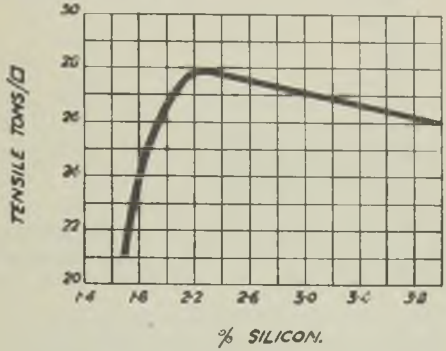

FIG. 9.—SYNTHETIC UNALLOYED IRON—EFFECT OF SILICON ON TENSILE STRENGTH IN THE RANGE 2.2 TO 2.4 PER CENT. T.C.

then adding the necessary silicon and manganese. Experiments were first of all made to decide which of all the carbonaceous materials commonly used in the foundry would give the greatest absorption of carbon. The procedure adopted in all cases was to charge the carbonaceous material on the bottom of the furnace, then steel, and after melting and superheating, silicon and manganese additions were made.

Table IV.—*Absorption Test. The Effect of Melting an All-Steel Charge with Varying Carbonaceous Materials.*

Heat No.	Carbonaceous material.	Metal charge.	Total carbon.	Carbon absorbed.
			Per cent.	Per cent.
	Finely-ground coke	90 lb. steel ; 5 lb. Fe-Mn; 4.3 lb. 47 per cent. Fe-Si; 5.0 lb. carbonaceous material.	2.46	49
35	Wood charcoal		2.91	58
36	Ground electrodes		4.13	82
37	Plumbago		2.42	48
38	Blacking		3.08	61

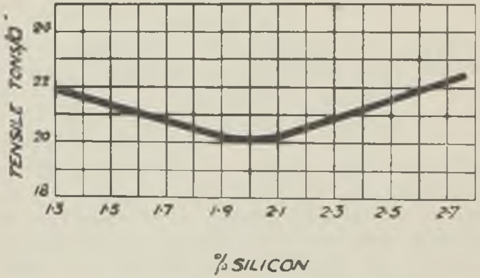

Fig. 12.—Synthetic Unalloyed Iron—Effect of Silicon in the Range 2.7 to 2.9 per cent. T.C.

Table IV shows the results obtained. Heat No. 36 with ground electrodes gave the greatest absorption. It was therefore decided to use this form of material for carburisation of all steel charges throughout the remainder of the experiments since there was available a reasonable supply of used electrodes. Subsequent results, using this material, gave absorption figures as high as 98 per cent. The average, however, was in the region of 90 per cent.

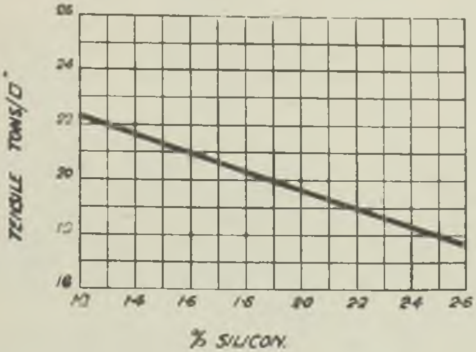

FIG. 13.—SYNTHETIC UNALLOYED IRON—EFFECT OF SILICON IN THE RANGE 3.0 TO 3.1 PER CENT. T.C.

Synthetic Unalloyed Irons

Following the procedure as described for the absorption tests, several heats were made with varying silicon and total-carbon contents in an endeavour to decide approximately the effect of these variations on tensile strength. Since the charge consists mainly of steel, with phosphorus and sulphur content in the region of 0.05 per cent., it has been taken for granted throughout the remainder of these tests that the effect of these elements remains constant; similarly with manganese, since additions were made to all charges to maintain this element at approximately 1 per cent. Table V shows the results obtained.

It will be seen from Table V that the total carbon varies from 1.7 to 3.1 per cent. and silicon from 1.2 to 3.9 per cent. In this series of tests the highest tensile strength obtained was 28 tons per sq. in., whilst the lowest was 18 tons per sq. in. Analysing these figures, the first point of interest is the effect of total carbon on tensile strength, and Fig. 8 illustrates this clearly.

The maximum point obtained, 28 tons, is in the range of 2.2 to 2.4 per cent. total carbon. The lower tensile strengths follow with higher total carbon until, at 3.1 per cent. total carbon, an average of 21 tons tensile is apparent. Increasing the total carbon beyond 3.1 per cent. causes the tensile strength to fall in direct proportion until, at 4.0 per cent. total carbon, only 9 tons per sq. in. is obtained. This shows that with synthetic irons and electric-furnace melting there is no improvement over cupola melting other than that which can be obtained by adjustment of the composition.

To study the effect of silicon in this range, it is necessary to sub-divide this group into three series of varying total carbon ranges, (I) 2.2 to 2.4 per cent., (II) 2.7 to 2.9 per cent. and (III) 3.0 to 3.1 per cent. total carbon. Unfortunately, the experiments have not advanced sufficiently to include sufficient evidence of the effect of silicon on the total-carbon range 2.4 to 2.7 per cent. It is intended to complete this range at a later date.

Dealing with total-carbon range (I), 2.2 to 2.4 per cent., *i.e.*, the range of highest tensile strength, Fig. 9 illustrates the effect of silicon.

It would seem that with increase of silicon from 1.6 to 2.0 per cent. the tensile strength is increased from 21 to 28 tons. Further increase in silicon appears to have very little effect on tensile strength, as at 3.9 per cent. silicon the tensile strength has dropped only two tons from the maximum, *i.e.*, to 26 tons tensile.

TABLE V.—*Synthetic Unalloyed Iron.*

Heat No.	43	3	19	27	28	29	30	31	32	34	35	37	38	73	74	75	76	77	78
T.C per cent.	3.1	2.8	2.7	2.3	2.8	2.2	1.7	2.2	2.3	2.5	2.9	2.4	3.1	3.1	2.7	3.1	3.0	3.0	3.1
Si ,, ,,	1.2	1.8	2.7	1.7	1.3	3.9	2.0	2.0	2.1	2.1	2.6	2.5	2.1	2.5	2.5	1.6	1.8	2.0	2.4
Tensile, tons per sq. in.	23	21	21	21	22	26	24	25	28	23	23	27	20	18	21	18	18	20	19

Fig. 10 illustrates the structure of Heat No. 32, the highest tensile, which shows a small quantity of evenly-distributed and finely-divided graphite. The magnification is × 100. Fig. 11 shows the etched structure (1 per cent. HNO_3 in alcohol) at a magnification of 200. The very fine pearlite grain size is worthy of note. This was not, however, clearly resolved until submitted to a magnification of 1,300.

In the next range (II), total carbon 2.7 to 2.9 per cent., Fig. 12 shows a silicon variation of from 1.3 to 2.7 per cent. produces very little effect on tensile strength. With a 1.3 per cent. silicon, the tensile strength obtained was 22 tons, whilst at 2.5 per cent. silicon, the tensile strength obtained was in the region of 21 to 22 tons per sq. in.

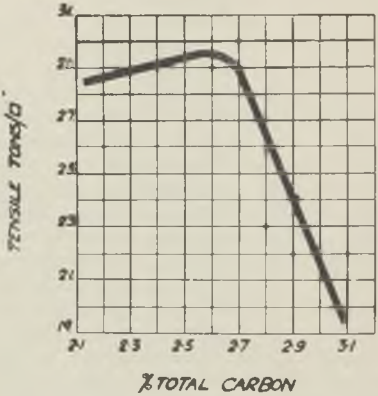

Fig. 17.—Synthetic Nickel Iron —Effect of Total Carbon.

In the final range (III), 3.0 to 3.1 total carbon, Fig. 13 shows that increasing the silicon from 1.2 to 2.5 per cent. causes a decrease in the tensile strength from 23 tons per sq. in. to 13 tons per sq. in. From these graphs it would appear, therefore, that with a total carbon of from 2.2 to 2.9 per cent., increasing the silicon beyond 2.0 per cent. has very little effect on tensile strength, while, in the range 3.0 to 3.1 per cent. total carbon, increasing silicon causes a reduction in tensile strength.

Synthetic Nickel Iron

Before proceeding to discuss the results obtained under this group, it should be understood that the term "high-duty iron" refers only to high-strength iron. For this reason, the nickel content will be in the range of what is known as the low nickel content group, *i.e.*, 0.5 to 2.00 per cent. It is therefore not intended to deal with the heat- and corrosion-resisting austenitic irons with a nickel content of from 12.0 to 20.0 per cent.

From what has been published about the effect of nickel on cast iron, the following summary for this group may be made:—

(*a*) Tendency toward graphitisation of free-carbide (if this normally would be present in the absence of nickel).

(*b*) A perceptible hardening of the matrix, due to pearlite lamination being made finer and approaching a sorbitic structure as nickel is increased.

The statement that nickel is at once a softener and a hardener is explained by Dr. Everest[4] and Dr. Hanson[5] as follows:—Nickel is apparently about half as effective as silicon in graphitisation of free (eutectic and eutectoid) cementite. The reaction in grey irons is peculiar, in that nickel and silicon apparently act cumulatively in graphitisation of free cementite; but below the eutectoid transformation, nickel under the cooling conditions prevailing in ordinary casting sections apparently does not readily graphitise the combined carbon (cementite) of pearlite, and conceivably may retard somewhat

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[4] "The Influence of Nickel Chromium on Cast Iron," "Foundry Trade Journal," January 3, 1929.

[5] "The Influence of Nickel on Iron-Carbon-Silicon Alloys containing Phosphorus," "Foundry Trade Journal," May 2, 1928.

the graphitising action of silicon. Silicon alone, within a certain range, decomposed the pearlite as well as the massive carbide.

Finally, concerning the effect of phosphorus, both Dr. Everest and Dr. Hanson conclude that phosphorus tends to reduce the influence of nickel on cast iron. From these observations the effect of nickel in personal experiments is at once apparent. First, as previously explained, since the charge consists of all steel with the phosphorus content in the region of 0.05 per cent., the maximum influence of the nickel content used, as far as this element is concerned, is obtained, and secondly, the conditions of casting the test-bars become more stable since cooling influences are less effective with nickel content.

Table VI shows the results obtained.

TABLE VI.—*Synthetic Irons with Nickel.*

Heat No. ..	8	14	20	23	24	61	63	62	64	65	66
T.C per cent.	2.7	2.9	2.7	2.4	2.6	2.8	3.1	2.8	2.9	2.8	2.9
Si ,,	1.5	1.8	2.8	1.8	1.5	1.7	2.1	2.1	2.0	2.0	1.8
Ni ,,	1.3	1.4	1.0	1.6	1.5	1.5	1.6	1.5	1.5	1.5	1.6
Tensile, tons per sq. in.	30	24	22	29	29	20	22	20	24	23	22

The range of total carbon is from 2.4 to 3.1 per cent.; nickel 1.0 to 1.6 per cent., and tensile strength from 20 to 30 tons per sq. in. Heat No. 8 gave the highest tensile strength of 30 tons. Fig. 14 illustrates the graphite structure of Heat No. 8, which is evenly distributed and reasonably finely divided. The magnification is 100 diameters. Fig. 15 shows the structure obtained by etching in 1 per cent. HNO_3 in alcohol, the magnification being 200 diameters. Fig. 16 shows very fine pearlite with some sorbite which is more apparent at a magnification of 1,000. In this series the effect of total carbon on tensile strength is at once apparent in Fig. 17. This agrees with the graph, Fig. 8, for synthetic unalloyed iron, in that the highest tensile strengths are in the range of lowest total carbon that is from 2.4 to 2.7 per cent. From what has been said regarding the influence of nickel, an interesting comparison has been obtained between heats of synthetic unalloyed irons of similar analyses and heats of synthetic nickel iron. These heats are set out in Table VII.

TABLE VII.—*Comparison of Similar Heats with and without Nickel.*

Heat No.	28	8	27	23	3	14	38	63	19	20
T.C per cent. ..	2.8	2.7	2.3	2.4	2.8	2.9	3.1	3.1	2.7	2.7
Si ,, ,, ..	1.3	1.5	1.7	1.8	1.8	1.8	2.1	2.1	2.7	2.8
Ni ,, ,, ..	–	1.3	–	1.6	–	1.4	–	1.6	–	1.0
Tensile, tons per sq. in. ..	22	30	21	29	21	24	20	22	21	22

The effect of 1.0 to 1.6 per cent. nickel seems to be greater on the lower total carbon and lower silicon ranges, where the tensile strength has been improved by as much as 8 tons per sq. in. or about 30 per cent. Fig. 18 shows this effect clearly. The numbers on the graph indicate the heat numbers.

Further experiments are still pending in this series, with varying nickel up to 2.5 per cent. on low total carbon 2.3 to 2.6 per cent. and low silicon from 1.3 to 1.8 per cent., when further illuminating results are anticipated.

Before leaving this series of tests it seems germane to describe an interesting experiment which was made in an endeavour to produce a grey iron by graphitising with nickel only. According to Pearce,[6] 4 per cent. nickel added to an iron with no silicon would produce supercooled graphite with resultant increased benefits. Heat No. 18R was made to check the results with a 300-lb. melt. Table X shows the analyses and test results obtained from this heat.

Fig. 19 shows an area of the graphite structure obtained, which is supercooled. The mechanism of the production of this structure is said to be

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[6] "The Graphite Structure of Grey Cast Iron and its Modification," "Foundry Trade Journal," March 25, 1937.

as follows:—" In ordinary flake graphite irons the inclusions are solid and crystalline." When the metal solidifies these inoculate the melt. In cases where supercooled graphite is deposited, it is suggested that the inclusions are still liquid externally when the metal solidifies so that these do not inoculate the melt, which subsequently supercools. Fig. 20 shows the etched structure, which has areas of pearlite free cementite and massive cementite. Either due to the presence of this latter structural constituent or to the presence of flake graphite as well as supercooled graphite or to the general combination, the test result on Table X is very poor, being only 17.2 tons per sq. in.

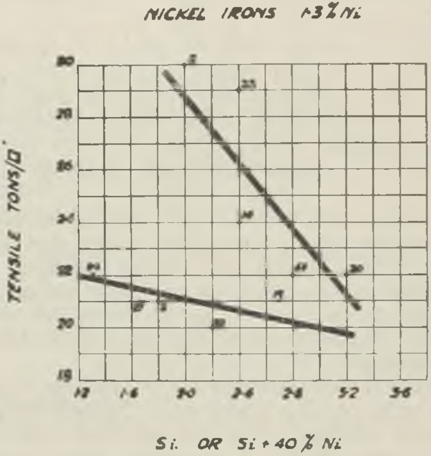

FIG. 18.—SYNTHETIC IRONS—COMPARISON OF SIMILAR HEATS WITH AND WITHOUT NICKEL (NICKEL IRONS CONTAINING 1.3 PER CENT. NI).

Synthetic Irons with Molybdenum

This series of tests originated in an endeavour to produce an iron which would give increased resistance to growth at temperatures about 315 deg. C. and little or no reduction in tensile strength at this temperature. From work published by Mussatti and Calbiani[7] there is some reason to believe that the carbide-stabilising tendencies of molybdenum may hinder growth after long periods at this temperature. The results of personal experiments in this field are not yet completed, but there are sufficient data to compare the effect of molybdenum on strength properties at atmospheric temperatures. Table VIII shows the results obtained in this series of experiments.

TABLE VIII.—*Synthetic Irons with Molybdenum.*

Heat No. ..	40	52	50	53	54	55
T.C per cent. ..	3.3	2.9	2.9	2.9	2.8	2.4
Si ,, ,, ..	2.3	2.2	2.4	2.4	2.6	2.0
Mo ,, ,, ..	0.46	0.48	0.5	0.47	0.48	0.47
Tensile, tons per sq. in.	17	22	20	22	24	28

It will be noted that the molybdenum content is maintained in the region of 0.5 per cent. When making these heats consideration was given to the high melting point of the 70 per cent. ferro-molybdenum used. This commences to melt at approximately 1,540 deg. C. and is not complete until a temperature of 2,100 deg. C. The procedure adopted in producing these heats was to melt the all-steel charge plus carbonaceous materials and superheat to about 1,600 deg. C.;

TABLE IX.—*Synthetic Irons with Nickel and Molybdenum.*

Heat No. ..	56	57	58	59
T.C per cent. ..	3.1	2.9	2.8	2.6
Si ,, ,, ..	1.7	2.0	2.1	1.0
Ni ,, ,, ..	2.0	2.0	2.0	1.8
Mo ,, ,, ..	0.47	0.48	0.45	0.32
Tensile, tons per sq. in. ..	25	24	31	33

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[7] "Le Metallurgia Italiani," June, 1930.

then the ferro-molybdenum, silicon and manganese additions were made and the whole maintained at this superheat temperature for a period of at least 10 min. Studying the results obtained

TABLE X.—*Graphitisation with Nickel Only.*

Heat No. ..	18 R	
T.C per cent. ..	2.84	G.C 1.34 per cent. C.C 1.5 per cent.
Si ,, ,, ..	0.51	
Ni ,, ,, ..	4.17	
Tensile, tons per sq. in. ..	17.2	
Brinell	302	

in the series, it will be noted that the tensile strength varies from 17 to 28 tons per sq. in. with total carbon varying from 3.1 to 2.4 per cent. Table XI gives an interesting comparison of synthetic unalloyed heats with heats of similar analyses from the synthetic molybdenum series.

TABLE XI.—*A Comparison of Synthetic Molybdenum Iron with Synthetic Unalloyed Iron.*

Heat No. ..	53	35	54	74	55	32
T.C per cent. ..	2.9	2.9	2.8	2.7	2.4	2.3
Si ,, ,, ..	2.4	2.6	2.6	2.5	2.0	2.1
Mo ,, ,, ..	0.47	—	0.48	—	0.47	—
Tensile, tons per sq. in.	22	23	24	21	28	28

This comparison shows that there is very little effect or improvement on the tensile strength by the addition of approximately 0.5 per cent. molybdenum.

Synthetic Irons with Nickel and Molybdenum

This series was also introduced with a view to producing an iron which would give increased resistance to growth with little or no reduction in strength at temperatures ranging from 200 to 320 deg. C.

However, the physical results in the as-cast conditions, as shown in Table IX, are very interesting, inasmuch as tensile strengths as high as 31 and 33 tons per sq. in. have been obtained. Fig. 21 shows the graphite structure at 100 magnifications of heat No. 59, which gave the highest tensile, *i.e.*, 33 tons, and Fig. 22 the etched structure, at 200 diameters. It should be noted that very little graphite which is small is present. The etched structure shows practically all sorbite, which is more apparent at a magnification of 1,300.

There are not enough data to make a comparison with any of these heats, but from what has been observed personally of the effect of nickel and of molybdenum on synthetic ordinary irons, it would seem that the higher tensile strengths ranging in this series of experiments are more a function of the nickel content rather than the molybdenum content. However, further work has still to be carried out to confirm this.

Conclusions

Summarising the conclusions arrived at in these experiments it would appear that:—

(1) Superheating is not the only factor, aside from composition, which materially affects the nature of the graphitisation.

(2) In synthetic low total-carbon unalloyed irons the tensile strength depends more on the total carbon. The highest range is in the region of 2.2 to 2.4 per cent. total carbon. Silicon beyond 2.0 per cent. appears to have little influence on tensile strength in the total-carbon range of from 2.2 to 2.9 per cent.

(3) In synthetic nickel iron 1 to 1.6 per cent. nickel induces an improvement in tensile strength, due possibly to the stabilisation of the cooling influences which prevail during casting (*i.e.*, retardation of graphite precipitation below eutectic temperature). The highest tensile range appears to be with total carbon from 2.4 to 2.7 per cent.

(4) Half of 1 per cent. of molybdenum in the lower total-carbon ranges, from experiments made, appears to have little effect on the tensile strength.

(5) In the nickel-molybdenum series a decided improvement was obtained, but whether this is a function of the 2 per cent. nickel added or the combination of nickel plus molybdenum, still remains to be proved.

(6) Finally, it would appear that the correct line of development for the production of strong irons is by lowering the total carbon, which results in a smaller quantity of graphite, whose individual flakes are smaller in a ground mass of very fine pearlite or, if possible, with sorbite, rather than endeavouring to produce refined graphite structures, as all the known methods of doing so are very uncertain in their results.

As has been stated at the beginning of this Paper, there are still several gaps to be filled in this series of experiments, the outstanding being the nickel-chrome series and nickel-chrome-molybdenum series. The author hopes at an early date, however, to be able to complete all of these.

In conclusion, the author wishes to express his appreciation of the very helpful co-operation of Mr. N. McManus and Mr. J. Arnott in connection with the preparation of this Paper; also to Mr. F. Hovell and Mr. Biles for their assistance in the production of the lantern slides; and finally to the directors of G. & J. Weir, Limited, foı permission to publish this Paper.

DISCUSSION

Mr. E. J. Ross (Branch-President), opening the discussion, said he wondered whether Mr. MacDougall, in speaking of future experiments, was promising another Paper at a future date. The Paper was a record of much valuable experiment. No doubt many of the members

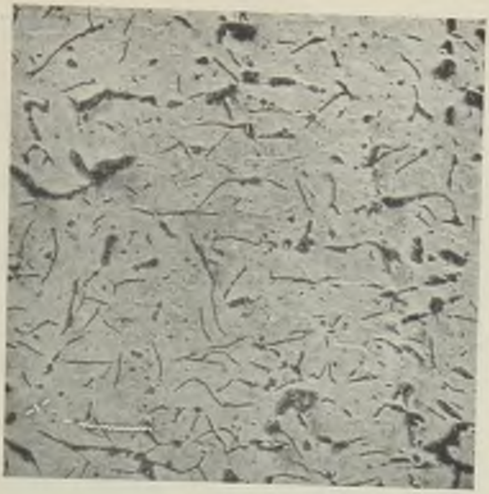

Fig. 2.—Heat 47, Cupola Melted. × 100.

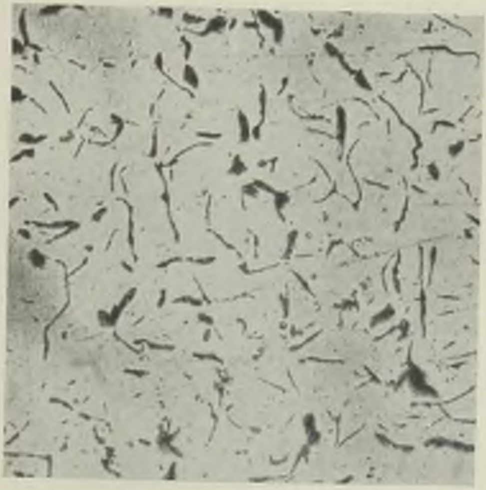

Fig. 3.—Heat 47 after Superheating. × 100.

Fig. 4.—Heat 48. × 100.

Fig. 5.—Heat 48 after Superheating. × 100.

Fig. 6.—Heat 33. × 100.

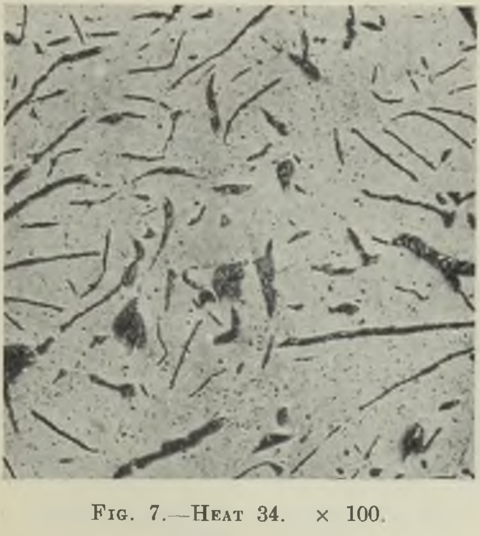

Fig. 7.—Heat 34. × 100.

Fig. 10.—Heat 32. × 100.

Fig. 11.—Heat 32. Etched. × 200.

FIG. 14.—HEAT 8. × 100.

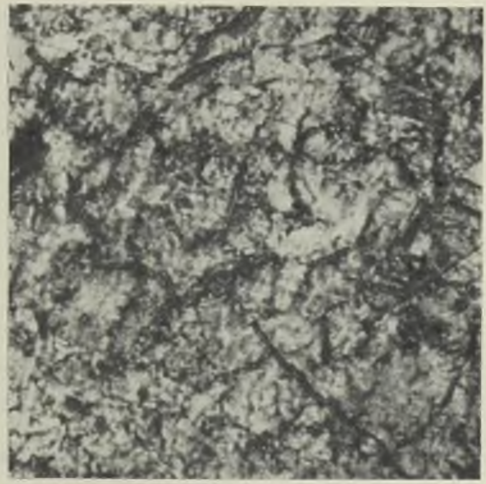

FIG. 15.—HEAT 8. ETCHED 1 PER CENT. HNO_3. × 200.

FIG. 16.—HEAT 8. ETCHED. × 1,000.

FIG. 19.—HEAT 18 R. × 100.

Fig. 20.—Heat 18 R. Etched. × 200.

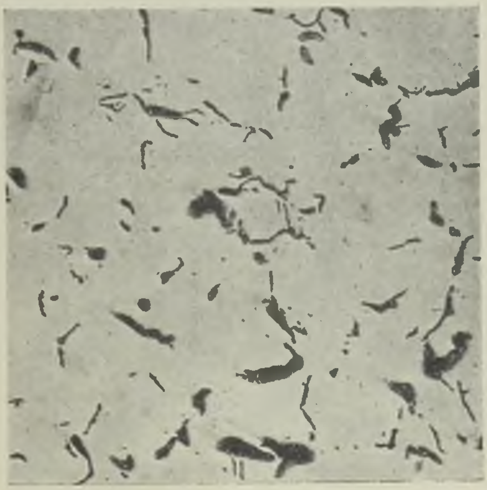

Fig. 21.—Heat 59. × 100.

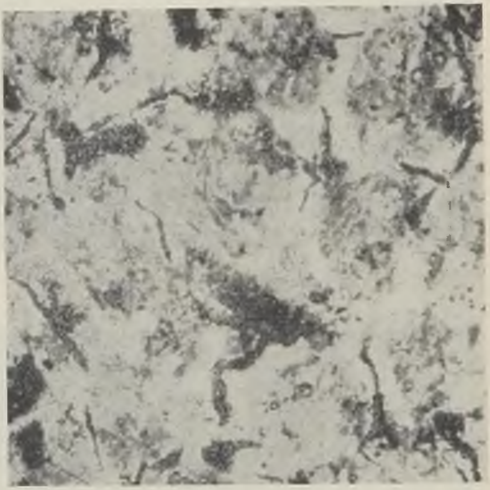

Fig. 22.—Heat 59. Etched. × 200.

present would wish to have some of the points elaborated, but it had to be remembered that the furnace in which the experiments were made was of recent design.

Fluidity and Temperature Measurement

Mr. D. Sharpe complimented the author and G. & J. Weir, Limited, upon instigating the extensive series of experiments and in placing the results before members of the Institute. A point he would like to raise was that of fluidity of the metal. Had fluidity tests such as the spiral test been taken? He thought it would be of interest to have definite figures to indicate the degree of fluidity attained, and the spiral test was of great assistance. Mr. Sharpe considered that the fluidity of the metal was almost as important as the high strength. Further questions related to the duration of soaking referred to, and what temperatures were attained and how they were determined. Did the temperatures of the nickel-molybdenum series correspond with the temperatures of the other series?

Mr. MacDougall said that fluidity spiral tests had not been made; he had only judged by practical tests. There had not been any difficulty in handling the metal, and he thought the running of the castings was sufficient indication of ample fluidity. As to soaking, he suggested holding the metal for sufficient time to eliminate the hyper-eutectic graphite. When running an all-steel charge 92 to 98 kilowatts were used and when superheating they purposely overloaded at 60 kilowatts in the molten charge. In regard to Mr. Sharpe's remarks on temperature determination, he thought that the question of temperatures always caused trouble. In the trials he had used a very practical test after the manner of steel smelters. A wrought-iron bar was plunged into the metal for 5 seconds and then examined. The kilowatts used were also noted, and in this way they obtained results as reliable as by the use of a pyrometer.

Mr. J. Arnott, F.I.C., thought that it should be made clear that the electric furnace was not the only method of producing high-strength cast iron. Some of the members present were obtaining strengths of 25 tons per sq. in. and over from iron melted in cupolas. The small electric furnace had proved to be a very useful unit for making small experimental casts. He took exception to the author's remarks about machinability; he had in mind machinability of materials for some motor-cars which were a very short time in the shops and a short time on the road. In his graphs Mr. MacDougall was inclined to make a straight line between points which varied quite a lot, and obtain relationships which were not fully proved. The Paper was a helpful contribution to the technique of high-quality irons.

A Practical Test

Mr. Braidwood said he had been interested in the author's method of estimating temperature, but he was inclined to think that a pyrometer should have been used. How exactly could the temperature be estimated by the wrought-iron test?

Mr. MacDougall replied that he used a $\frac{1}{4}$-in. sq. rod, which was moistened and then plunged in the bath for 5 seconds. The length of rod melted off was then measured.

Mr. R. S. M. Jeffrey, after congratulating the author on the amount of work which he had so carefully performed, said that the tensile strengths of 18 to 28 tons obtained were not exceptional. The few tests over 28 tons, notably that of 33 tons with a nickel-molybdenum addition, were specially interesting. It was, however, difficult to discuss fully the matter, because the work was not complete. His own experience was that there was very little improvement effected by nickel; he was regularly obtaining the same results without nickel additions from metal melted in the cupola. He thought the carbon plus silicon total was a more important criterion than the silicon content alone, and he was not altogether in favour of reducing the silicon and replacing with nickel and molybdenum.

Mr. MacDougall said that there was something to be said for lowering the silicon and replacing by nickel, but in the tests which he had made the biggest improvement was effected by using low total carbon and silicon.

Future Research Hints

Mr. A. Campion said he had noticed the apparent lack of agreement in the total-carbon-plus-silicon figures. The same result seemed to have been obtained with totals of 6.1 and 4.2 in the tables shown. It had to be remembered that the figures which Mr. Jeffrey had given referred to cupola-melted iron, and it was possible that a different balance applied to metal melted under the conditions of the present experiments. The author appeared to be surprised at the small increase of tensile strength which resulted from the addition of molybdenum, but it was just about what the speaker would have expected. In his experience, molybdenum was not a large strength raiser, its main effect being to increase shock and fatigue resistance. If Mr. MacDougall made such tests, he thought some very interesting results might be obtained.

He was pleased to note that the author had in mind experiments on the chrome-nickel series, but he thought more useful results would be obtained from a straight-chromium or a chrome-molybdenum series; the latter was a particularly useful combination. Mr. MacDougall's experiments had been carried out in a rocking furnace, and it was an interesting conjecture as to how far the agitation of the molten metal had contributed to the results.

The Branch-President proposed a vote of thanks to the author, which was enthusiastically given.

Mr. MacDougall, responding, said it was his first attempt at lecturing, and he was grateful for the attention and encouragement which the members had given. He was pleased to have Mr. Campion's confirmation of the effect of molybdenum, as he had been puzzled by the contradictory nature of his own figures compared with those which he had found in Papers by some other workers. He would bear in mind the chrome-molybdenum series which had been suggested.

COMMUNICATION

Mr. V. A. Crosby, of Detroit, Michigan, in a written contribution to the discussion of this Paper said that there were a number of items in the Paper with which he agreed, such as data shown in Table I and Table III. It is felt, however, that the conclusions drawn relative to the comparative effects of molybdenum and nickel in increasing tensile strength properties are worthy of further consideration.

The writer notes that it was considered necessary to superheat in the case of the synthetic molybdenum irons to a temperature of 1,600 deg. C., because of the high melting point of the ferro-molybdenum. He disagrees with the essence of this statement since it assumes that melting point and solubility are one and the same. Pure molybdenum wire with a melting point of 2,537 deg. C. has been used for alloying purposes in molten cast iron at approximately 1,452 deg. C. with effective results. The wire was placed in the ladle, the metal was tapped in, and no stirring was required to effect solution and dispersion. The alloying of iron with ferro-molybdenum in percentages up to 1.00 per cent. Mo can be effected very successfully at temperatures of 1,454 to 1,500 deg. C. It is a personal opinion that the superheating temperature of 1,000 deg. C. was excessive and contributed largely to the comparatively poor properties of the molybdenum iron.

It has been personal experience that synthetic irons tend to go dendritic (with resultant

TABLE A.—*Physical Properties of High-Duty Irons.*

Heat No.	1228	1299	1265	1266	1305
Total carbon, per cent.	2.62	2.50	2.49	2.50	2.46
Combined carbon, per cent.	0.60	0.60	0.66	0.65	0.64
Graphitic carbon, per cent.	2.02	1.90	1.83	1.85	1.82
Silicon	2.50	2.82	2.71	2.80	2.59
Manganese, per cent.	1.11	0.98	0.97	0.99	1.06
Molybdenum, per cent.	1.00	—	1.03	1.04	1.00
Nickel, per cent.	1.05	—	1.01	—	—
Copper, per cent.	—	—	—	—	1.06
Superheating temp., deg. C.	1,537	1,482	1,482	1,482	1,482
Pouring temp., deg. C.	1,454	1,454	1,454	1,454	1,454
Transverse test (1.2 × 18 in.), lbs.	3,365	3,806	5,440	4,510	4,025
Deflection in ins.	0.241	0.280	0.570	0.415	0.320
Brinell hardness No.	325	285	331	302	352
Tensile (0.800 in.), tons per sq. in.	23.4	31.1	35.9	33.1	36.4
Impact (1⅛-in. rd., 6 in. centres), ft.-lbs.	35	—	106.9	118.1	—
Transverse (2.0 × 24 in.), lbs.	12,000	13,790	16,800	17,100	16,200
Deflection in ins.	0.227	0.333	0.470	0.455	0.392
Brinell hardness No.	293	255	302	286	302
Tensile (0.800 in.), tons per sq. in.	26.5	24.4	29.2	33.4	30.1
Impact (1⅛ in. rd., 6 in. centres), ft.-lb.	46.9	44.4	120.0 +	113.1	120.0 +
Matrix	Acicular	Pearlitic	Acicular	Acicular	Acicular
Type of graphite	Eutectic	Normal	Normal	Normal	Normal

eutectic graphite formation) more readily with similar degrees of superheating than cast iron of the same composition made from pig-iron. This explains, in part, why superheating may be beneficial to an iron carrying a large percentage of pig in the charge, while the same degree of superheating applied to a non-graphite-bearing charge would result in a dendritic structure and, therefore, failure to produce maximum physical properties.

Table A outlining physical properties is given to show the effect of superheating a synthetic iron of a high quality. For example, the effect of an additional 50 deg. C. of superheating is shown strikingly in the case of Heat 1228 *versus* Heat 1265. Although the compositions are quite similar and the irons have identical matrices, a remarkable difference in physical properties, due primarily to the character of the graphitic formation, is unmistakably evident. It will be observed that Heat 1299 contains no alloys but, being properly made and securing the right type of graphite, this material compares very favourably with Heat 1228, which is highly alloyed but failed to develop maximum strength because of too high superheat.

TABLE B.—*Electric Furnace Irons.*

No.	1	2	3	4	5
T.C., per cent.	3.31	3.31	3.27	3.24	3.27
C.C., per cent.	0.70	0.70	0.72	0.70	0.83
Gr, per cent.	2.61	2.61	2.55	2.54	2.44
Si, per cent.	1.81	1.83	1.89	1.79	1.90
Mn, per cent.	0.84	0.84	0.86	0.83	0.88
S, per cent.	0.087	0.080	0.09	0.08	0.09
P, per cent.	0.159	0.161	0.15	0.15	0.17
Mo, per cent.	—	0.29	0.63	1.03	1.41
Tensile, tons per sq. in.	18.75	20.5	22.9	24.4	27.3
Brinell hardness	217	223	228	241	269

A comparison of Nos. 1299 and 1265 shows the advantages of alloys in an iron properly made in both cases. A comparison of No. 1265 with

No. 1266 shows the contribution of nickel to the physical properties of a molybdenum iron. Heat No. 1305 is given to show the comparative effects of copper-molybdenum iron with plain molybdenum and nickel-molybdenum irons of similar base composition. All of the irons shown in Table A were made in an electric furnace of the induction type holding 30 lbs. of metal.

Unfortunately, Mr. MacDougall does not offer an unetched micrograph of any of the molybdenum irons, although heat No. 59, a nickel-molybdenum iron, does show a normal graphitic structure. It is possible, however, that the addition of 1.8 per cent. nickel (a graphitising agent) has facilitated the formation and development of a normal graphite. It is also believed that the molybdenum irons referred to in Table VIII of the original Paper would reveal a graphitic distribution similar to that shown in Fig. 19, heat 18 R, and, because of this type of graphitic structure, disappointing physical properties have resulted, especially in the higher strength irons. It is quite true that in irons ranging from 14 to 18 tons per sq. in., the presence of a dendritic pattern may have little effect on tensile and transverse strength, although dendritic formations most assuredly exert their influence in higher strength irons of 22 tons and upwards.

TABLE C.—*Cupola Irons.*

No.	1	2	3	4	5
T.C., per cent.	3.31	3.27	3.23	3.23	3.26
C.C., per cent	0.57	0.63	0.61	0.67	0.71
Gr, per cent.	2.74	2.64	2.62	2.56	2.55
Si, per cent.	2.02	2.02	1.96	1.93	2.06
Mn, per cent.	0.67	0.67	0.63	0.73	0.76
S, per cent.	0.12	0.12	0.11	0.10	0.10
P, per cent.	0.18	0.18	0.17	0.17	0.17
Mo, per cent.	—	0.11	0.23	0.36	0.55
Tensile strength, tons per sq. in.	15.6	17.4	18.7	19.6	20.5
Brinell hardness	207	212	217	228	248

Moreover, deflection values of all irons are invariably lower than for normal graphitic patterns.

The above statements are offered as an explanation of the findings of Mr. MacDougall: " It would seem that the higher tensile strengths ranging in this series of experiments are more a function of the nickel content than the molybdenum content."

Relative to Mr. MacDougall's conclusions concerning the apparent negligible effect of molybdenum in quantities up to 0.50 per cent., the writer submits in Tables B and C data showing the progressive improvement in tensile properties of cast iron with increasing amounts of molybdenum.

All of the iron shown in Tables B and C had normal graphite structures and pearlitic matrices. For this reason, no micrographs are submitted. When these fundamental findings are not substantiated with Mo additions up to 1.0 per cent., personal experience has been that there are other factors present which are of greater importance than the alloy additions.

Lancashire Branch

SOME POINTS ON NON-FERROUS FOUNDRY PRACTICE*

Paper No. 644

By A. PHILLIPS (Member)

In surveying the field of non-ferrous foundry work there are some points which appeal more strongly than others as showing the need for discussion to assist in the further progress of the industry. The type of work in small non-ferrous foundries is totally different in manufacture from the work in larger foundries, and, again, the foundries which produce aluminium alloy castings and die-castings have different problems from the others.

However, there are certain principles in foundry technique which are common to all, and whilst this Paper may mention certain points with which some foundrymen are fully conversant, these can no doubt be improved by suggestions brought out by co-operative discussion. Naturally, as non-ferrous foundry practice includes so many varying classes of work, of so many shapes and sizes of patterns and different types of alloys, only a brief description of a few can be given.

COPPER CASTINGS

For the electrical industry copper castings having a conductivity of 80 per cent. or over are called for, and have been used for a number of years. In the engineering and electrical industry, the casting technique in the non-ferrous foundry has not received the attention of writers that other alloys have done. Copper castings can be, and are, made in brass foundries using standard equipment and methods with which foundrymen are familiar. The im-

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* The author was awarded a Diploma for this Paper.

portant points in the foundry practice are:—(*a*) Use of electrolytic copper ingots; (*b*) correct melting and fluxing; (*c*) suitable and exact amount of deoxidiser; (*d*) pouring without turbulence and controlled pouring temperature; (*e*) control of freezing to avoid shrinkage defects, and (*f*) attention to contamination of scrap.

Electrolytic Copper Castings

It must be fully realised that if high-conductivity castings are sought, the purest of ingot metal must be used. Copper oxide is not revealed by chemical analysis, so that determination of the suitability of copper by analysis only is ruled out, although the chemical analysis will show if there are any undesirable elements.

Melting Conditions

The metal can be successfully melted in a crucible furnace. To protect the metal during melting it is usually recommended that it be covered with a layer of some flux which is not very gassy. It is not advisable to place charcoal at the bottom of a hot crucible, as there is a strong tendency for charcoal to absorb moisture and gases, which, if not burned, may cause gas porosity in the metal. Charcoal can absorb about 10 per cent. moisture on exposure to the air. The melting process itself is very important, and it must not be carried out in a reducing atmosphere. A neutral atmosphere is to be aimed at, but, failing this, one should have a slightly oxidising atmosphere.

It obviously appears paradoxical to recommend an oxidising atmosphere when initially the copper must be as free from oxygen as possible. In a reducing atmosphere, unburnt fuel gases other than oxygen are liable to be absorbed by the metal, and these cannot be removed by deoxidisers. Therefore, it yields a casting which has a gas porosity. If, however, there is a slightly oxidising atmosphere, the oxide absorbed can be removed from the liquid metal by deoxidisers. Also, oxide in this form is not as stable in the molten metal as oxides which are present in the initial solid material.

The fact that castings do sometimes contain hollow cavities or gas holes has led to a number of authorities studying the relationship which exists between gases in the metal under widely varying conditions. Without going deeply into the subject it may be considered under three headings:—(1) Metal may absorb gas at a low temperature, and give it out again when the temperature is raised. (2) Gas may result from reactions which occur within the metal whilst it is in process of solidification, or after it has been partly solidified; with this condition it is impossible to cast a sound casting. (3) The gas may be dissolved in metal much as air dissolves in water; ordinary water contains more or less air in solution, and when water is heated or the pressure reduced, bubbles of gas appear. Everyone is familiar with this reaction.

Solubility of Gases

The solubility of gases in non-ferrous metals is, however, a very complicated study, and from the foundryman's point of view gas reaction presents a great difficulty. It is in the recognition and classification of these symptoms that the foundryman needs assistance. He then has a number of methods of handling the situation. Volumes have been written about the cures for various defects as operated from the laboratory, where it is possible to reproduce similar conditions, but it is more difficult for the foundryman, as he operates under conditions peculiar to his shop and plant. When an infallible method of detecting the fault is available, half the foundryman's troubles will be over. The remedies he can use are:—(*a*) Sufficiently long melting to complete certain reactions; (*b*) addition of a suitable reducing chemical agent, and (*c*) addition of some element which will assist the metal to absorb the gases. The first essential to negative gas effects and one that is of great practical importance is proper and correct melting coupled with the most suitable pouring temperature.

High Conductivity

In the melting of copper for copper castings, the addition of elements or material to reduce gas effects is very limited, and the choice is made from those which, whilst removing the gas effects, retain a high conductivity. Among others there are boron and silicon.

Silicon is introduced by the addition of 15 per cent. silicon-copper. Just sufficient must be added to complete the reaction, as any excess will lower the conductivity and make the metal brittle. Silicon when added to copper containing oxide of copper reduces the copper oxide to copper + silicon oxide. The silica insoluble in copper rises and is skimmed off. As different consignments of the high-grade copper will vary, the exact amount of silicon-copper to add to neutralise the effects of dissolved gas and oxides is very difficult to estimate, and probably the best practical method is to make a trial melt. This can be carried out in the following manner. Melt 100 lbs. under a suitable flux, raise to a temperature of 1,200 deg. C., then add $1\frac{3}{4}$ ozs. of silicon-copper (this being just below the quantity used in usual practice), and stir with a plumbago stirrer. Pour small ingots at 1,160 deg. C., and when cold examine top and the fracture. Repeat by adding or reducing the amount until correct quantity has been determined. No. 1 section of Fig. 1 shows a high-grade electrolytic copper melted without any addition. During solidification the top of such an ingot bleeds and flows over, and the section shows it to be full of gas holes; No. 2 carried an addition of $1\frac{1}{2}$ ozs. of silicon-copper and shows fewer gas holes; No. 3 with $1\frac{3}{4}$ ozs. of silicon-copper showed a rise of the top face with a few gas holes in the section, and the final one, No. 4, with an addition of 2 ozs. of silicon-copper exhibited a flat top and a section free from gas holes.

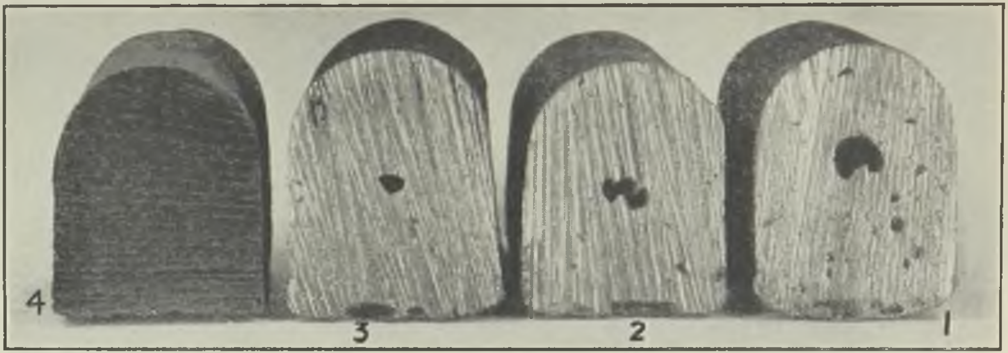

Fig. 1.—Cast Copper Ingots, showing Gas Porosity.

Moulding

The moulding in general follows quite closely the practice adopted for manganese-bronze, with a slight modification in the gating. As every foundryman will agree, each pattern is a problem in itself, and should be treated as such. In general the runner is very small; in fact, in some instances only a flash thick, as is shown by casting No. 1 in Fig. 2. This illustration shows various copper castings with different positions of runners. Some on the left side of the picture, No. 2 and No. 3, enter directly into the feeding head. In this case the temperature of the metal in the head is hotter than in the casting, thus ensuring that the castings will be fed with hotter metal. Others in the centre, No. 4 and No. 5, for instance, feed direct into the casting; and on the extreme right No. 6 is fed by means of the skim or bridge runner—a type such as is used on all manganese-bronze castings to prevent dross entering the mould. It will be noticed this is a deep casting poured at the bottom; hence the use of a skim or bridge runner.

As the liquid and solidification shrinkage of cast copper is high, the foundryman prevents the formation of voids which are due to a shortage of liquid metal just before or at the moment of solidification, by the use of a proper feeding head, which is supplied with hot metal at certain periods. Some different types of these feeding heads are shown in Fig. 2. The size and position of these are governed more by acquired experience than by a fixed rule. Whilst on the question of feeding heads, it is advisable, when the casting has been poured, to pull the charcoal from the top of the crucible to the top of the head metal. This helps to keep the head metal hot and prevents skin formation whilst waiting for shrinkage. Also, whilst for small castings sufficient deoxidiser has been added, one sometimes finds that it is insufficient for larger types with slower rates of cooling. An indication of this state of affairs is when sparks, in fountain-

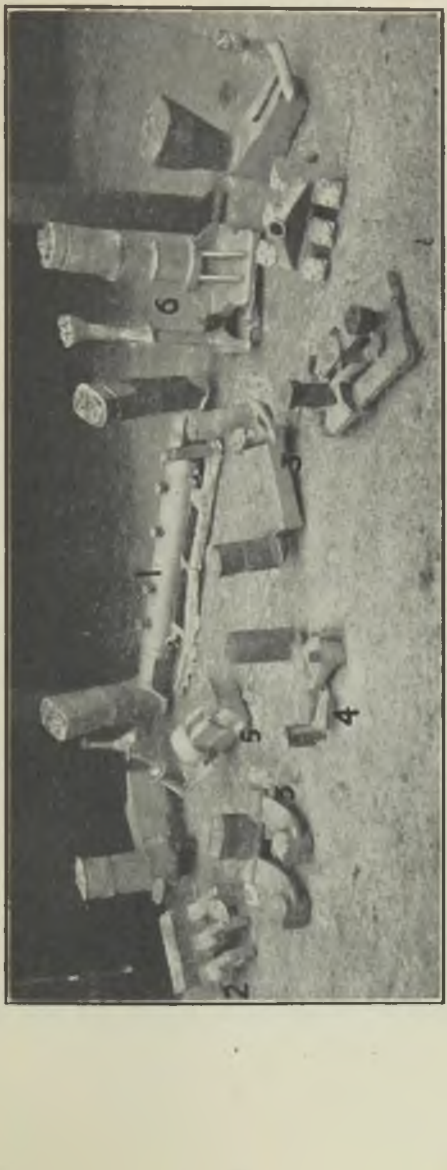

Fig. 2.—Copper Castings with Different Types of Runners and Risers.

form, come from the head, and the head afterwards begins to bleed and flow over.

Electrical Properties

Table I shows the conductivity of different samples of copper with varying amounts of silicon-copper added. Here it will be seen that samples No. 1 and No. 2 made from high-grade electrolytic copper give 90 per cent. with 2 ozs. and 88 per cent. with 2¼ ozs. of added silicon-copper to 100 lbs. of electrolytic copper. Nos. 3, 4 and 5 show the effects of adding 3 ozs. of silicon-copper to varying mixtures of high-grade and scrap copper, and No. 6 shows the conductivity of the scrap copper with 3¼ ozs. of silicon-copper added.

Contamination of Scrap

From a study of the conductivity figures, it will be readily understood that scrap heads and runners must be carefully separated from other metals, as a small amount of any of the other metals commonly used in the brass foundry will reduce the conductivity below the desired figure.

MANGANESE-BRONZE OR HIGH-STRENGTH BRASS

The chemical composition of manganese-bronze varies according to the physical properties required, and the foundry making the alloy. Usually, for the specifications up to 40 tons ultimate tensile strength, small amounts of manganese, iron, tin and aluminium added to the common 60-40 brass will give the result required. When a strength between 40 and 50 tons is required, it is found that probably the addition of a small percentage of nickel will give the desired results.

Alloying

Manganese-bronze can be bought in ingot form or made by using copper with the addition of special hardeners. Copper and zinc form a large percentage of a manganese-bronze alloy, and it is advisable to use high-grade copper and zinc of

Table I.—*Conductivity Tests on Copper Castings.*

Sample no.	Resistivity. Microhms per cm. cube.	Temp. Deg. C.	Conductivity. Per cent.	Remarks.
1 ..	1.90	18.2	90.0	2 ozs. Si–Cu added to 100 lbs. electrolytic Cu.
2 ..	1.94	18.2	88.0	2¼ ozs. Si–Cu added to 100 lbs. electrolytic Cu.
3 ..	2.17	20.0	79.5	3 ozs. Si–Cu added to 100 lbs. electrolytic Cu.
4 ..	2.56	20.0	67.5	3 ozs. Si–Cu added to 50 per cent. electrolytic Cu, 50 per cent. scrap Cu.
5 ..	2.60	20.0	66.4	3 ozs. Si–Cu added to 66 per cent. electrolytic Cu, 33 per cent. scrap Cu.
6 ..	3.21	20.0	53.5	3¼ ozs. Si–Cu added to 100 per cent. scrap Cu.

99.95 purity. Manganese is usually added by means of a Mn-Cu hardener, consisting of 70 per cent. Cu and 30 per cent. Mn. Iron can be added in the form of ferro-zinc, ferro-manganese or a copper-iron-aluminium hardener. Nickel is added as cupro-nickel.

As there are such a large number of commercial alloys under various trade names, besides different alloys which have been published in the Press, no definite composition will be given, but it can be stated that the manganese-bronze and high-strength brass alloys are generally of the following character:—Copper, from 50 to 60 per cent.; tin, up to 2 per cent.; iron, from 0.25 to 3 per cent.; manganese, from 0.25 to 4.5 per

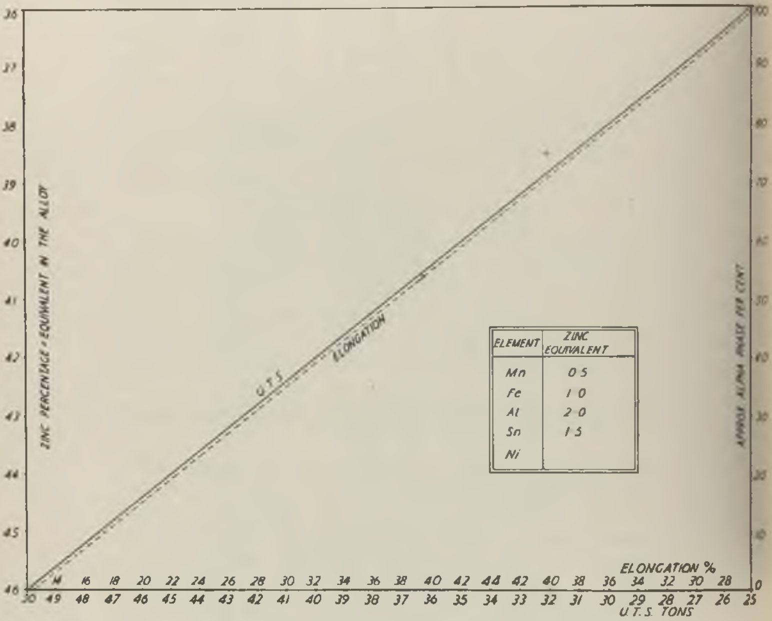

FIG. 3.—PHYSICAL PROPERTIES OF MANGANESE-BRONZE.

cent.; aluminium, from 0.25 to 5 per cent.; nickel, from 0 to 4 per cent., and zinc remainder.

As a rapid change in physical properties is due to the variation in the proportions of the alpha and beta constituents in manganese-bronze, a careful control over the composition is necessary.

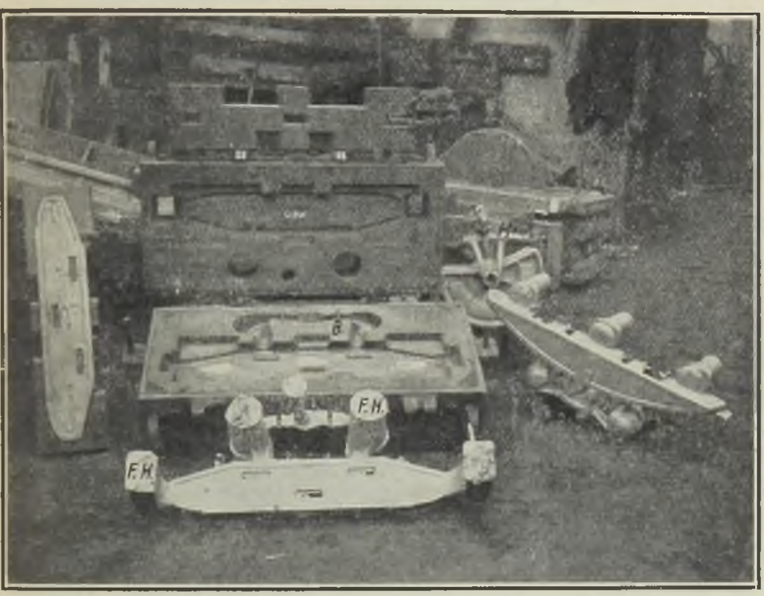

Fig. 4.—Pattern, Mould and Casting of Manganese-Bronze Cross-Bar.

Fig. 3 shows a graph prepared from a large number of tests giving the approximate relation between the alpha and beta phase, zinc percentage, alloy equivalent, and the corresponding physical properties. In the inset are given the calculated zinc equivalents of the various elements used. In one type of practice these remain fairly accurate as long as the iron, manganese and aluminium do not exceed 3.5 per cent. each. It will be noticed that a figure is not stated for nickel, because during some recent experiments the addition of nickel to a beta high-strength brass has given very high physical results, and so long as the gamma constituent can be avoided, high-strength brasses containing copper, nickel, manganese, iron, aluminium and zinc can be regularly produced with physical properties averaging 46 tons U.T.S.

Nickel (according to Fig. 3) in the region below the 40 per cent. alpha, is an element which, in conjunction with a small percentage of aluminium and the other elements will probably in the near future produce some remarkable physical properties in high-strength brasses. From a number of tests indications are that nickel has a zinc equivalent figure similar to aluminium for calculation purposes when used in manganese-brasses containing Mn, Fe and Al, and having less than 40 per cent. alpha.

Melting

Carefully controlled melting practice is necessary, and various types of melting plant may be used. For anyone not very familiar with the characteristics of the metal, it is suggested they first try the alloy in the crucible, as this form of melting is probably the easiest to control. In the flame type of furnace the flame should be kept slightly oxidising. The melting procedure can be as follow:—First melt the copper, together with the various hardeners of Mn-Cu, cupro-nickel and iron hardener, and when molten add the aluminium and zinc. Various fluxes may be used, and the choice is extensive, but a covering of charcoal (salt, borax and ground glass) is a very good flux during the early part of the melt. When the first part of the mixture is molten, a covering of anthracite coal is a suitable protecting flux whilst the other elements are added, if the alloy is in an open-flame type of furnace.

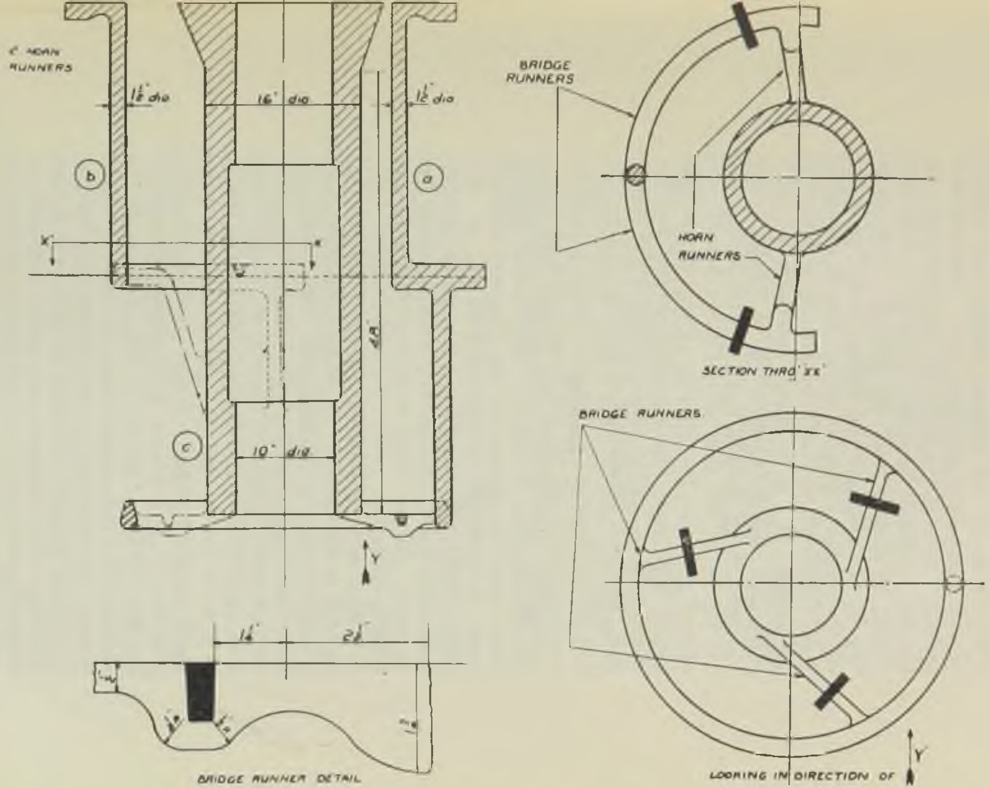

Fig. 5.—Method of Running a Liner Bush in Manganese-Bronze.

Runners and Heads

Fig. 4 shows the pattern, mould and casting of a manganese-bronze cross-bar. Here it will be seen that the casting is poured from the bottom; whenever possible, castings in this alloy should be poured from the bottom. Any agitation of the metal in the runner basin or in the runner creates a scum or dross. This is prevented from entering the mould by placing a bridge in the ingate, B. It is always advisable to use a skim gate for manganese-bronze castings, and for some large moulds two or three skim gates are placed in the flow of the metal before it is allowed to enter the casting. Coupled with the use of skim gates, the horn gate is used to allow metal to enter at the lowest point of the mould, and these can be seen at H in Fig. 4.

Feeding

To avoid unsoundness due to the high liquid or solidification shrinkage, voluminous feeding risers must be placed on the heaviest sections. Some of these can be seen at FH, Fig. 4. For certain types of castings a combination of chills placed at heavy sections and feeding heads can be used. Copper chills have been found to give good service.

Whilst it is considered advisable to run the casting at the bottom, there are instances where a second runner is advantageous. Fig. 5 shows a liner bush approximately 16 in. outside diameter, 12 in. inside diameter, and 4 ft. high. The first runner is at the bottom, shown at *a*, but as this is a heavy section, and to ensure dense metal, it was necessary to place a chill round the outside. If the casting were completely poured by the bottom runner, a hot spot would be maintained and segregation shrinkage would occur. To avoid this, a horn runner is placed at *b*, metal being poured down it when it is judged sufficient has entered the mould through *a*. When *b* runner is used *a* runner is stopped up with sand to prevent any rising metal.

ALUMINIUM ALLOYS

Aluminium alloy castings can be placed into three classes:—(1) Castings used as cast; (2) castings used as cast with the metal modified or treated during the melting process, and (3) castings which have to be heat-treated before use. In the first group there are 2L5 (13 per cent. Zn, 3 per cent. Cu); 2L8 (12 per cent. Cu), and 3L11 (8 per cent. Cu), and others of a similar type.

In the second group there are the aluminium-silicon modified alloys. In the third group there are the " Y " alloy, the R.R. alloys and similar alloys.

As the so-called " modified " aluminium-silicon alloys introduced during the last decade have proved to have advantages over the previously-known cast light alloys, for ease in producing sound castings of awkward shape, and are in fact the best alloy for the foundryman to handle, it is proposed to give a brief description of them.

Modified Light Alloys

Composition.—The alloys contain silicon varying from 7 to 13 per cent., and are usually very low in impurities.

Characteristics.—They have physical properties varying from 9 to 13 tons per sq. in. tensile strength with elongation varying from 5 to 18 per cent., and are definitely superior to the older alloys in resistance to corrosion, being especially good for marine service due to their better resistance to salt-water corrosion.

Structure

The refinement of the microstructure which constitutes modification is well known, and it is to the modifying treatment applied that the alloy owes its success. The modifying is carried out by the addition of salts or metallic sodium whilst the alloy is molten. Fig. 6 shows the microstructure of an unmodified 7.5 per cent. Si-Al alloy at 100 diameters, and Fig. 7 shows under similar conditions the microstructure after

FIG. 6.—MICROSTRUCTURE OF UNMODIFIED AL-SI ALLOY. × 100.

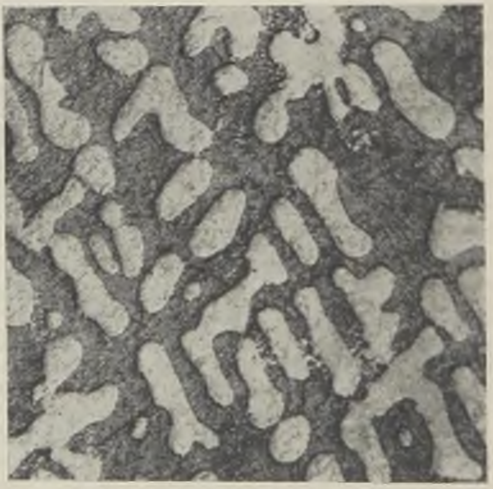

FIG. 7.—MICROSTRUCTURE OF MODIFIED AL-SI ALLOY. × 100.

modification. It should be emphasised that the physical properties of a sand-cast bar represent far more nearly the properties of actual castings than do chill-cast bars which have been so frequently quoted for specification purposes. A bend can be given to the modified 1-in. diameter sand-cast bar similar to a horseshoe, and a normal casting will withstand considerable distortion by hammering before cracking and breaking. The characteristics of this alloy allow box-shaped castings similar to Figs. 8 and 9 to be cast without easing the mould, which is necessary when other light alloys or cast iron are used. It is sometimes found that, for certain services, a cast-iron bearing surface is required, and when this condition arises cast-iron inserts are used. Fig. 10 shows the pattern, mould, cores and cast-iron insert C.I. The runners R in this instance are placed so as to allow the hot metal to enter near the cold insert and assist in obtaining a good bond of the alloy round the cast iron.

Melting

The melting of this alloy is different from that carried out with the brasses and bronzes. In this case, it is advisable to have a slightly reducing flame, as during the slow cooling in the furnace the alloy is able to release the absorbed gases. If, however, an oxidising flame is used, one is unable to add deoxidisers as in the case of brasses and therefore the alloy is contaminated with detrimental oxides. Fig. 11 shows in the background a battery of open-flame oil-fired furnaces marked O·F used for melting this alloy. In the foreground is a group of miscellaneous castings made in the 7½ per cent. aluminium-silicon alloy.

Runners

Aluminium alloys are gated differently from the brasses or copper castings. Aluminium "rolls" somewhat similar to manganese- or aluminium-bronze. This can be seen by observing the rising metal in a feeding head.

FIG. 8.—FRAME-SHAPED ALUMINIUM-SILICON ALLOY CASTING.

Any scum or dirt is apt to roll to the outer edges and become trapped, whereas with bronzes and brasses, the metal rises with a slight concave surface, and any scum remains in the centre.

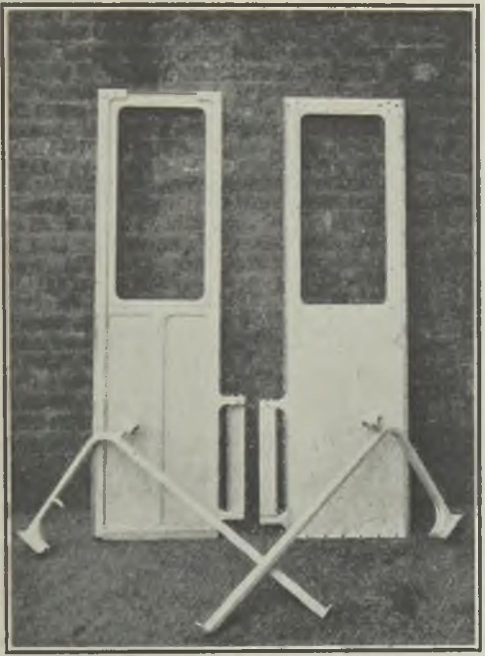

Fig. 12.—Thin Sand-Cast Door Castings in Aluminium-Silicon Alloy.

Wherever possible aluminium-alloy castings are poured at the bottom, and to do this the use of the horn gate is largely adopted. Feeding heads are in some cases made with straight walls or, if anything, slightly larger at the bottom.

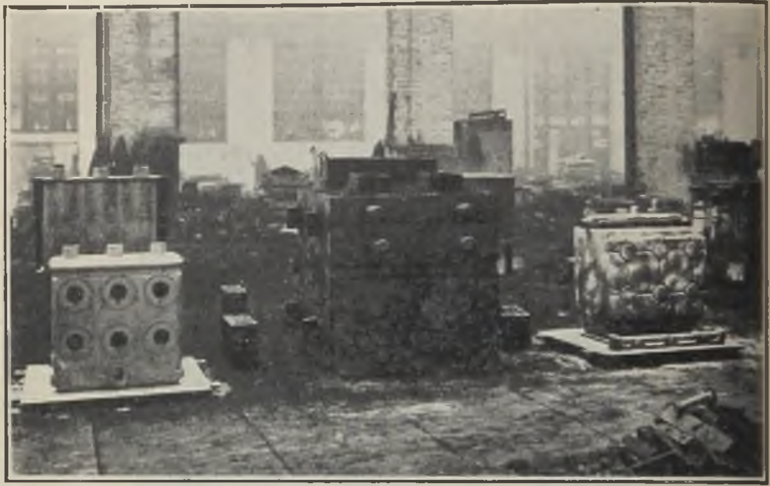

Fig. 9.—Box-Shaped Aluminium-Silicon Alloy Casting.

Fig. 10.—Aluminium-Silicon Alloy Casting with Cast-Iron Insert.

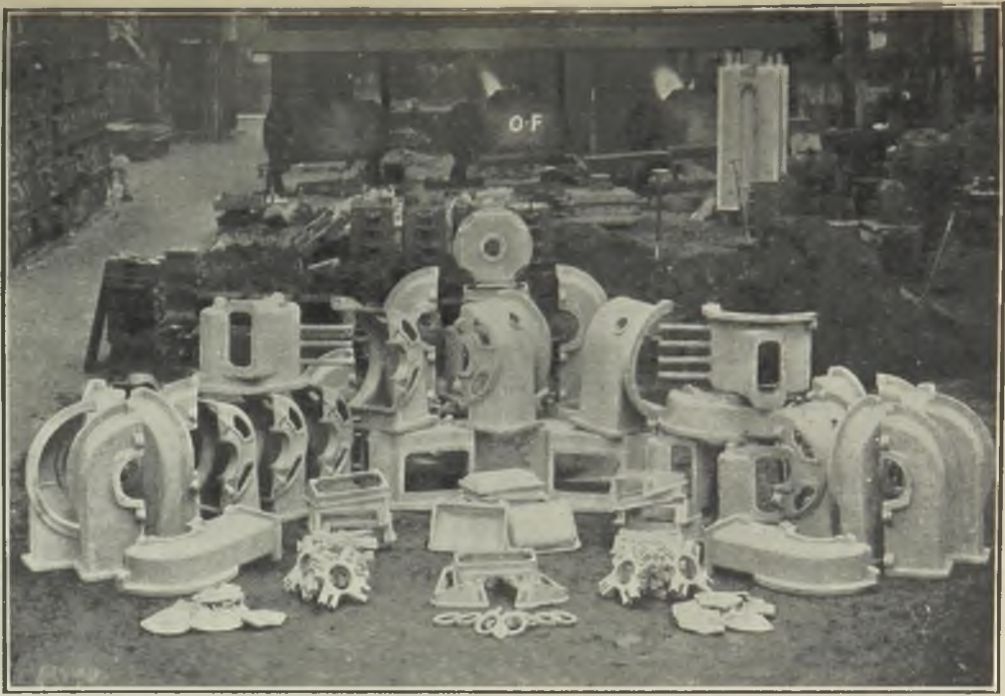

Fig. 11.—Group of Aluminium-Silicon Alloy Castings and (in background) Battery of Oil-Fired Melting Furnaces.

Sand

The moulding sand used is somewhat similar to that employed for ordinary brass castings. If, however, the casting has a large surface area, and the section is small, it is better to use an open coarse red sand freely in the mixture. Locally, the Manchester coarse red as described in a previous Paper* is suitable. Although the face of the casting has a slight bite on it, the metal will be allowed to run freely and give a uniform casting thickness. Fig. 12 shows castings 6 ft. by 21 in., the metal thickness on the plate being $\frac{1}{8}$ in. They have been made in sand moulds, and poured in $7\frac{1}{2}$ per cent. silicon-aluminium alloy. Both cores and moulds should be well vented, and the vent wire should be used much more freely than it is used in moulds and cores for cast iron.

Welding

Aluminium-silicon alloys can be welded without the usual cracking troubles associated with other aluminium alloys. By using the oxy-acetylene flame with rods of the same composition as the alloy, castings can be satisfactorily welded. Thus, two semi-circular castings when welded together will be free from air leakage when tested with 400 lbs. air pressure and submerged in water. Also, when destroyed by hammering, they will not break at the weld. Owing to the freedom with which this alloy can be satisfactorily welded, the foundryman, when deciding how to make castings, must be "welding conscious." Fig. 13 shows on the right the three simple parts, A, B, and C, which go to make a casting. On the left side are seen these parts welded into position, and these when together produce a job of complicated shape. These castings, when welded together with parts of the welds polished, show the absence of cracks or cavities.

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* I.B.F. Proceedings, 1935-36, Vol. XXIX, p 415.

BRASSES, BRONZES AND GUNMETAL

As there is such a wide variety of alloys which enter into this category, only general principles can be dealt with.

Melting

The conditions when melting brasses, bronzes and gunmetal are different from copper. In copper there are soluble oxides, but as both tin and zinc reduce copper oxide, the insoluble oxides of tin or zinc are formed. Zinc oxide is very light and quickly rises to the surface of the melt, where it can be skimmed off. Tin oxide, which is nearly as heavy as the metal, does not readily rise to the surface, and is therefore more difficult to eliminate. Frequent discussions have taken place regarding the use of phosphorus, a popular deoxidiser for bronze, to reduce tin oxide. It is just as essential to prevent oxide finding its way into the casting by mechanical as well as chemical means. The first precaution is to insist that the scum is properly skimmed off the melt, and secondly to ensure that the runners are so formed and placed to prevent oxide or scum entering the mould.

Runners

The gating of brass, bronze and gunmetal castings is a subject that has a very wide discussion. Gating castings presents problems requiring careful thought and knowledge of the alloy used. For instance, the red brasses or bronzes are gated differently from aluminium alloys or manganese bronzes, and as this subject is large and would require a vast amount of detailed description, only two different methods will be indicated. Fig. 14 shows two castings with their moulds; the one on the right is poured in Admiralty gunmetal (88 : 10 : 2), and that on the left is a slip-ring alloy. Here are two totally different types of runners, but in all cases of runners, the down runner is always made sufficiently large to allow a good stream of metal

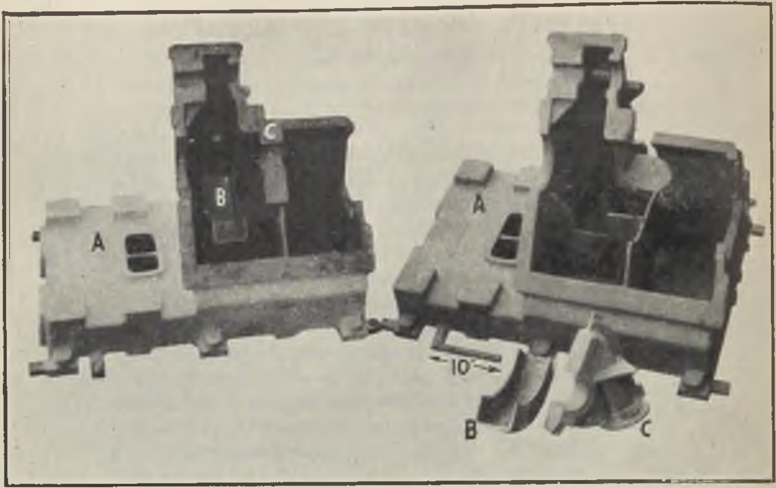

FIG. 13.—COMPLICATED CAST ALUMINIUM-SILICON ALLOY ASSEMBLY, ACHIEVED BY WELDING TOGETHER THE THREE CASTINGS SHOWN ON THE RIGHT.

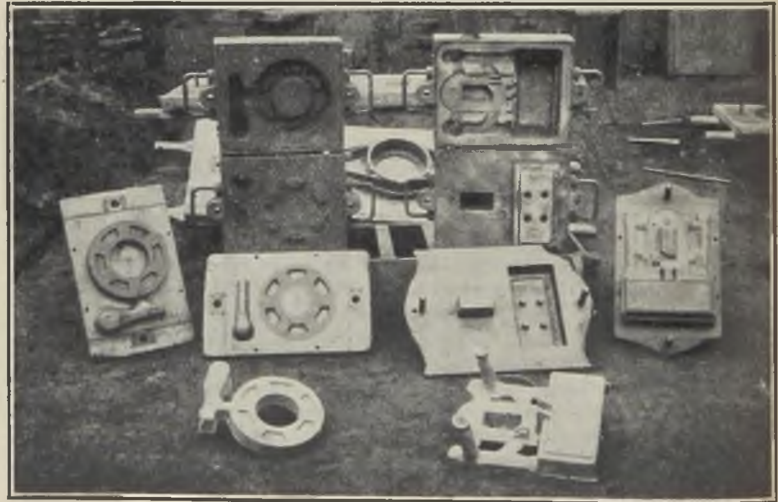

FIG. 14.—CASTINGS IN A.G.M. AND SLIP-RING ALLOY, TOGETHER WITH PATTERNS AND MOULDS.

from the ladle to enter it. This allows the temperature to be maintained in that portion of the runner, and enables the supply of metal at the correct temperature through the ingates. Down runners are made much larger than what would be the practice in cast iron.

Practically every non-ferrous foundryman has made castings in Admiralty gunmetal (88 : 10 : 2), and has experienced difficulty in meeting the specified physical properties. Table II sets out the different test results obtained from this alloy which, when examined, showed the presence of oxides. These bars were poured from one crucible of metal. The A bar, poured at a high temperature, would pass the specification, and from this it can probably be said that oxidised metal is better poured at a higher temperature than is the usual practice. If, however, castings are made with metal in this condition, those poured at the latter part of the pour would be totally unsuitable and on machining would show up various defects.

Table II.—*Physical Tests on Gunmetal* (88 : 10 : 2) *Poured at Different Temperatures from One Crucible of Metal.*

Bar.	Pouring temp. Deg. C.	Y.P. Tons per sq. in.	U.T.S. Tons per sq. in.	E. Per cent.	R.A. Per cent.
A ..	1,200	9.0	17.4	18.6	21.0
B ..	1,160	9.5	12.2	3.4	4.0
C ..	1,100	8.9	11.0	4.6	5.0

Pouring Temperatures

It is very important that pyrometers be used constantly. The regular use of a reliable pyrometer in all non-ferrous foundries is a practice which is to be strongly commended, as by this means one phase of non-ferrous foundry practice can be standardised and valuable data obtained. One point with regard to the fixing of casting temperature limits perhaps deserves to be mentioned. The generally prevalent idea is that the

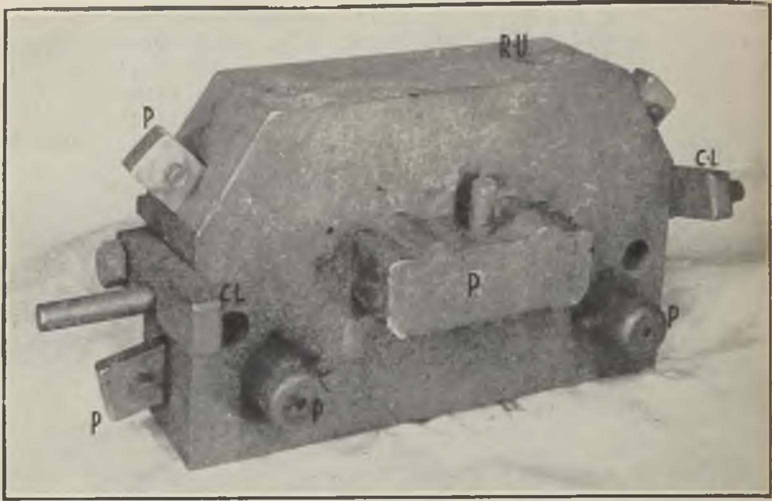

FIG. 16.—PERMANENT CAST-IRON DIE ASSEMBLED.

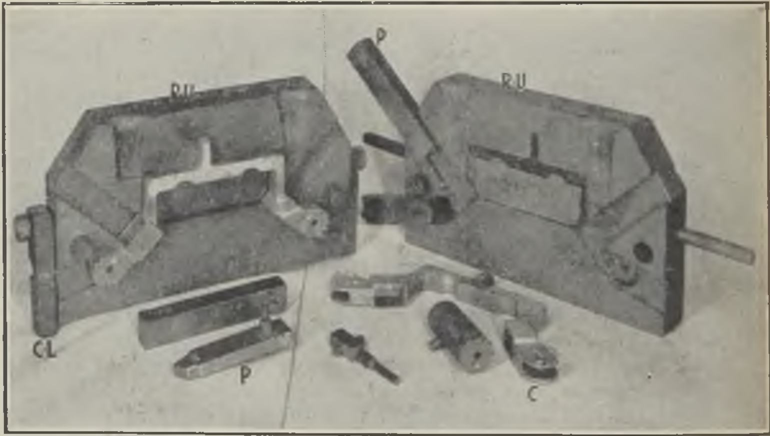

FIG. 15.—PERMANENT CAST-IRON DIE, WITH ALUMINIUM-BRONZE DIE-CASTING AND DIFFERENT PLUGS.

heavier the section of the casting the lower the casting temperature should be. This is not always strictly true, as a very important factor is being neglected if only this aspect is considered, and that is, the distance the metal has to travel to the farthest point of the mould. It should be realised that once the metal has entered the mould the temperature falls with great rapidity, so that by the time it has travelled a short distance the temperature is very different from that of the metal in the pot.

Table III.—*Range and Average Pouring Temperatures for Various Types of Metals and Alloys.*

Type of casting.	Temp. range. Deg. C.	Average. Deg. C.
Copper	1,150–1,280	1,160
A.G.M.	1,090–1,250	1,160
Phosphor bronze..	950–1,160	1,030*
Mn-bronze ..	990–1,080	1,030
Al-silicon (7½ per cent.)	600– 720	620

* According to phosphor-tin content.

Thus, in fixing the casting temperature, this very important factor must be taken into consideration. The casting temperatures used vary according to type, size and section of casting. They are set out in Table III.

Die-Castings

Another branch of non-ferrous foundry work is die-castings. This method of producing castings outside the sand-cast field has had a rapid growth during the last few years, and as it should form the subject for a complete Paper, only a very brief description of it will be given. The term " die-casting " covers the production of castings in metallic moulds with either metal or destructible cores. The moulds may be filled by gravity, when the resultant castings are known as permanent-mould castings, or the metal can be forced into a metallic mould by mechanical pressure whilst the metal is in the molten or semi-plastic state. The castings thus produced are usually termed pressure die-castings. Pressure die-castings may be sub-divided into low-pressure and high-pressure castings. The low melting-point alloys are usually used with the low-pressure machines, whilst brass and aluminium alloys are used in the high-pressure machines. Fig. 15 shows the cast-iron metal mould for a permanent-mould casting. The casting, which is made in an aluminium-bronze alloy, can be seen at C. The steel plugs for the various holes and faces are shown at P, and the runner at R.U. The clamps for holding the die together during the pouring operation are indicated by CL. The assembled mould is shown in Fig. 16. A man can produce approximately 20 castings per hour from such a die, and the finish on the castings is excellent. Castings made in permanent moulds are invariably poured from the top. In Fig. 17 is shown a casting made in a permanent mould, PM, and the same design made in a plastic pressure die machine DM. Both these castings are made in brass, yet they are poured in different ways. Fig. 18 shows a section of a plunger machine, of which there are various types. The use of this type of machine is

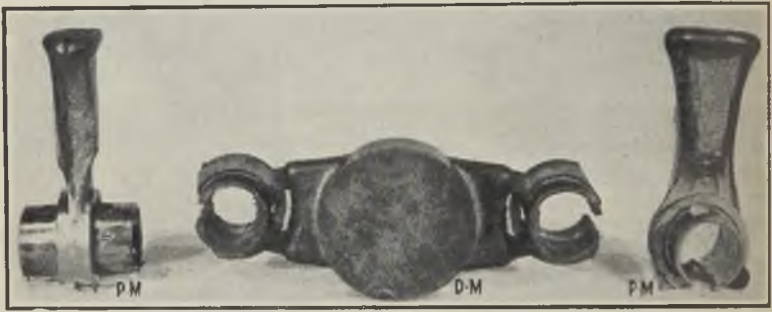

Fig. 17.—Methods of Running Pressure-Cast and Permanent-Mould Die-Castings.

limited to alloys of a low melting-point. As the metal is forced through the nozzle by means of the plunger, it can be readily seen that the wear

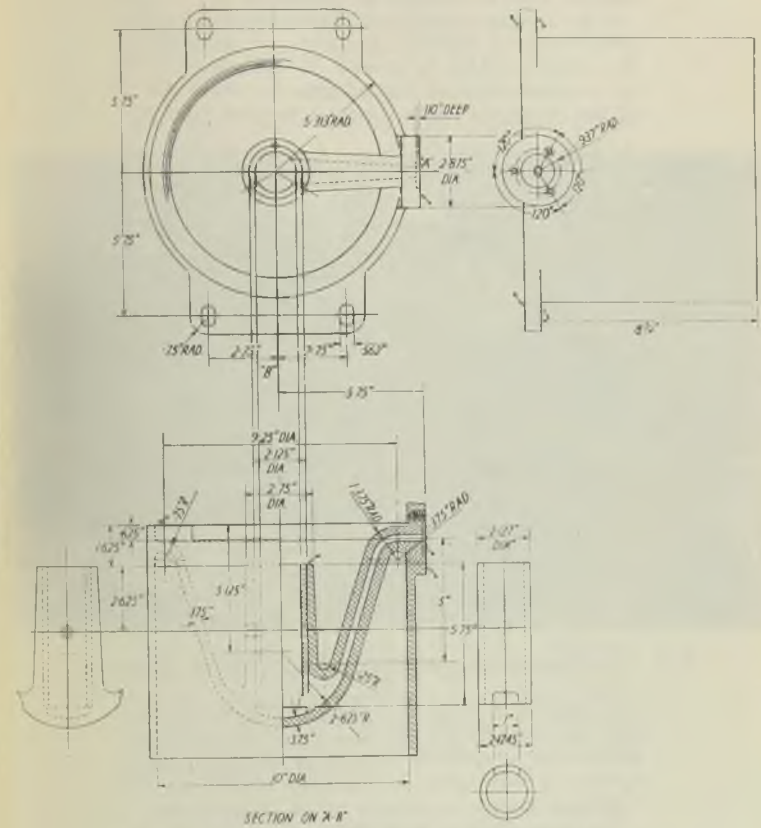

FIG. 18.—PLUNGER TYPE OF DIE-CASTING MACHINE.

and attack on the surface of the plunger with a high melting-point alloy would soon make it stick. Castings with a tin, lead or zinc base are usually made with this machine. If castings made in zinc-base alloys are to be exposed to atmospheric corrosion, it is most desirable that zinc of 99.99 per cent. purity be used.

Fig. 19 shows a high-pressure machine for the production of castings in brass or aluminium. The metal, which is placed in the chamber C in a plastic state, is forced into the steel die D by the plunger P, at a pressure varying from 500 to 1,750 lbs. per sq. in. The opening of the die and the withdrawal of the plugs are done by mechanical means, whereas with the permanent mould all the plugs are usually withdrawn by hand.

Fig. 19.—High-Pressure Plastic Die-Casting Machine.

The die-casting process, like any other process, has its limitations, and it is advisable to consult an up-to-date die-casting concern before attempting to design die-castings, as they have all the necessary data of the various alloys together with their limitations of manufacture.

The author wishes to thank the Metropolitan-Vickers Electrical Company, Limited, Trafford Park, Manchester, for permission to publish this Paper, and especially to Mr. W. Jolley, superintendent of foundries and patternshop, for his advice in its preparation.

DISCUSSION

On the proposition of Mr. Norman Cook, seconded by Mr. E. J. L. Howard, a vote of thanks was accorded to Mr. Phillips for his Paper.

Deoxidisers and Electrical Conductivity

Mr. Howard, who opened the discussion, said he had had extensive experience of copper castings, particularly for electrical purposes, and he had adopted identical methods to those which had been mentioned. As had been pointed out by the lecturer, the usual deoxidisers could not be used, in view of the conductivity which was demanded. A few years ago a method of deoxidising copper had been introduced which consisted of passing nitrogen through the molten metal. It was fairly successful, but he was unaware to what extent it was used. Copper castings in which a high conductivity was not required could be successfully produced by the addition of about $\frac{1}{5}$ per cent. tin, and then deoxidising with phosphor-copper.

Mr. Phillips said that the use of nitrogen, referred to by Mr. Howard, had been practised in some cases, but personally he did not think it was a commercial proposition. It was not easily manipulated in the foundry as was the silicon-copper method.

Crankshaft Wear due to Leaded-Bronze Bearings

Mr. R. A. Jones said he had been troubled by grooves being cut into the crankshaft by leaded-bronze bearings, and so wearing it out. Could a remedy be suggested? He was unable to say what the composition was.

Mr. Phillips observed that there was a great variety of leaded-bronze, and, unless the product was examined, it was hard to give a reply to the question. The higher lead contents resulted in a softer material and less liability to scour shafts. In a copper-lead-bronze, lead segregation occurred unless some addition, such as a small percentage of nickel, was made to assist even dispersion. Pouring temperature effects were also experienced with leaded-bronze, and if the pouring temperature were too high, there was a liability to get the larger portion of the lead at the bottom of the casting. Directly opposite that was a phosphor-bronze; cast at high temperature, the tin was forced out at the top.

Making Slip-Ring Castings

Replying to Mr. Brown, who asked for further details regarding the slip ring referred to in the Paper, Mr. Phillips said that this was not 88-10-2 gunmetal, but a slip ring alloy which contained lead. For that particular size, and for ease in quantity-production, the ring had been placed on a board, but if it were larger, it would be run from the inside, and chills placed on the outside; a bridge runner would be used to break the flow of the metal. For a small ring there was a large feeding down-runner, and the runner on the joint went past the in-runner on the casting, which allowed any scum to go past, and only the clean metal to enter the mould. As had been stated, chills were placed round the outer periphery, these chills being ground in one direction to allow any gas which collected on the faces to escape up the furrows or grooves. It was important for the chills to be ground in the same direction as the flow of the metal, especially when chilling non-ferrous castings.

Manganese-Bronze Liners

In regard to the manganese-bronze liner, there was a horn runner fed from a channel on the middle joint of the casting; it did not come in with just a point, and thereby create a squirt, but extended downwards in length. A little slot was cut down from the underside to ensure a gradual rise of the metal, thus eliminating splashing or turbulence.

Sufficient experiments had not been carried out regarding gases absorbed in moulds to enable any definite statements to be made. Immediately an infallible guide for detecting gas faults could be found, trouble experienced with gases would be overcome. Gases absorbed in the melt could be caused by steam from moisture in the mould. A metal like copper might absorb water vapour, and if copper was being run into a mould in which moisture was present, this formed a gas which would be readily absorbed, and consequently the casting would give trouble when machined. A point which should always be borne in mind when deoxidisers or degasifiers were being added to an alloy was whether they were being added to remove the gas, or to help the metal to absorb the gas. For example, a certain quantity of salt could be dissolved in a glassful of water, but something could be added which would precipitate the salt; that could also be done with molten metal to precipitate or liberate gas. Alternatively, an addition could be made to the water to enable it to take more salt into solution. Was the same thing being done to the alloy to assist the metal to absorb or remove the gases? These were points which had to be thrashed out by foundrymen by experiments.

Live-Loads and Inter-Crystalline Corrosion

Mr. Reynolds asked if the lecturer had ever used phosphor-copper as a deoxidiser in the case of high-conductivity copper castings; if so, what were his conclusions as compared with silicon-copper? The firm with which the speaker was connected used phosphor-copper as it usually gave a more fluid metal, and practically no difficulty was experienced with conductivity providing the requisite amount was used.

Personally, he admired the large boxed-shaped silicon-aluminium casting, and asked what kind of core was used—whether it was an oil-sand core, or a naturally-bonded one. Did the lecturer ever find it necessary to use a deoxidiser for manganese-bronze, and had he any experience of its behaviour under live-load conditions, that was, electrical current conditions, on exposure to atmosphere? Many alloys, particularly light alloys, had given trouble under atmospheric conditions with live-load by inter-crystalline corrosion, caused usually through the copper-aluminium compound which formed with even 2 per cent. copper in aluminium, and which sometimes led to complete disintegration of the alloy. As there was aluminium in manganese-bronze, he would be interested to know of any experience the lecturer had had of its behaviour under similar conditions. The action was tantamount to a galvanic action caused by the difference of contraction between the two metals, copper and aluminium.

Had the lecturer any experience—experimental or in general production—of making copper castings by either the gravity or pressure-die methods?

Silicon-Copper Advocated

Mr. Phillips replied that he had had a little experience with the use of phosphor-copper, barium carbide, and several other elements for reducing gas effects in high-conductivity copper castings. He had found, however, that to produce castings having over 80 per cent. conductivity, silicon-copper was the most satisfactory. With phosphor-copper the reduction of the conductivity was too severe, because of the quantity that had to be used, and there was more trouble from gas effect during machining than there was with silicon-copper.

The casting referred to by Mr. Reynolds was made with an ordinary sand core, which was made very weak. With aluminium alloys, cores had to be weak, because there was not the same chance of the core gases escaping as there was with higher temperature alloys like bronze or cast iron. When making an aluminium alloy U-shaped casting, cast with the flange up, the vents should always be liberated from the bottom of the U-face core so that the gases could get away very quickly from the bottom faces. Aluminium alloys quickly solidified, and gases caused trouble if they could not escape freely and rapidly. Oil-sand cores were used very extensively on a large casting similar to the one referred to, and to the same extent as they were used in cast iron, or any other alloy.

As to fluxes for manganese-bronze, and the use of deoxidisers, there was a very large amount of zinc present which was self-acting as a deoxidiser. He had no experience of live-loads in atmosphere with manganese-bronze. Aluminium alloys disintegrated more readily under live-loads. He could not give a great deal of information on live-loads at the time, but he would reply to any questioner in writing.

Copper Die-Castings

No appreciable amount of success had been experienced with high-conductivity copper die-castings. As was the case with phosphor-bronze die-castings, trouble was caused by gas. An examination of the skin of a permanent-mould gravity die-casting showed it to be full of holes, as though it had been poured in a cold die; moreover, with copper large shrinkage holes caused difficulty.

Casting Temperatures of Si-Al Alloys

Mr. A. Hopwood asked if the maximum casting temperature of 720 deg. C. for silicon-aluminium covered the high-silicon percentages, or whether it was confined to the low-silicon alloys. He also asked what types of castings were cast at that temperature. With regard to the ease with which scum formed in silicon alloys, he would like to know more regarding the casting temperature, and the effect it had on the formation of scum from, say, the poor formation of runners and gates. From what little experience he had had, the castings showed more dross formation when cast at the lower temperatures than the higher range. Mr. Hopwood said he was referring to 13 per cent. silicon alloy.

Casting Temperature and Runner Size

Mr. Phillips said that when he had spoken about the maximum pouring temperature of 720 deg. C., he implied castings of normal size, because aluminium-silicon alloys were similar to phosphor-bronzes. In a phosphor-bronze they had a definite pouring temperature, and if the metal reached a higher temperature, trouble would result. Therefore, the size of the runner was increased to assist in filling the casting, and the same process was used in regard to aluminium-silicon alloys, irrespective of whether the silicon was 13 per cent., 12 per cent., 10½ per cent. or 7½ per cent. The size of the runner was increased so that a pouring temperature as near to the minimum as possible was obtained.

Regarding scum in aluminium castings, the castings were invariably poured at the bottom, and providing there was no dampness or hardness round the runner, and the temperature was kept at about 720 deg. C. or below, he did not think any trouble would occur. It might arise with higher temperatures.

Alkaline Metals and Pinholing

Mr. Hopwood had been told that if alkalis were present in aluminium alloys there was no pinhole or gas effect. From his own observations, he did not agree with that. Had Mr. Phillips any data on the subject? Also, what trouble occurred when casting silicon alloys at too high temperatures?

Experiments with Superheated Light Alloys

Mr. Phillips said that if a bar were cast at too high a temperature there would be gas effects in the centre of the bar, and a much coarser grain structure. The opinion was once held that if an aluminium was melted at over 900 deg. C. the alloy would be spoiled. From his own experience, he could say that these alloys had been melted at 1,060 deg. C. They were allowed to cool, and in the cooling stage test-bars were made, fractured and examined for gas effect. As soon as it was found that the structure had no gas effect, then the men could start pouring.

He disagreed with the statement that if there were an alkali metal in aluminium alloys there would not be pinholing. His experience over a number of years was that most definitely there could be pinholing when alkali metals were in the aluminium-silicon alloy. Pinholing resulted from various conditions, one being modification at too low a temperature; the pinholing was due to the gas effect. Another condition was pouring a casting at too high a temperature, as there was gas in solution. If the runner could be adjusted, and the pouring temperature be adapted to approach the minimum, pinholing would be avoided. One method in which pinholing was not prevalent was to melt the metal and bring it to a very high temperature, probably 1,060 or 1,070 deg. C., and then to modify it with the material which was used at that temperature, and allow it to cool down slowly. Samples were taken in the cooling stage, which would probably occupy a period of about two hours with a cast of metal of 600 lbs. When it was found that there were no gas effects in the bar, the castings could be poured. It was thus probably at the right temperature, and he did not think much trouble would be experienced with pinholing. Damp moulds, hard moulds and cores would also give the pinholing effect.

Beryllium-Copper Castings

Mr. E. Longden asked if Mr. Phillips had ever introduced beryllium into copper. It was a very expensive metal, but remarkable results had been achieved with 2 per cent., up to 70 tons tensile strength having been obtained. With copper tuyeres there was not the same difficulty with electrical conductivity, but they were certainly difficult to cast. In introducing phosphorus one had to be careful to use just as much as would be practically eliminated in the deoxidising of the copper. It was not always possible, however, to know how much phosphorus to add because of the absorption of cuprous oxide in the metal. With copper mixtures, the purest of copper alloy must initially be used to avoid having any need to deoxidise.

Modification Conditions

Mr. Phillips had not given much information with regard to the modification of silicon alloys. The time of modification was very important, because of the vital changes which took place during the modification period. If the time of modification was not sufficient, they had poor and insufficient refining, or if the period of modification was too long, they had a reversion to the unmodified conditions. The lecturer had stated that cores were made in dry sand; surely they were in green sand, not dry sand? Aluminium castings were endangered if made in oil sand, since contraction was too rapid for the expulsion of the oil from the core sand, unless the castings were simple and massive.

Mr. Phillips replied that dry sand was used, but oil-sand cores could be used. Many actually were used in aluminium alloy work, but these were made of a very weak and friable nature, so that there was no question of the burning of the gas having time to cause any ill-effects. He had not had experience of beryllium in copper, but he gathered that a 2 per cent. addition certainly would produce up to 70 tons tensile strength. The proposition was very expensive, but most valuable for the foundryman who wanted a very high strength copper. The addition of phosphorus to copper in some instances resembled the addition of phosphor-tin to bronze. Tin sweat was created when a phosphor-bronze was cast at a higher temperature than was normal. If, however, the same percentage of tin and copper was cast at the same temperature, tin sweat did not result. Therefore, tin sweat could be traced definitely to the action of the phosphorus in the metal. When cast iron was cast in a chill of, say, 2½ in. diameter, there was a squeezing out of the phosphide eutectic in the centre, which occurred when there was a partial solidification of the casting. The squeezing out of tin in a phosphor-bronze occurred in a similar manner. Phosphor-copper added to molten copper for high-conductivity castings lowered the conductivity more than silicon-copper. Better results were obtained by using silicon-copper than phosphor-copper, for the reason that phosphorus had such a delayed action when the material was solidifying; it was far better to have something which had not that action, if a sound casting was required for machining.

Modifying Al-Si Alloys

The first of several methods of modifying aluminium-silicon alloys was the fluoride method, which consisted in throwing potassium fluoride salts on the top of the molten metal at a temperature of about 900 deg. C., and allowing the action to take place. In a second method, metallic sodium was used, and a small quantity was put in a metal cup and plunged into the metal; this was sufficient to alter a coarse structure to one which gave an excellent bend test. Additionally, sodium hydroxide could be added in a similar way to potassium fluoride, or again sodium carbonate—a later method requiring a higher temperature, the metal having to be heated up to about 1,060 deg. C. When the metal was covered with the flux there was a violent reaction, and a burning of the sodium. This reaction gave the metal the essential fine-grained structure illustrated by one of the microstructures shown in the Paper.

Mr. Longden had referred to reversion. If the alloy was held too long after it had been modified it would revert to an unmodified structure. Immediately the correct temperature was attained the casting should be poured.

Use of Charcoal in Crucible Practice

Mr. A. Jackson said that the two essentials in the non-ferrous foundry were correct melting and temperature control. The method of covering the metal with charcoal was very old. He was recently interested to learn there were three ways in which charcoal could be introduced. It might be preferable to put the charcoal in the bottom of the crucible, and when the metal above melted, it would pass through the charcoal in the same way that the iron passed through the coke and slag in the cupola. The second method was to sandwich it centrally, and the third was to leave the charcoal until all the metal was in the crucible. Of the three methods, could Mr. Phillips say which was the best? The first method had been strongly recommended for manganese-bronze, but was found to be unsuitable for aluminium-bronze.

Recently, he knew of a case where a gunmetal bush, 6 in. long, 3½ in. in diameter, and ½ in. thick, had been returned. It was made in two halves, but he could not say how it was run, because the ends had been ground. A curious feature was that a wedge-shaped part of the casting was of iron. This part was the full thickness of the casting, 1 in. wide at the end, 3 in. in length, and tapering to a point. The iron appeared to have segregated, yet the bond with the gunmetal was perfect. He imagined that the mould had been cast tilted and the iron had separated out when the casting was poured. Was this a natural phenomenon, when too much iron was present in gunmetal?

Dangers from Wrong Use of Charcoal

Mr. Phillips said charcoal was not used by itself for a covering flux in manganese-bronze: in the foundry with which he was associated charcoal mixed with borax, salt and ground glass was used, so as to form a slag and a covering for the top of the bronze. For copper, as he had previously said, charcoal should not be put at the bottom of a highly-heated crucible. Charcoal was able to absorb about 10 per cent. of moisture, which would probably be given off as water vapour, and the metal would absorb that vapour. When melting in a crucible, it was best to place the charcoal on the top of the metal.

Iron in Gunmetal

Regarding the question of a wedge of iron in the gunmetal castings, this was quite easily done. If there were some iron in the scrap when the metal was being re-melted, it would not dissolve in the brass or the gunmetal; it would remain undissolved and would form the wedge. He had known cases where bolts had been made from scrap brass. The bolts looked satisfactory, but one or two snapped like carrots, because beneath the outside skin of brass there was a core of iron in the centre. Much difficulty was experienced in mixing iron and brass, and the iron was usually added as ferro-zinc or ferro-hardener; otherwise it would not go into the solution, but would remain as a separate metal.

Referring to the graph (Fig. 3), Mr. Phillips gave the following explanation, using as an example the following:—

3.5	per cent.	Mn	Mn ÷ 2	—	1.75
1.0	,,	Fe	Fe	—	1.00
2.5	,,	Al	Al × 2	—	5.00
35.0	,,	Zn	Zn	—	35.00
Remainder Cu			Total		42.75 Zn equivalent

From the graph this gave 42 tons ultimate tensile strength and 28 per cent. elongation, and just over 30 per cent. alpha structure. If the tonnage be divided by 0.22, it gave approximately 190, which gave the Brinell number. The Brinell hardness increased progressively in a manner similar to the tensile strength.

London and Birmingham Branches Joint Meeting

Paper No. 645

NATURALLY-BONDED OR SYNTHETIC MOULDING SAND?*

By A. TIPPER, B.Sc. (Member)

One very important aspect of the progress in the mechanisation of foundry operations is the planning or perhaps the re-organisation of foundries, and it is thought that those men on whom this responsibility falls cannot neglect the question of sand. What type of sand is to be used? Which will be most economical? Which will give a minimum of scrap castings? And so on. The possible field includes green-sand, dry-sand or oil-sand moulding, but the main choice really lies between naturally-bonded and synthetic sands.

To some extent the decision will depend on the particular circumstances of the foundry, but an endeavour will be made to show, in this Paper, what is actually being done in various British foundries to-day, both with natural and synthetic sands, in the hope that this information will assist those whose ideas on the subject are still vague, in any decision they may have to make.

So many Papers dealing with sands are now appearing both abroad and in this country that it is difficult to keep up-to-date with published work. For those particularly interested in synthetic sands a short list of contributions to this subject which have appeared within the past 12 months or so has been drawn up for reference. It is considered, however, that one can still look back with pride to the Paper given to the Institute in 1933 by Sheehan ("Recent

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* The author was awarded a Diploma for this Paper.

Developments in British Synthetic Moulding Sand Practice "), as an outstanding contribution on the subject. In that Paper Mr. Sheehan dealt with his own particular problems as typical of the day. That was more than three years ago, and since then other foundrymen in this country have been confronted with somewhat similar problems. Such problems include the demand of the engineer for castings with narrower limits of accuracy, smaller machining allowances and greater uniformity, and a natural desire for lower scrap losses and greater output. These problems can be solved, and are being solved, though not always in the same way.

American Practice

In America, the home of synthetic-sand practice, most steel, iron and malleable iron foundries use a synthetic sand. This is in part due to the lack of good deposits of natural moulding sands, which no doubt fostered the early growth of synthetic-sand practice, but the successful and continued use of this sand argues well for the suitability of such sands in general. As in this country, cost is a prime factor, and local sands are used if possible to avoid freight charges.

The author has been able to obtain a few details of the cost of sands in America (set out later) which show that the difference between the two countries is not very great, except that silica sands in America are nearly as cheap as our moulding sands. Non-ferrous foundries in America use mainly natural bonded sands if obtainable locally. With the introduction of American methods of production, mechanisation of foundries and the employment of semi-skilled labour, sand control became very necessary in order to obtain consistent results, and in the search for further improvements synthetic sands were tried.

How far these have proved successful in certain British foundries has already been stated in Papers to the Institute by F. Hudson, J. J. Sheehan, H. H. Shepherd, and T. R. Walker. Naturally, changes of this sort are rather slow, for it is only when some big change or development takes place in a foundry or serious trouble is encountered with sand that an alteration is visualised.

In this country, as far as can be gathered, there are roughly between 2,700 and 3,000 foundry concerns (including steel, cast iron, malleable and non-ferrous). Of these approximately 30, or 1 per cent., are using synthetic-sand practice, either wholly or in some section of the foundry. Additionally there are two foundries using cement-bonded sand.

Constitution of Sand

By synthetic sand is meant a moulding sand built up from a selected silica sand or other sand and a suitable bonding agent. The three main constituents of a moulding sand are (1) the sand grains, (2) the bonding material, and (3) moisture. All three are of primary importance in determining the characteristics of the sand, but whereas with natural moulding sands one can control and adjust to some extent items (2) and (3), with synthetic sands all three constituents are carefully selected to give the desired properties, and are controlled within fairly close limits.

Sand Grains

Everyone is familiar with the type of sand grains (Fig. 1) found in sea sand or other bondless silica sands, which have been scrubbed free of other mineral matter by water and wind action, becoming in the process more or less rounded and worn. In natural bonded sands these grains also make up perhaps 90 per cent. of the sand, the remaining 10 per cent. being composed of disintegrated mineral matter, associated with the quartz or silica grains. These grains (Fig. 2) form the porous structure of the sand and, according to their size, shape and sur-

Fig. 1.—Typical Microstructure of Bondless Sand.

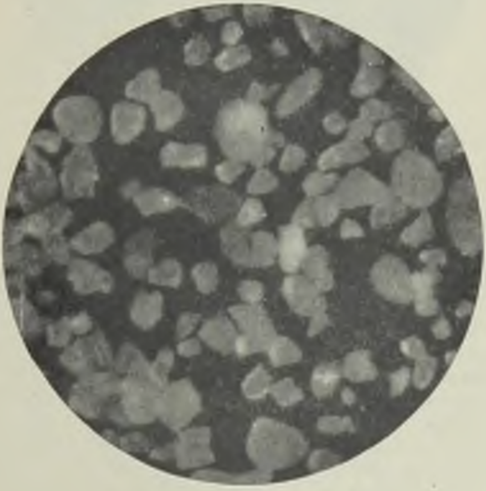

Fig. 2.—Microstructure of Naturally-Bonded Sand.

face condition, determine the permeability and materially affect the moulding properties of the sand.

The sand grains from natural moulding sands are not usually rounded or worn to anything like the same extent as with a sea, river or desert sand, whilst their grading or size is much more varied, *i.e.*, not classified.

Fig. 3.—Microstructure of an Irregular-Grained Sand.

When examining a sand, a picture is formed of the distribution of the various sizes of grains from the results of a sieve test. This is a very important test, and it has now been agreed both by the Iron and Steel Institute Moulding Materials Sub-Committee, and the Institute of British Foundrymen Sands Committee to standardise on a series of sieves. These are the B.S.S. Nos. 8, 10, 16, 22, 30, 44, 60, 100, 150, 200 and 300. It is known that the permeability of a sand decreases as the size of grains

TABLE I.—*Grading of Natural Bonded Moulding Sands. Sieve Tests on Washed Sands (Clay Free).*

Type of sand.	Mansfield red.	Bromsgrove red.	Midland red.	Wombourne red.	Wolverhampton red.	Blankshire facing sand.*
Per cent. remains on—						
30 mesh	—	—	—	—	—	—
40 ,, ...	1.0	1.2	1.0	1.6	2.9	11.2
60 ,, ...	1.9	5.8	7.3	6.6	6.2	8.2
80 ,, ...	2.8	9.2	16.3	9.4	1.4	7.2
100 ,, ...	6.7	14.0	18.1	16.2	11.3	9.5
120 ,, ...	2.7	4.5	5.3	4.9	3.0	3.2
150 ,, ...	27.2	23.6	21.7	27.1	27.2	23.6
200 ,, ...	28.9	12.2	10.6	9.1	14.2	12.8
Passes 200 mesh	18.0	18.4	14.5	17.0	23.5	12.1
Clay, per cent. (A.F.A. method)	10.5	11.1	5.1	7.9	10.3	12.3†

* This sand gave unsatisfactory finish.

† Includes coal-dust.

decreases, and that as the size of grains decreases the surface area of grains in a given volume of sand increases, so affecting the bond or strength; but it is probably not realised to what a marked extent the distribution of various sized grains affects the properties of the sand. This has been clearly shown by an American contributor, Mr. G. K. Eggleston, in a recent Paper on "Non-Ferrous Sands."

Taking a sand consisting of all 40-mesh grain with a permeability of 500 A.F.A., and a second sand consisting of all 270-mesh grain with a permeability of 40 A.F.A., the addition of 10 per cent. of the 270-mesh material to the 40-mesh grain reduces the permeability to 100, and the addition of 15 per cent. of a 140-mesh material to the 40-mesh reduces the permeability to 150. To compare with these figures, the permeability of cores made from Southport sea sand is 140 A.F.A.; King's Lynn sand, 165 A.F.A., and Ryarsh silica sand, 60 A.F.A.

Other Cardinal Points

The *surface condition of the grains* which, together with the surface area, affects particularly the bonding properties or strength of the sand (Fig. 3), and *the expansion characteristics*, are particularly important. Since one can regard all sand grains as having approximately the same expansion characteristics, the difference in behaviour of a mould when subject to heat depends on such factors as the density of the mould (*i.e.*, packing of the grains), and the presence of materials which will give way or afford room for the increased volume of the quartz grains, so avoiding buckling or distortion of the mould face. Obviously, when a sand is made up of a great variety of sizes of grains or a high proportion of fine grains, the effect of expansion is more difficult to overcome.

At this point it is appropriate to compare the grain size and distribution of typical natural bonded moulding sands with those sands used in synthetic-sand mixtures. Until recently the

TABLE II.—*Grading of Silica Sands used as a Basis of British Synthetic Moulding Sands. Sieve Tests (Unwashed Sand.)*

Type of sand.	Sea sand. Southport dune sand.	Leighton-Buzzard medium.	Erith silica.	King's Lynn silica.	Leighton-Buzzard bank sand.	Ryarsh silica.
Per cent. remains on—						
30 mesh	Less than 0.1	6.3	1.0	6.4	1.5	—
40 ,, ...	0.7	20.0	8.6	13.4	—	0.5
60 ,, ...	26.7	50.5	49.4	34.6	32.3	0.8
80 ,, ...	39.9	15.2	26.9	26.3	26.6	2.1
100 ,, ...	27.3	4.5	10.7	13.0	—	1.5
120 ,, ...	2.9	2.4	1.0	1.8	29.3	0.7
150 ,, ...	2.0	0.5	2.0	3.6	7.5	66.9
200 ,, ...	0.5	0.4	0.5	0.4	1.8	18.7
Passes 200 mesh	—	—	v. small	0.5	1.0	8.8
Clay or silt, per cent. ..	—	—	—	v. small	0.6	up to 1.5 (varies)
Loss on ignition, per cent. ..	0.8	Less than 0.1	Less than 0.1	0.25	—	—

natural bonded sands were chosen as a result of practical trials from deposits of widely differing types—in Scotland the rotten rock sands; in Northern England the yellow sands of Yorkshire or red sand from Worksop or Mansfield; in the Midlands one of the numerous Bunter red sands, and in the South the light yellow or grey loamy sands of London or Southampton districts. Each particular type has certain features of its own, although there is a general similarity between all red moulding sands which makes them of general use, except for steel moulding, all over the country.

In a recent questionnaire issued by the Institute's Sands Committee, red sands were used in 35 out of the 84 facing mixtures examined. These include mixtures for cast iron, non-ferrous and malleable work.

Table I gives details of sieve tests made on a number of naturally bonded sands used in Midland iron foundries for green-sand moulding. Note particularly the way in which the grains are spread over the whole range of sieves from 60 to 200, with considerable percentage passing 200 mesh. (It should be mentioned that all the test results shown have been made on Tyler IMM standard sieves, and should not be confused with the new British standard sieve sizes.)

Compare now the grading of silica sands used as the basis of synthetic-sand mixtures used in this country (Table II). It will be noted how the bulk of grains in each sand occurs between two or three sieve sizes, and that, apart from Ryarsh, they are all graded between the 60 to 120 sieves. The SiO_2 content varies from 97 to 99.5 per cent.

Before arriving at any conclusion, a consideration of the other two components of the sands as used is worth while.

Bonding Material

The natural bonding material of sands is formed by clays of varying composition and physical properties, together with other mineral

TABLE III.—*Natural Bonded Sand Mixtures used in Midlands for Cast Iron—Green-Sand Moulding.*

Type of sand.	Proportion of new sand used. Per cent.	Class of work.	Moisture per cent.	Green compression str. lbs. per sq. in.	Green permeability A.F.A. No.	Dry compression str. lbs. per sq. in.
Mansfield red . .	8–9	General engineering	6.0	3.1	25	41.5
Bromsgrove red . .	unit sand 1 per cent. 0.2 C.D.	Small electrical fittings	6.0	5.2	30–40	80–85
Midland red . .	25 3 C.D.	General engineering	5.5	7.1	23.3	73
Wombourne red . .	10 5 C.D.	Medium wt. valves . .	5.5	5.0	38.5	—
Bromsgrove red . .	17 3 C.D.	Small castings high duty iron.	5.5	2.7	41	40
Stourbridge red* . .	35 6 C.D.	General engineering up to 10 cwts.	6.8	5.3	16.5	121
Wombourne red . .	33 6 C.D.	Stove plate for enamelling.	4.2–4.5	4.6	22	—
Harborne red* . .	33 8 C.D.	Machine tools small and medium wt.	6.7	5.0	26.4	94

* Hand moulding.

matter, such as limonite (hydrated iron oxide), which is often present, adhering to, or coating the particles of clay and quartz grains. The proportion of bonding material present in a deposit of moulding sand varies considerably, but the sand can be graded to give a fairly uniform amount of bonding material, and some of the best deposits show surprisingly little variation over long periods, as shown by the sieve test and clay content.

Recent investigations of the physical and chemical properties of bonding clays, both in America and in this country, by the B.C.I.R.A. have shown that much depends on both the chemical nature and the physical characteristics of the minerals in the bonding substance.

To summarise briefly, the conclusions are as follows:—

The green strength of a moulding sand, apart from such factors as grain size, moisture, milling and percentage of bond, is dependent on the particle size of the bond.

The dry strength is dependent on both chemical and physical properties of the bond and can be correlated with the base exchange value of the sand. This value expresses the ability of the sand or other material to hold either basic or acid ions* on their surface. Owing to the great surface area of bentonite, this property can be increased or decreased by the addition of alkalis or acids.†

The life or property of the bonding substance to be rehydrated after exposure to elevated temperatures (so recovering its plasticity) varies with the type of minerals present in the bonding substance.

The bonding substances can be roughly divided into three groups:—

(1) *Bentonite Clays.* Here the particle size is less than 1 micron diameter, which is ex-

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* Atoms or molecular groups of atoms carrying a charge of electricity.

† The addition of small proportion (0·5 per cent.) alkali to a dispersion of bentonite in water, materially increases its viscosity.

TABLE IV.—*Moulding Sands used for Cast Iron in British Foundries, showing Variation in Composition and Properties.*

Type of Casting.	Ratio new sand to old.	Ratio coal-dust to sand.	Moisture per cent.	Green compression str. lbs. per sq. in.	Green permeability A.F.A. No.	Dry compression str. lbs. per sq. in.
Light—						
Minimum	1–100	1–500	3.5	2.4	22	24
Maximum	1–1	1–5	8.0	6.5	46	100
Average	1–3	1–35½	6.0	4.8	30	79
Medium—						
Minimum	1–40	0	3.5	3.1	16.5	25
Maximum	1–1	1–50	7.0	10.0	53	200
Average	1–3½	1–18½	6.75	5.0	31.3	90
Heavy—						
Minimum	1–12	0	3.5	4.5	20	50
Maximum	2½–1	1–19	8.0	9.5	60	162
Average	1–2	1–15	6.75	5.8	35	95

tremely small. The green bonding value is very high, the base exchange value being 100. Its chief constituent is montmorillonite, that is a hydrated aluminium silicate. Its life is very good, rehydration taking place up to 540 deg. C., whilst the refractoriness is fairly good, being of the order of 1,300 deg. C.

(2) *Kaolinite Clay Substance (including silicious clays).* The chief constituent of kaolin or china clay type is hydrated aluminosilicate, which is also the constituent of many plastic clays and fireclays. Its particle size varies widely, reaching up to 20 microns. The green bond varies, and may be improved with continued use owing to subdivision of clay particles. The refractoriness is very high, but varies up to 1,650 deg. C. Its life is only fairly good, rehydration taking place up to 426 deg. C.

(3) *Limonite* or hydrated iron oxide may be ferrous or ferric, but generally is given the formula of $2Fe_2O_3 \cdot 3H_2O$. It occurs as a coating or staining on grains but it can also occur in a colloidal form, and gives improved green and dry strength in the presence of other plastic bonding clays. Its refractoriness is comparatively low owing to fluxing effect of iron oxide with silica forming a ferrous silicate slag. Its life is poor and rehydration takes place up to approximately 180 deg. C.

Expansion Characteristics

The expansion characteristics of clays vary. Some clays begin to contract at high temperature and so may cause failure of a mould face. In British sands, the bonding substance is often a mixture of types 2 and 3, though the exact mineral nature is very difficult to identify. With a few exceptions the bond of these sands is not sufficiently refractory for steel moulding practice; hence the use of Continental sands and " compo " mixtures.

However, there are a few British deposits of clays which are both refractory and sufficiently plastic to act as bonds in synthetic sand mixtures. These are the ball clays or plastic clays occurring in the South of England, to a very limited extent. The chief available bonding substance with one exception is the imported American bentonite (sold under trade names).

The use of such substances with very high bonding properties and good life enables most economical proportions to be used in synthetic mixtures, at the same time developing equal or higher bonds than obtained from natural sands. In Table III particulars have been tabulated of a number of facing sand mixtures, using naturally bonded sands, as used in the Midlands for a variety of work in cast iron. Note the physical characteristics of these sands. The moisture is roughly 5.5 to 6.5 per cent.; the green bond 5.0 lbs. and the permeability 20 to 40 A.F.A. Note also the wide variation in proportion of new sand used in these mixtures.

When comparing naturally bonded sands used in various parts of the country, one is impressed by the tremendous variations both in proportions of new sand to old, and also in the physical properties of the mixtures, as is shown in Table IV. It is obvious that the satisfactory results obtained can only be attributed to the skill and local experience of the moulders with that particular mixture. Any attempt to standardise procedure with such a variety of mixtures would be disastrous.

Synthetic Sands

Examining the types of synthetic sand mixtures being used in this country and their properties, details of actual mixtures in use for various green sand work in cast iron, together with their chief properties, are set out in Table V. The outstanding differences in properties between these mixtures and those given in Table III are the moisture content only 3 to 3.5 per cent., and permeability much higher at 60 to 75, whilst the green bond at 6 to 8 lbs. per sq. in. is also somewhat higher. Two of these mixtures are from

TABLE V.—*Synthetic Sand Mixtures in Use for Cast Iron.*

In British Foundries—Green Sand Moulding.

Sample no.	1	2	3	4	5	6
Type of base sand used	Leighton Buzzard	Southport sea sand	Sea sand and Leighton Buzzard bank sand	Erith silica sand	Leighton Buzzard No. 26 or Bedford silica	Scottish rotten rock
Particulars of mixture	System sand. 99.4 Old sand 0.56 New sand 0.06 Bond clay	54 Old sand 36 New sand 4 Colbond 6 Coal dust	91 Backing sand 3 Bentonite 6 Coal dust	System sand. 99.7 Old sand 0.25 New sand 0.05 Bentonite	70 Old sand backing 20 New sand 3.5 Colbond 6.5 Coal dust	System sand. 97 Floor sand 1 to 3 Rock sand 0.7 Coal dust 0.1 Wood extract
Class of work	C.I. baths for enamelling	Pot castings, high-duty iron	Light castings (facing sand)	Light castings in high-duty iron. 70 per cent. steel	Automobile cylinder castings. — Facing sand	Hydraulic engineering castings. Hand and machine moulding.
Moisture, per cent. ..	3.0	3.0—3.5	3.5	3.8	4.0	6.0
Green compression str., Lbs. per sq. in.	4.5—5.0	6.0	9.5	5.9	8.0	6.0
Green permeability, A.F.A. No.	60—70	70—75	70	65	50—60	53

mechanised casting plants and the very economical proportions of new bonding material added should be noted.

It should be borne in mind, that in any sand mixture, the preparation of the sand by milling is most important to secure proper distribution of the bond, with consequent economy in amount of bonding materials required to produce certain results. It is a fact, mentioned by Shepherd in his Paper last year, that the green strength of many mixtures can be raised considerably by additional milling without serious detriment to other physical properties. This applies particularly to the mechanised plant where the milling time is cut down to a minimum in order to obtain the required output of sand, and for this reason it is usually necessary to commence operations with a higher proportion of bonding clay to sand than theoretically necessary, and gradually reduce the additions after the mixture has been in use for a short time. The same also applies to a natural bonded sand on a continuous system.

There are at least two foundries where the introduction of modern sand preparation plants resulted in the complete elimination of any new sand additions for at least 12 months owing to the better utilisation of the available bond, and with the addition of coal dust, burnt sand or core sand being added to make up bulk.

Moisture

Now to consider the third constituent—moisture. The presence of moisture is necessary in both natural and synthetic bonded sands where a mineral bonding substance is used. It is present both in the combined form as part of the bonding minerals, which depend for their plasticity on this combined water, and also as free or excess water held mechanically on the surfaces of the sand grains or absorbed by the silt and clay. This excess of free water assists in the effective distribution of the bond over the sand grains, but it is the first to be converted to steam on the application of heat.

This takes place very rapidly when molten metal comes in contact with the sand, and for this reason, moisture added to temper the sand either in excess or not properly distributed leads to trouble.

The combined effect of the bond and moisture is to impart plasticity (or " deformation " as the Americans call it), and coherence between the sand grains. There is an optimum moisture content for any sand mixture at which its strength is at a maximum value. This can be readily determined by experiment (see Table VI and Fig. 4).

TABLE VI.—*Variation in Properties of Sands with Moisture, per cent.*

Sand.	Moisture. Per cent.	Green compress. Lbs.	Green perm. A.F.A.	Dry compress. Lbs.	R.D.
No. 1	4.4	6.2	28.1	47.0	—
	5.5	7.1	23.3	73.0	—
	6.5	6.8	26.8	106.0	—
No. 2	5.0	5.1	65.0	44.0	1.45
	5.5	5.4	59.0	—	1.45
	6.2	5.9	56.0	88.5	1.45
	6.5	7.0	33.0	—	1.65

Whether the sand in practice is used at this optimum moisture percentage will depend on several factors, such as the available bond, grain size, method of moulding, etc. For example, a heavily-bonded fine-grained sand will usually be worked with a lower moisture content than optimum, in order to avoid too plastic a mixture. No. 2 of Table VI is an example of this, the working moisture content being in the region of 5.5 to 6.0 per cent. This is a very usual figure for natural moulding sand mixtures for green sand work, as will be observed from tabulated details already given, whilst with synthetic sand practice, the moisture is usually around 3 per cent. This is partially accounted for by the smaller surface area of sand, and particularly by the absence of silt or inert bond.

Owing to the much higher permeability and composition of these sands, the loss of moisture during handling of the sand is more rapid than with naturally bonded sands. This becomes a serious problem in mechanised systems where the temperature of the sand rises to a dangerously high level after a few hours unless special methods are adopted for cooling the sand in the system.

In retempering, the best method for a mechanised system is to add the greater part of the required water to the sand as early as possible in the cycle, in order to allow as much tempering time as possible, at the same time reducing the sand temperature, and only the final adjustment made at the mill of, say, the last 0.5 per cent.

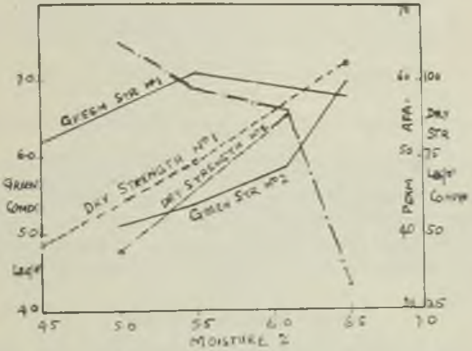

FIG. 4.—PROPERTIES OF SANDS MODIFIED BY MOISTURE CONTENT.

The loss of moisture can be reduced by the incorporation in the sand of such agents as glycerine and calcium or magnesium chloride, but moisture control is still one of the big problems in operating such plants. Recently in America the addition of fuel oil has been tried, to replace part of the coal dust addition, and it is stated that this enables a lower moisture content to be used with consequent less trouble in drying out.

The moisture content in such sands should not vary by more than $\frac{1}{2}$ per cent. up or down for satisfactory results, and, according to Dietert, the correct amount of tempering moisture can be calculated for any sand from the following formula:—

Per cent. moisture required

$$= \frac{\text{Fines}}{20} + 6.7 - \frac{\text{Green compression}}{5}$$

Where fines = percentage of sand grains retained on (200, 270 and Pan) in the Screen Test.

As examples.—Take, say, No. 2 Mixture of Table I.

$$\text{Moisture} = \left(\frac{30}{20} + 6.7 - 1\right) = 7.2.$$

For synthetic sands, however, the results appear too high.

The foregoing remarks and the mixtures given apply particularly to cast iron founding, but since synthetic sands are in use for steel, malleable and non-ferrous castings, a few remarks and details of such mixtures will not be out of place.

Steel Moulding Sands

For steel castings, green sand and dry sand moulding is practised; the dry sand is often bonded with an organic or oil binder, using a pure silica sand, with or without bentonite. Compo may also be classed as a synthetic moulding material, and cement sand mixtures are the latest innovation for steel-casting moulds.

Typical Steel Moulding Sands of the Green sand variety are:—

(I) 75 per cent. Old sand.
25 per cent. King's Lynn silica.
1.5 per cent. Bentonite.
0.25 per cent. Core gum.
Moisture, 3 to 4 per cent.

(II) 84 per cent. Old sand.
15 per cent. Belgian.
0.5 per cent. Bentonite.
5 per cent. Moisture.

Non-Ferrous Moulding Sands

In the non-ferrous foundry, though the naturally bonded sands are particularly suited for most classes of work, there are a few instances in which synthetic moulding sands have been called into service. For example, in the casting of Elektron or other magnesium-aluminium alloys, a silica base sand is in general use, bonded with bentonite, Colbond or an organic binder.

The production of special motor and aero engine castings of complicated form in both ferrous and non-ferrous metals is carried out in dry sand or oil sand moulds and cores prepared with mixtures of silica sand and a proportion of naturally-bonded sand.

Typical Dry sand Facing Sand (Motor Cylinder) :—

10 Shovels ..	.. Old dry sand (crushed).
4 Shovels ..	.. Old floor sand.*
1 Quart ..	.. Coal dust.
1 Quart ..	.. Colbond.
1 Quart ..	.. Bondol.

Moisture, 5 per cent.

* (Contains some Kingswinford Red.)

Cement-Bonded Sands

This method of bonding sand grains for moulding purposes was used about 20 years ago by Moldenke in America for coremaking. More recently the patented Randupson process has been developed in France, and there are now two foundries using the process under licence in this country. The mixture used for moulding consists of a clean well graded silica sand, similar to those used in a synthetic sand mixture, mixed with about 10 per cent. of Portland cement and from 4 to 6 per cent. water. Portland cement is produced by heating together lime and a siliceous clay or ground slag, and grinding the resulting sintered mass to a fine powder. On wetting this finely divided powder of complex silicates, chemical changes occur with the absorption of water and the mixture sets to a hard stone-like mass. These changes take an appreciable time to complete, and the damp mixture of sand and cement, which is prepared in the usual type of mill, remains in fit state for moulding over a period of two or three hours after mixing.

Usually this mixture is only used as a facing (approximately 1 in. thickness), the backing consisting of old crushed moulds or cores with sufficient cement added to give the required bond. Moulding practice resembles that used for oil sand work, the half moulds being stripped on to flat plates for " curing " or " setting." For the first 18 to 24 hrs. after moulding the mixture must be stored in a humid atmosphere or protected from losing moisture to the atmosphere if maximum " set " strength is to develop, after which the moulds are allowed to dry-off as quickly as practicable.

The curing or setting can be accelerated by increasing the room temperature, provided that the humidity is maintained to prevent loss of moisture from the moulds during the first period. Altogether the interval between moulding and pouring will be from 36 hrs. upwards, and when dressing the mould face with blacking, etc., the total time is increased up to two to four days.

The moulds are then assembled and cast in the usual way. Owing to the open grain class of silica sand used, the surface finish of castings made in untreated moulds is not always as smooth as desirable, and spraying or painting the mould face with blacking gives much better results for cast iron. Steel may be poured into untreated moulds or a special silica flour wash used. After casting the used moulds are crushed up for re-use. The " set " mixture does not recover its plasticity when retempered with water and must be rebonded with fresh cement.

Future Possibilities

Owing to the effect of the hardened cement in lowering the refractoriness (due to its basic character) and permeability of the moulding material if re-used, it is considered that it is best to use this old sand only for "backing," although by the use of special sand recovery plant it is feasible to recover a large proportion of sand for re-use in facing mixtures. The plant consists of a suitable grinding mill, screens and dust extraction plant, to remove as far as possible the dried cement and leave a mass of clean separated grains. All-new sand is recommended for steel. Further points worth mentioning are:—

(1) Possibility of using other types of cement or adding chemicals or substances to reduce the curing time.

(2) Control to close limits on moisture are essential in practice.

(3) Suitable storage for two to four days' production of moulds must be provided.

(4) Extended milling of the sand-cement mixture in preparation should be avoided to reduce moisture loss to a minimum.

Physical Properties of Cement-Bonded Sands

The following figures taken from a Paper by C. A. Menzel of the Portland Cement Association, U.S.A., show the physical properties of typical mixtures using a Missouri silica sand of medium grain size (50 to 100 mesh).

	Using normal cement.	Using H.E.S. cement.
Cement content ..	8.3—12.5 per cent.	8.3—12.5 per cent.
Green compressive strength	2.5—4.5 lbs. per sq. in.	1.5—2.5
Dry compressive strength (3 days after ramming)	600—800 lbs. per sq. in.	400—600
Permeability	130—95	120—100

This author advocates the use of a "High Early Strength" cement to reduce the "setting" time and obtain higher green and dry strength.

The properties of the sand-cement mixture may be compared with ordinary moulding sands and oil sands as follows:—

Green strength is lower than naturally-bonded sand mixtures but higher than most oil sand. Sufficient green bond to prevent sagging or distortion is obtained with correct cement and water contents. This mixture like other synthetic sands has good flowing properties, and does not require special skilled moulders.

The permeability is high and necessity for venting thereby lessened. In many respects it can be compared with oil sand practice except that the dry strength and strength at high temperatures is much greater. This is an advantage where there is considerable thickness of metal or against a runner where an oil sand might break down, but is a serious disadvantage when it comes to removing cores which are practically surrounded by metal.

According to the developers of this process the main advantage is in the reduction of labour moulding charges and standardisation of foundry practice, but it should be observed that this can be claimed for synthetic sand mixtures as a whole.

Estimated Cost of Mixture (Raw Materials Only)

Reckoning cement at 50s. per ton and silica sand at (1) 15s. per ton or (2) 10s. per ton.

Cost of facing mixture (1) 18s. 6d. per ton or (2) 14s. per ton; 10 per cent. cement.

Examples of savings in labour charges (supplied by Messrs. Hinckleys):—

(*a*) Iron foundry producing 60 tons of castings per week—overall labour charges reduced by 38s. per ton.

(*b*) Steel foundry producing 55 tons of castings per week—overall labour charges reduced by 40s. per ton.

The cost of preparation is about the same as for other sands, but if recovered sand is used then sand recovery plant must be installed. No drying stoves or ovens are required in this process, thus cutting out a considerable cost on dry sand work, whilst owing to the higher strength of the dry mould, the total amount of sand used will be less. The process is being used for steel, cast iron and non-ferrous metals, and constitutes another example of the replacement of naturally-bonded sands by a synthetic mixture.

Analysis of cement bonded sands:—SiO_2, 83.3 per cent.; CaO, 7.0 per cent.; Al_2O_3, 2.0 per cent.; MgO, 0.5 per cent.; Fe calculated as Fe_2O_3, 4.0; alkalis, 2.0, and loss on ignition, 1.74 per cent.

The next consideration is the relative advantages and disadvantages of the two classes of sand. These may be briefly summarised as follows:—

Natural Bonded Sands.

Advantages.	Disadvantages.
(1) Low cost of sand in most districts.	(1) Skilled operatives often necessary for moulding.
(2) Strict control of mixture not essential.	(2) Poor permeability means much venting necessary, and ample coal dust.
(3) Excellent surface finish can be obtained on castings with due care in sand preparation, etc.	(3) Variable moulding results and scrap losses often high, particularly in mechanised plants, due to short milling time. Sand pellets occur.
(4) Particularly suitable for non-ferrous work, and with metals having low surface tension.	(4) Accumulation of old sand or cost of dumping.
(5) Moulds can be readily patched or sleeked.	

Synthetic Sands.

Advantages.	Disadvantages.
(1) Ease of moulding, hand or machine, *i.e.*, free flowing.	(1) Not usually easy to patch.

(2) Good physical properties ensured by regular control—reduces scrap losses.	(2) Loses moisture rather rapidly, may cause "murly" or weak friable edges on moulds.
(3) No waste sand to dump.	(3) Higher first cost of sand. Finish not always satisfactory.
(4) Selected properties of sand to suit class of work and moulding equipment.	

Costs of Sands

Entering into more detail with some of these points:—

Since costs are always of first importance it is interesting to compare natural and synthetic sand mixtures on this basis.

Table VII.—*Sand Costs.*

(1) *In this country*—

Cost of new moulding sand varies from 5s. to 10s. per ton d/d.
,, silica sand or sea sand varies from 6s. to 20s. per ton d/d.
Cost of bentonite .. say £10 per ton.
,, other clays say £3 to £6 per ton.

(2) *In America*—

Cost of new moulding sand (local)	7s. 6d. to 12s. 6d. per ton d/d.
,, silica sand.. ..	10s. to 15s. per ton d/d.
Bentonite	£4 to £4 10s. per ton.

(3) *Cost of batch milling.*

	Natural.		*Commence synthetic.*		
A	80 old	=nil	Silica sand ..	95 at 15s.	71.25
	20 new	=10	Bentonite ..	3 at £10	30
	2 C.D.	= 4	Coal dust ..	2 at 4s.	4
	102 tons	£14			£105.25
	Cost = 2s. 9d. per ton.		21s. per ton.		
			Revivify.		
B	77	..= Nil			
	33	..=£16 10s.	Old sand ..	87.5 ..	Nil
	2	..= 4	New sand ..	10 at 15..	7.5
			Bentonite ..	0.5 ..	5
		£20 10s.	C.D. ..	2 ..	4
					£16.5
	Cost = 4s. per ton.		Cost 3s. 6d. per ton.		

Taking first of all *batch mixings* of facing sands, and ignoring cost of preparation as common to both. The figures of first cost are definitely in favour of the naturally-bonded mixture, *i.e.*, 2s. 9d. to 4s. per ton, as against 21s. per ton, though this does not take into account any cost of dumping old sand when using naturally-bonded sand. A price is assumed of 10s. per ton for new naturally-bonded sand for calculation, which it is realised is high for some districts (such as the Midlands for instance), unless the sand is ready milled or sieved. Yet against this must be reckoned the 15s. taken for silica sand which is also high for many areas near to supplies of suitable silica sand.

After the high initial cost of the synthetic sand, the maintenance or regular week to week cost is very much less, and taking a representative addition of 10 per cent. new silica sand with 0.5 per cent. bentonite, this mixture only costs 3s. 6d. per ton, without any dumping costs. On continuous sand plants the management is able to get down much more closely to actual sand costs. Details are given in Table VIII of actual costs of operating sand systems on a natural sand and three synthetic mixtures. It is obvious from these figures that apart from first cost of stocking the system, there is very little difference in actual running costs for sand maintenance.

Cost figures for American practice submitted by Dietert show considerable saving, varying from 2s. 6d. to 5s. per ton of metal poured when operating a specially bonded synthetic sand, in comparison with the use of naturally bonded sand mixtures, with new sand costing from 11s. 2d. to 14s. 3d. per ton. This is achieved by eliminating almost completely facing sand, using fettling shop sand, burnt core sand, and used moulding sand. This of course is also being adopted in several foundries in this country.

Working Properties

The practical man will naturally want to consider the working properties of these sands, and

TABLE VIII.—*Comparison of Sand Costs in Continuous Sand Systems.*

System.	No. 1.	No. 2.	No. 3.	No. 4.
Type of sand	Natural	Synthetic	Synthetic	Synthetic
Total sand in system. Tons	24	70	62	35
Rate of sand circulation. Tons per hr.	24	60	50	30
Amount of new sand added per day or 8-hr. shift. Tons	1.1	3.0	1.0	0.5
Amount of bonding material added per day or 8-hr. shift. Lbs.	Nil.	600	400	50
Price of new sand. Per ton	10s.*	21s.†	6s. 6d.	15s.
Price of bonding material	—		£10	£6 10s.
Per cent. new sand addition	0.57	0.6	0.25	0.02
Cost of additions per 100 tons of sand treated	5s. 9d.	12s. 7d.	10s. 8d.	1s. 10d.
Ratio of metal poured per ton of sand used for moulds	1 cwt. per ton	—	0.9–1 cwt. per ton	—

* Ready milled. † Cost of prepared mixture.

what sort of castings are produced in them, particularly as regards surface finish on the castings. [To illustrate what is being done a number of examples of castings made in regular production in synthetic sand from different foundries were exhibited. These were in all cases cast green, and represented varying sections and composition of metal, high and low phosphorus, common and engineering irons.]

It is suggested that although the finish is not perhaps as good as the best obtainable with natural bonded sands, it is really very satisfactory. At first the results were often rather poor, but by slightly modifying mixtures and adjusting the grain size of the sand, considerable improvement has been made from the point of view of surface finish.

The addition of a small proportion (say 10 per cent.) of a fine grained natural bonded sand, or burnt foundry sand, is the usual method of procedure, and although this does reduce the permeability, this can be held at a satisfactory figure, once the requisite amount of fine grained sand has been introduced into the system, or general heap sand. Therefore, under this heading of synthetic sands are included those mixtures which contain a proportion of naturally bonded sands, and it is thought that in future instead of choosing a perfectly clean silica sand for the base of a synthetic mixture, the most suitable sand will be found to be one possessing already a coated grain (*i.e.*, grains already possessing a film of clay or bonding substance). In theory there is no reason why one should not use silica grains with a natural bond already present, provided that one can obtain a satisfactory grain size, and also that the bond is sufficiently refractory for the purpose. Such sands are to be found in this country. An example of such a sand reached the author quite recently from the Sheffield district. The sand has beautiful worn rounded grains of pure quartz, with a very fine coating of clay, so evenly distributed that it is not noticeable to the naked eye. It contains just under 1 per cent. of dry clay substance sufficient to cause the grains of sand to clot or adhere weakly when dried.

The difficulty usually is to get rid of undesirable fines or mineral matter which is not effective as a bond producer, but merely absorbs water and clogs up the pores or voids in the sand.

In a number of mechanised sand plants operating with natural sands, classifying or dust extraction plants are fitted which aim at removing the fines from the system. This is an attempt at correcting an inherent property of the sands being used, and in general these also remove a considerable amount of valuable sand. When dealing with a synthetic sand, there is no necessity for such a plant. There is every reason to believe that in practice there is very little, if any, disintegration of the sand grains, apart from those sufficiently near to the actual metal to be subject to extremely rapid heating. Such sand is almost entirely removed with the casting to the fettling shop. Silt is more likely to be produced by breakdown of the bonding material, particularly if this be of a crystalline nature, but here again the dehydration or destruction of bond is only in that part of the mould close to the metals, and with re-use of the sand the dehydrated or decomposed bonding material either forms a thicker coating on the silica grains or is agglomerated (probably by the distillation products of coal dust or other bonding substances added) without impairing the permeability of the sand.

Conclusions

To conclude this section of the Paper, some of the desirable properties of moulding sands have been listed which should be sought in choosing a new sand.

(1) Choose a sand with close grading of the grains in order to secure the required permeability, and casting finish. Permeability (green) of 50 to 70 is satisfactory for cast iron.

(2) The new sand should not contain more fines than desired in the working sand, and 10 per

TABLE IX.—*Classified Characteristics of Sands for Various Purposes.*

Purpose.	Facing sand.				Heap sand.			
	Permeability.	Bond. Lbs. per sq. in.	Moisture. Per cent.	Coal dust. Per cent.	Permeability.	Bond. Lbs. per sq. in.	Moisture. Per cent.	Coal dust. Per cent.
For castings from ½ to 4 cwts. ..	75	9.0	3.5	5.5	90	8.7	3.5	3.0
For castings 1 to 2½ cwts.	85	8.5	3.5	5.5	110	7.0	3.5	3.0
For malleable castings from 20 lbs. to 1 cwt. to stand high temperature	100	8.5	3.0	5.0	120	7.0	3.0	4.0
For castings from 1 lb. to 80 lbs. ..	70	9.5	3.5	5.5	75	7.0	3.5	3.0

cent. passing through a 200 mesh is the approximate limit.

(3) The refractoriness of the sand should be sufficiently high to prevent burning on; this, of course, depends on the type of metal and casting temperature, etc. "Not fritted" at 1,300 deg. C. is suggested as suitable for cast iron.

(4) Choose a bonding material with a high bonding power and good life.*

As a final example of a specification for synthetic sands, Table IX reproduces some figures published by the Ford Motor Company, of Dagenham, in one of their recent booklets, showing characteristics of sands for four classes of castings.

It is hoped that the above remarks have not been unduly biased by personal opinions; the facts are stated as clearly as possible for both sides. The object is to induce a more intelligent and economical use of domestic resources of moulding sands in the future.

Finally, the author wishes to express his thanks to those individuals and firms who have so generously supplied details of their mixtures, provided samples of sand and examples of castings, and to the directors of his own company, the Fordath Engineering Company, Limited, for granting him the facilities for the preparation of this Paper.

COMMUNICATION

Mr. F. Hudson, in a written contribution, complimented the author upon the excellence of the Paper, and then referred to Mr. Tipper's cost summary, in which it was stated that the price of new moulding sand in this country varied from 5s. to 10s. per ton delivered. These figures, Mr. Hudson continued, were not actually representative of ruling prices throughout the British

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* Determined by retempering a sample of the sand after heating to temperatures over the range 300 to 1,800 deg. F. (150 to 1,000 deg. C. in increments of 200 to 300 deg. F.), and measuring the drop in green strength produced. A sand showing an average loss over the whole range of not more than 60 per cent. is considered to have a bond with good life or durability.

Isles, and as examples he drew attention to the cost, delivered, of Scottish Rotten Rock Sand, which was 17s. 6d. per ton, and silica sand which varied from 4s. to 20s. per ton delivered.

He also suggested that when a foundry turned over from naturally-bonded sand to a synthetic sand, it was not always an economic practice to commence production with synthetic sand, made entirely from silica sand, coal dust and bentonite. It was much more economical to make the change gradually by stopping the addition of new sand and replacing it with silica sand in the form of old oil-sand, etc. In the course of a few months a synthetic sand would be in operation and would have been obtained at a very low cost.

Author's Reply

In reply, MR. TIPPER thanked Mr. Hudson for drawing attention to the cost figures of sand in this country, and whilst admitting that circumstances would alter the cost appreciably—either lessen it or raise it—he contended that his figures did probably represent the bulk of English supplies.

With regard to the gradual change over from naturally-bonded to synthetic moulding sand, he admitted that this might be more economic, and would be advantageous since it would not upset conditions in the foundry so much. Where the existing sand mixture was low in permeability and strength, however, he did not concur that this practice would be advisable, since without a reasonably well graded base-sand, the synthetic bonded mixture might suffer from the faults of the original natural-bonded mixture, or require unduly high proportions of additions to maintain its conditions.

East Midlands Branch

Paper No. 646

PATTERNMAKING FOR PRODUCTION MOULDING*

By S. A. HORTON (Associate Member)

The author has purposely selected patternmaking for production moulding, because he is of the opinion that this type of patternmaking is of more general interest, but pattern equipment for one-off or small production castings must not be disparaged. The construction of some of these patterns requires a considerable amount of skill, whilst others are more or less pattern joinery which leave much to the imagination and skill of the moulder.

It would be ridiculous to attempt to state any hard and fast rules regarding the design or construction of any kind of pattern equipment to be used in foundries generally. Each individual foundry is designed for, and has installed, different equipment, *i.e.*, moulding machines, moulding boxes, core ovens and labour; therefore, each suggested design for a casting is a different problem for each individual foundry.

[After reviewing the requirements of a patternmaker, and urging the closer co-operation between the foundry and the patternshop, the author continued:]

MATERIALS USED

The following materials are used in the construction of production pattern equipment:—Yellow pine; mahogany; plaster of paris; cast iron; brass; aluminium alloy, and neutral stone compound. Each of these materials possesses admirable characteristics, and when correctly applied excellent results are obtained. The

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* Slightly abridged.

following is a brief account of their general application.

Yellow Pine (*Pinus Strobus*)

The characteristics of this wood are too well known to require any comments. It is an excellent wood for the construction of "master" patterns and coreboxes, possessing a soft even grain which is of great assistance when being hand or machine worked; a well-seasoned wood will not shrink or warp either in the foundry or in storage. This wood is not often used in the construction of wooden production patterns because it does not withstand the rough usage foundry conditions impose.

Mahogany

This wood is very widely used for the construction of production pattern equipment. It is obtainable in various grades, all suitable for pattern work, but obviously the cheaper grade has not the qualities of the more expensive grades, the grain being brittle (to use a workshop term, "bony"). The other grades when well seasoned are free cutting with even grain. Although this wood is always referred to as a hardwood, it is easily hand-worked.

The wood must be well-seasoned; it is useless to expect a patternmaker to construct satisfactory pattern equipment from unseasoned timber, but when well seasoned it will withstand the varying conditions of the foundry—neither shrinking nor warping when in contact with hot and wet sand. It does not distort easily, but it is liable to splinter if the vent wire comes into frequent contact with the pattern surface. When used in suitable combination with either aluminium or brass very satisfactory results are obtained from it.

Plaster of Paris

Plaster of paris is used in the construction of master patterns. It is obtainable in three grades, coarse, fine and super fine, and satisfactory results can be obtained when using the fine quality. Plaster of paris is chiefly used for making casts of undercut sections of the wooden master patterns, also for making casts of production coreboxes. This method of pattern construction will be fully explained later. One advantage of using plaster of paris compared with wood is that it can be cast into any desired shape. In preparation clean water must be used and when stored the material must be kept clean and dry. A certain amount of practice is necessary to become familiar with the degree of consistency required to produce satisfactory results; it is inclined to be messy in use, and speedy work is essential because it solidifies quickly. The plaster cast when completed is rather fragile and must be moulded with care. Usually the moulder is so afraid of breaking the cast that he does not need telling to be careful. As a very smooth finish can be obtained it considerably assists in the preparation of a satisfactory mould.

Cast Iron

There is no doubt that this is the most extensively used metal for the construction of metal patterns, the chief disadvantage being excess weight, which causes unnecessary fatigue. Its use in the construction of production pattern equipment is therefore limited. Patterns to be used on Sandslinger machines are usually constructed of cast iron because the surface does not become pitted or defaced by the minute slag inclusions in the sand. Coreboxes to be used on the core-blowing machine are also made of this metal. When correctly prepared, cast-iron pattern equipment gives excellent service, withstanding the rough usage satisfactorily. Although this metal is inclined to be brittle breakages are rare, though the majority of patterns and coreboxes are approximately $\frac{1}{4}$ in. metal section.

Aluminium Alloy

Aluminium alloy is used in the construction of all types of metal pattern equipment where service conditions are not too severe. The production pattern equipment is made from a commercial alloy of the following composition (3.L.5 alloy):—Zinc, 12½ to 14½; copper, 2½ to 3; iron and silicon, 1.5 per cent. max., and aluminium remainder.

Providing the equipment is suitably prepared a very satisfactory service life is obtained. One disadvantage when in production is its tendency to become pitted if the vent wire is not carefully used. Aluminium-pattern alterations or repairs cannot be carried out so easily, although an aluminium solder of the following composition gives fairly satisfactory results after a slight experience in its application:—Tin, 81; zinc, 11, and aluminium, 8 per cent.

Brass

Brass has been in common use long enough not to need any comments. It is used in the construction of "spray" patterns, which, being of unit construction, have to withstand a considerable amount of rough usage, and the fact that they will bend rather than fracture extends their service life considerably.

Ordinary scrap brass is used in spray pattern construction; additions of varying quantities are made of copper, zinc, and lead when necessary. Although an excellent finish is obtained before the equipment is placed in production, this finish appears to improve as production progresses.

Stone-like Compounds

Neutral stone compound is a commercial product, of which there are several proprietary brands. It has been developed especially for the making of pattern plates and "oddsides." Speed is an important feature of its application, and it has an advantage over metal because it does not contract or expand. The compound produces moulding patterns with accuracy and gives exceptionally clear definitions, dependent of course upon the condition of the mould into which it is cast.

The method of making a pattern plate of this material is similar to that used when making a metal pattern plate. A good clayey moulding sand is required and must be rammed hard. The mould should be dusted with good-quality plumbago and brushed into the surface of the mould to fill up all the pores in the sand. The surface should then be skin-dried with a blow-lamp or gas jet, or methylated spirits can be used.

The compound, which is in powder form, should be thoroughly mixed with the liquid which is supplied in a clean bucket to a consistency that will readily flow. When cast, the best results are obtained by allowing to set in a normal temperature. When the compound pattern plate is thoroughly hard, which will be in 12 to 16 hrs., it can be removed from the mould and finished off. When set the surface can be buffed without fretting, and consequently a very high polish can be obtained. This compound is used fairly frequently in the construction of twin plate patterns which are cast into cast-iron box-parts to give increased strength. Great care must be taken in the preparation of the pattern mould because good pattern equipment cannot be cast from an indifferently prepared mould. An example of the application of this material will be shown later.

PATTERN LAY-OUT AND CONSTRUCTION

The designing of pattern equipment to obtain the greatest economy of time and material is a very important feature of pattern construction. It has been found an advantage first to lay-out the design full size, if possible, or on as large a scale as can be done, on a smooth board, showing one or two views which are not shown on the drawing. This assists in obtaining in the mind a correct picture of the required casting. If the views shown on the drawing are copied, it is possible to commence pattern construction without having thoroughly visualised what the resultant casting will be like.

This lay-out should be made as accurately as possible, according to the contraction rule, and should clearly show all details of construction as well as all pattern partings, coreprints, corebox joints and loose pieces, if any; moreover, pattern taper should be shown. The sectional view is usually very useful to the foundry because it shows the sectional thickness of the casting. When the lay-out is too large to be accommodated on a board, it can be set out on white chalk lines on the patternshop floor.

The lay-out need not be any more or less complicated than the design requires. This lay-out is also useful as a check on the draughtsman's errors; drawing mistakes have been found by this method of checking, which would have considerably increased the pattern costs if they had not been noticed until the construction had advanced.

Sometimes patterns require to be made in pairs because of right- and left-hand design, and with a comprehensive lay-out it is often a simple matter to design a corebox which can be easily handed to produce both sets of cores. When the construction of a wooden pattern is commenced, all pieces or sections as they are constructed should be marked out from a centre or datum line, this line being clearly marked on all pieces. This will facilitate the pattern assembly. The individual pieces can be hand or machine worked to the required shape and, as each piece is assembled, the shape of the pattern is gradually formed. To assist construction, it is desirable to reduce hand-working to the minimum; with the introduction of precision woodworking machinery, the construction of pattern equipment has been expedited.

With production patternmaking, sturdy construction is essential, and aids to patternmaking, such as leather fillets, plastic wood and bees-wax, should be used very sparingly, becaus when a pattern is continually in and out o production these additions either wear off or become loose and require attention. A superior pattern is constructed when all fillets are worked integral with the general construction.

There are, generally speaking, four forms of wooden pattern construction:—The box-shaped pattern; the pattern built up of segments or staves; the plate-pattern, and the solid pattern.

Box-Shaped Pattern

The box-shaped pattern must be constructed in such a manner that it will be strong enough to withstand any abuse it may receive in the foundry. The most satisfactory method of construction is first to construct a framework something similar in principle to the iron girderwork which is erected in the construction of a ferro-concrete building. This framework should be so designed that all pattern surfaces will be substantially supported; the correct construction of this framework is the most important feature of this shape of pattern.

When the framework has been completed and the pattern surfaces are being assembled, it is essential that all the timber which is to form the vertical surfaces should be cut so that the grain travels in the same direction as the pattern will be withdrawn from the mould. To allow for any shrinkage across the grain, narrow strips are fastened at each corner, and the top and bottom surfaces are then cut to fit inside the vertical surfaces. With this method of construction, there is no end-grain that can adversely affect the removal of the pattern from the mould, and further, a pattern constructed in this manner will not alter dimensionally through the varying conditions operating in the foundry.

Pattern Built of Segments or Staves

The pattern, built of segments or staves is usually of circular design. The purpose of segment construction is to have the grain of the wood following the outline of the design, thus ensuring great strength as well as rendering it easier to form the necessary shape. This construction is the strongest of all, and it can be easily adapted to innumerable designs which require to be hand worked or machined. End grain being entirely eliminated, a very good finish can be obtained. As is well known, the segments are usually a section of a circle, dependent on the size and shape of the construction, and are built up in successive layers called courses, each segment half covering the segment below.

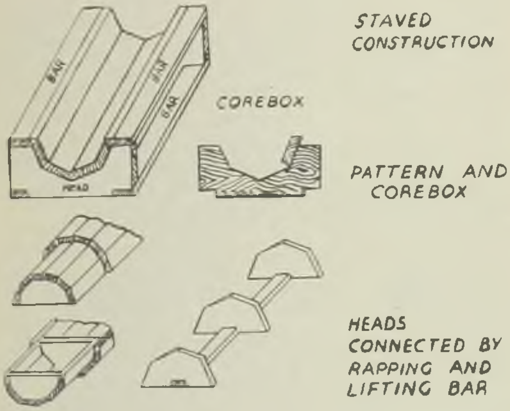


Fig. 1.

Staves are usually used in the construction of a cylindrical design. This method can either be used to construct a pattern or a corebox. The heads which support the staves must be strong, because the strength of the construction is dependent on them. Usually the staves run the length of the construction, which has the advantage of minimising the dimensional inaccuracy due to timber shrinkage. A pattern constructed by the method shown in Fig. 1 will remain perfectly round a very long time, regardless of adverse conditions in the foundry.

Plate Pattern

The plate pattern is sometimes a very frail construction, this of course being dependent on the design. No matter what the design of the casting may be, however, a pattern strong enough to withstand the service conditions of the foundry can be constructed by the following method:—First construct the moulding board on which the pattern is to be mounted, then build the pattern on the board. Quite different methods of construction can now be used to form the pattern, as it has not to be a self-contained unit. The moulding board gives support to the pattern, all ribs or bosses or facings can be firmly secured to the board, and there is sufficient strength to support any metal components that service conditions make necessary. This principle of construction can be applied successfully to an unlimited number of designs.

Tooth End

The pattern shown in Fig. 2 illustrates one application of this method of construction. The circular portion is constructed of hardwood and built on the moulding board and turned to the necessary shape on the board. A master pattern was made of the fingers, and these fingers, 39 in number, were cast in brass, worked to shape and secured in their correct position by screws. This method of construction was quicker and cheaper than constructing a metal pattern, and the result was quite as satisfactory.

The solid pattern is used frequently in the construction of master patterns, as it is often quicker to form the pattern from a solid piece of timber than to build it up. Since its period of service is short, strength is not necessary. Convenient designs of production patterns are made solid, but general application is rather limited, due to difficulty in obtaining suitable timber and excessive cost.

These four forms of pattern construction can be used individually or collectively in the construction of a certain design, and the knowledge of how and when to combine these different features is one of the arts of patternmaking.

Metal Patterns

Metal patterns are extensively used for production moulding, and, providing care is taken in their construction, a very satisfactory equipment is produced. When a number of similar patterns are required it is often cheaper to make metal patterns, but owing to the fact that a master pattern is required first, the initial expense is greater than when a wooden pattern is made. This one disadvantage does not restrict their general application; all types of casting design can be produced, and there are no difficulties of construction.

Metal patterns are generally produced from wooden master patterns, this being the quickest and cheapest method. Plaster of paris is another material which is used, and when used in combination with wood excellent results are obtained.

When the most satisfactory method of moulding for the required casting has been decided, the wooden master pattern is made exactly as designed on the drawing, the moulding of the pattern being disregarded entirely. Only when the master pattern is completed is the method of moulding reviewed, and any section that will not mould is noted.

A plaster of paris cast is then made of the undercut section, sufficient material being allowed to permit the formation of the core print. The cast when set is removed from the pattern and worked to the necessary shape. This plaster cast (Fig. 3), being the shape of the undercut section and coreprint, is now used as a pattern for the moulding of another plaster cast which, when completed, is used to produce the production corebox. When both plaster casts are completed, one is secured to the wooden master pattern to form a core print, which locates the core produced by the corebox constructed from the other plaster cast. This method of constructing coreprint and corebox from plaster casts entirely eliminates all defects which might be caused through core and mould not matching up, and in consequence causing distortion of the casting surface.

Wherever possible machining allowances are made on the master pattern to reduce hand working to the minimum. It has been the usual experience that the construction of a satisfactory wood pattern is more easily accomplished than the construction of a satisfactory metal pattern. Generally, the skill of the wood patternmaker is superior to the skill of a metal patternmaker. This perhaps is due to the fact that a number of metal patternmakers have drifted into the patternshop from another section of the engineering trade. The difference in the skill of a tradesmen who has served his apprenticeship to metal patternmaking and one who has drifted into the patternshop is very noticeable.

SIMPLE TYPES OF PATTERNS

Generally speaking, no two patterns are alike. Patterns constructed to solve certain moulding problems resulting from the external and internal shape of a design are never identical, although the methods of construction may be similar. It must not be inferred that each problem of construction is in each case confined exclusively to one particular type of pattern, because a number of problems could be embodied in a single pattern.

When studying patternmaking, it is essential thoroughly to understand each type of simple pattern, because a careful study of the simple type of pattern is essential if the principles they represent are to be understood and recognised when they occur in more complicated forms. The ability to do this is necessary successfully to determine the type or combination of types to be adopted in the construction of any new design.

Type 1.—“ Flat Back ”

This type of pattern is the most simple pattern to construct and mould. It is usually a one-piece or easily-constructed pattern, and may be a replica of the required casting or perhaps be partly cored. The taper to facilitate removal from the mould is usually in one direction, dependent on the service conditions, this being a point for the patternmaker to decide. The principles of this pattern being so well understood, no illustrations are necessary to show its application in production moulding.

Type 2.—“ Two-Piece ” Pattern

This is the simplest form of a jointed pattern. It is made in two sections, not necessarily equal sections, these two sections being held in the correct relative position by means of dowels. A cylinder with a flange at each end is a simple illustration of this type of pattern. Such a pattern is easily mounted on a board, either on single or twin boards. The advantage of a “ two-piece ” pattern construction is that a straight moulding joint is produced, and there is no necessity to form a joint, as would be the case if the pattern were made solid.

Type 3.—“ Three Part ” Pattern

This type of pattern usually consists of a “ two piece ” pattern, but its design is such that it cannot be drawn from the mould if moulded with only one joint; therefore, a moulding box with three sections must be used. The “ three part ” pattern is seldom used for production moulding. It is common practice to dispense with the third section of the moulding box by incorporating a cored section in the pattern equipment, and a practical application of this principle will be shown later.

Type 4.—Patterns with Loose Piece

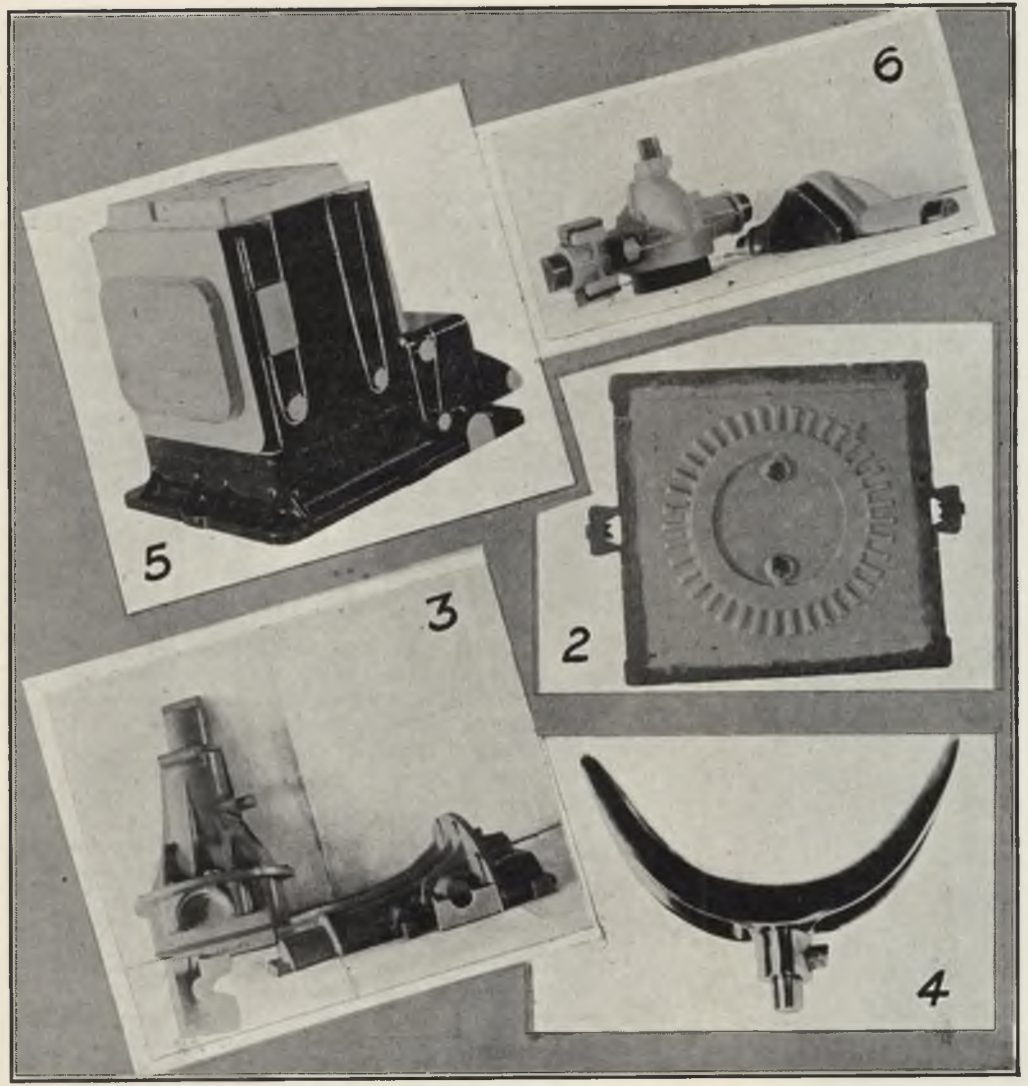
Many suggested designs of castings are such that projecting parts form impractical moulding propositions, because these projections prevent the pattern being removed from the mould. The projection may either be placed in the cope or drag. These projections have to be formed by loose pieces which are fastened in position on the main body of the pattern by loose dowels or " skewers."

To permit the drawing of the main body of the pattern from the mould, the skewers are removed as the mould is rammed, and when the body of the pattern is withdrawn, the loose pieces remain in the mould and are drawn carefully into the cavity left by the pattern. To avoid the general use of loose pieces on production patterns, cores are substituted wherever possible. If this is not possible, the projections are positioned by a dovetailed piece which is made flush with the surface of the main body, or sometimes a change in design may be suggested.

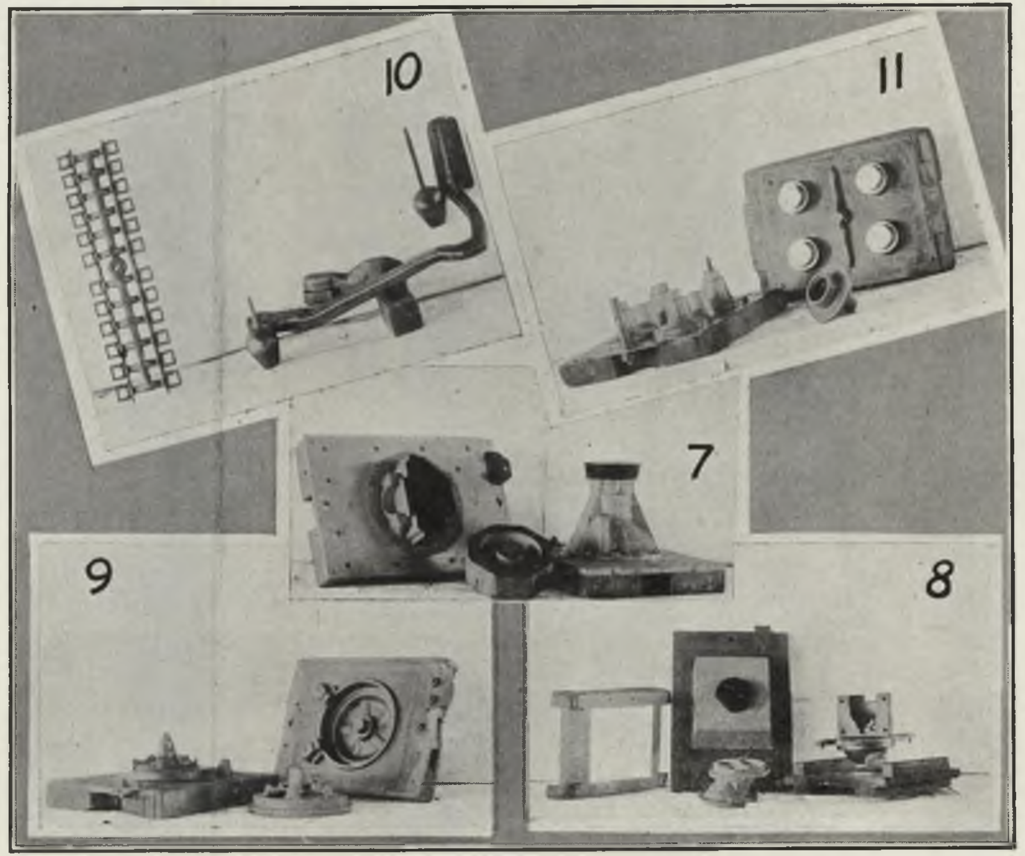
Type 5.—Patterns Moulded with Drawbacks

This type of pattern is used almost exclusively in the production of large castings. Drawbacks are iron plates inserted in the mould to carry undercutting projections which cannot be drawn into the mould, or they can be sections of the pattern itself. They are called " drawbacks " because an open space is left behind them in the mould, into which they are drawn with the portion of the mould which they carry. They are used more frequently on jobs moulded in the foundry floor or in dry-sand work.

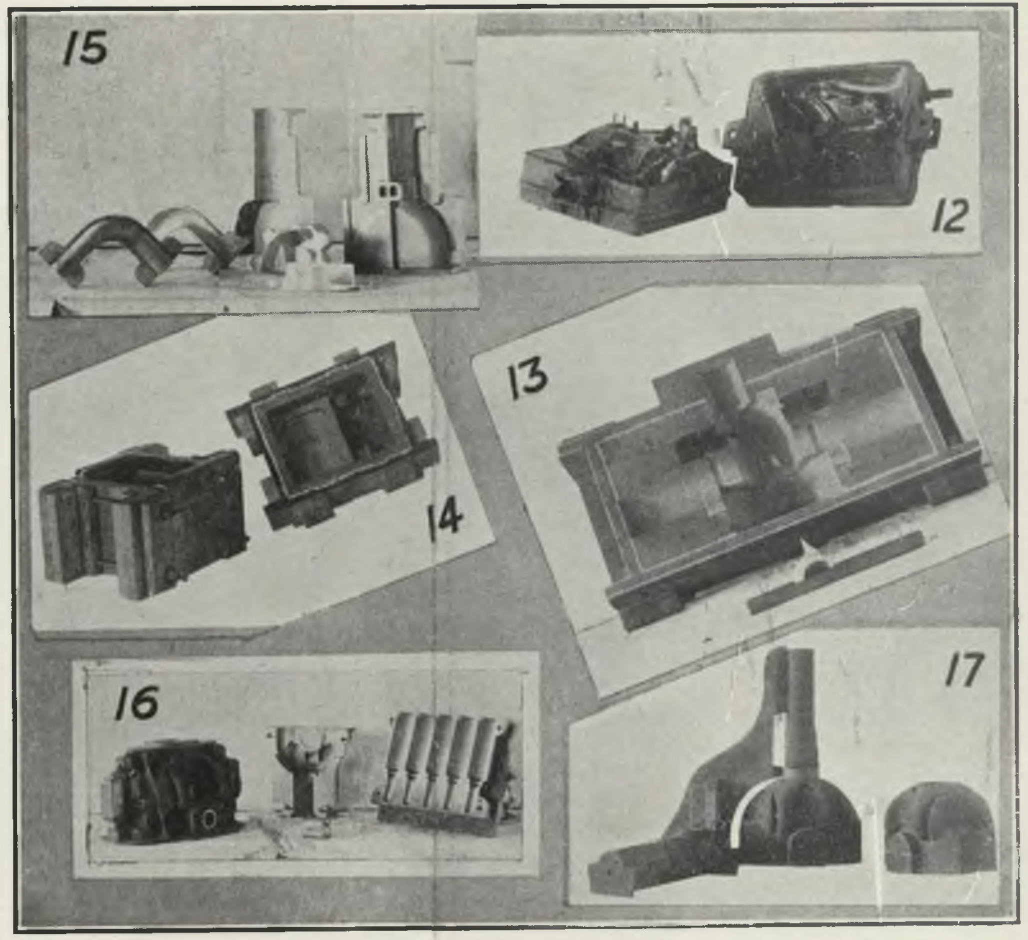
The author has never seen a " drawback " used to mould production pattern equipment in his foundry, although, as Fig. 4 shows, this method of moulding is still considered a practical proposition by one of his customers. This pattern was submitted for the production of 50 castings, and needless to say it was not used as submitted; the boss on the stem was removed and made to work loose and was drawn into the mould when the main portion had been withdrawn.



Figs. 2-6.—Examples of Patterns for Production Moulding.



Figs. 7-11.—Examples of Patterns for Production Moulding



Figs. 12-17.—Representative Patterns for Production Moulding.

(*To face page* 556).

PRODUCTION PATTERNS

The patterns selected to be used as illustrations are patterns which have been successfully used on production moulding, and the descriptions of all pattern equipment will necessarily have to be brief.

As this is not a Paper dealing with moulding no reference will be made to the location of gates and feeders, although several illustrations are given where such are attached to the patterns. These components are designed by the foundry, and as they are considered an integral part of the pattern equipment they are constructed and secured in position by the patternmaker. There are unquestionably alternative methods of moulding the examples shown, but it must be understood that the methods shown have proved very successful, and the majority of these patterns have been in constant production ever since they were constructed.

Switch Box (Type 4)

The pattern shown in Fig. 5 is an example of the box construction. The sides with the grain running in the direction in which the pattern will be withdrawn from the mould are assembled about a well-constructed framework; corner strips are assembled at the four corners to allow for shrinkage across the grain, and each end is fitted inside the four sides. This pattern illustrates that by thoughtful construction, the incorporation of loose pieces need not adversely affect the strength of a production pattern. A number of the projections carried by the loose pieces can be seen, the total being seven. To design and produce cores to form these projections would in this instance have considerably increased the cost of the pattern construction, and moulding time would not have been reduced.

As this design is one that the author's foundry does not produce in sufficient number to warrant the mounting of the pattern on a board, it is worked loose, but it could very easily be mounted. The two hinge flanges would require coring out beneath the centre of the hinge boss, and the print on which the pattern now stands would have to be removed. The casting weight is 184 lbs..

Rear-Axle Housing (Type 2)

Fig. 6 shows a hardwood pattern of segment and stave construction, two cylindrical portions being assembled on to a main body. It will be noticed how easily the mould joint will be produced through jointing the pattern at the centre line. The pattern was for an experimental design, and if at some future date it is placed in production, metal facings will be substituted wherever considered necessary.. The flanges and coreprints at each end of the axle tube, the coreprints on the cover face, all ribs and fragile projections will be made of either brass or aluminium, as provision was made in the construction to allow these portions to be easily removed, so enabling replacements by metal.

This pattern will no doubt be mounted on twin boards, and when mounting very great care must be taken to ensure that the two halves match up correctly. Usually a centre line through the box-pin holes is taken as the datum line. The casting weight is 109 lbs.

Differential Carrier (Type 3)

Fig. 7 illustrates a pattern which is an example of the combination of hardwood and metal, the main construction being wood with metal facings. The covering core and small flange are of aluminium; the main flange and ribs are brass, and the face of the main coreprint and horns are sheet brass. This pattern has given excellent service, withstanding the rough usage in the foundry admirably. It will be noticed this is a three-part construction, but to dispense with the three-part moulding box, the covering core is used This portion is made loose and the cope is of sufficient depth to produce a mould to the face of the covering print.

The loose piece is removed before the cope is withdrawn, to allow the removal of the pattern; the covering core is an added advantage. When the main core has been assembled and the cope replaced, the exact position of the core in relation to the mould can be seen and adjustments made, if necessary, before the covering core is placed in position. To assemble the two halves on twin plates, the two plates are secured with the moulding faces together and located in the box-pin holes. A predetermined diameter hole is machined in the plates, and a similar diameter dowel is formed on the two halves of the pattern. The casting weight is 32 lbs.

Gearbox End Plate (Type 3)

The pattern equipment shown in Fig. 8 is an example of the three-parted pattern designed for production moulding. The block coreprint dispenses with the second mould joint. It will be noticed that the portion of the casting from the unmachined face of the main flange to the face on which the casting stands is formed by the core. The pattern equipment is an excellent combination of hardwood and metal. The block coreprint is constructed of wood. Unfortunately the aluminium portion of the pattern which is on the opposite side of the board cannot be shown, but the top face of the casting shows the design.

A frame-constructed corebox with a brass replica of the outer casting shape is used to produce the block core and the brass body is jointed to assist core production. It is located in correct position by dowels. The strickled face of the frame, as well as the internal surfaces, are faced with sheet brass, and a cast-iron corebox constructed from a plaster cast is used to produce the centre core. The casting weight is 12¼ lbs.

Front Wheel Hub and Brake Drum (Type 2)

Fig. 9 shows a brass pattern mounted on twin plates; it was constructed in three sections, the first section forming the internal surfaces of the brake drum and hub. The mould joint was formed at the edge of the strengthening flange and along the centre line of the five arms. This section was machined all over and the five arms were assembled after the machining was completed. The second section was a coreprint in the form of a block machined an exact fit inside the first section, and the third section was a shell that fitted over the second section to form the outer surfaces of the hub and brake drum.

It will now be understood that section I is constructed to form one-half of the pattern and sections II and III the other half. The mould joint along the centre line of the arm was machined to templates, and a perfect joint was formed. The five arms on section III were milled on a radial miller, and their position was perfect. The battens fastened beneath each pattern should be noted. If the design of the pattern be such that a considerable amount of pattern protrudes beneath the pattern plate, a box section is constructed about the pattern to prevent it becoming damaged in the foundry. The casting weight is 13¼ lbs.

Conveyor Chain Link (Type I)

Fig. 10 shows a "spray" pattern, and it should be noted that there are 24 patterns assembled on a ⅛-in. diameter bar which forms the coreprint. The important feature of this equipment is that each pattern must be exactly the same size as the other 23, because the castings must be interchangeable. All assembly fits are as cast, and the section of finished chain shown illustrates the extreme accuracy with which the castings are produced. The "spray" is constructed of brass, and considering the design, it is a fairly robust pattern equipment. The casting weight is ⅜ oz.

Clutch Pedal (Type I)

Fig. 10 also shows a "spray" pattern of unit construction, and it will be noticed that the length of the pedal arm necessitates the pattern being constructed of a metal that will not readily fracture. A wooden master pattern is first constructed, and the brass production pattern is moulded from the master pattern. The $\frac{1}{4}$-in. brass rods, which are incorporated in the construction to assist to steady the pattern when being withdrawn from the mould, are noteworthy. To prevent a new moulding joint having to be produced for each mould, this pattern is moulded in an " oddside." The casting weight is 3½ lbs.

Front Wheel Hub (Type 2)

Fig. 11 shows an aluminium pattern equipment, with four patterns mounted on twin plates and the mould joint at the face of the flange. The patterns were constructed from a master pattern, and the design is such that it was possible to machine all the surfaces. To position the patterns on plates dowels of a predetermined diameter are constructed on the face that assembles to the plate, and eight holes of a similar diameter are machined in the plates.

It will be noticed that these castings are produced with the full flange on one plate. This method of production increases inspection difficulties, because it is impossible to check casting off-set without the use of calipers; to overcome this difficulty three oblong strips, $\frac{1}{8}$ in. by $\frac{1}{4}$ in., are placed in a position on the plate relative to the outside diameter of the flange, and if these strips are not exactly on the outer flange diameter of a finished casting, the casting is off-set. The casting weight is 6¾ lbs.

Hinge Bar (Type 2)

Fig. 12 shows a neutral stone-compound pattern equipment, with a twin-plate construction cast inside the two halves of a moulding box. The design of the casting involves a difficult mould joint, and it will be noticed that this difficulty has been successfully overcome. Two advantages of using this material are the short time it takes to construct a suitable pattern plate, and the ease with which intricate moulding joints can be produced. As this material does not contract or expand, plate patterns can be constructed from shell patterns with very satisfactory results. The casting weight is 14 lbs.

THE COREBOX AND CORES

The corebox used on production work suffers rougher usage than the pattern, so it is essential that the construction be as robust as possible. A very satisfactory method is to construct the actual corebox within a frame, this outer frame receiving the " rapping," and when it becomes mutilated, another frame can be easily made to replace the old and the actual corebox is not impaired.

Rear Axle Housing

The corebox illustrated in Fig. 13 shows the principle of its construction. The outer frame is strongly constructed, the ends being rebated into the sides and supported with battens at the four corners. The corebox is of hardwood construction, and the extra cost involved when compared with the softer woods is compensated by the extra service life; also, repairs are not so frequent. This corebox was made for an experimental design, and before it is put into production the loose pieces shown, which are at present made of hardwood, will be made of aluminium; moreover, brass strips will be rebated into the joint face of the two halves to maintain the correct core joint. This core is designed to be made in halves and jointed in the mould.

Switch Box

When the design of a core necessitates the corebox being sectioned to release the core, it is sometimes constructed to part at diagonal corners. In order to secure the corebox when the core is being rammed, bolts pass through the sides holding the box in position; to assist in the easy removal of the core, wing nuts are fitted to the bolts. The robust construction is well shown in Fig. 14, the sides and ends being well battened. It is good practice to secure the battens very firmly in position, but they should not be glued because, under the adverse conditions that operate in a foundry, there will be slight movement of the timber and, when the battens are secured by screws, this slight movement can take place without any detrimental effects.

For correct core location it is essential that the portion which assembles in the coreprint be produced by the corebox. This may necessitate loose pieces in the corebox, but the results obtained justify the extra cost.

Square Box

Fig. 14 also shows a very good example of this, and illustrates these remarks. The four loose pieces are designed to form the taper of the coreprint; the taper of the core is in the opposite direction, and if loose pieces were not used the print taper would have had to be formed by the moulder when assembling the core, which is not a very satisfactory method.

There is an old foundry saying, " flash before a crush," but this does not apply to production moulding, and there is really no need for either, because both can be avoided with properly constructed equipment. This question of coreprint and core sizes is a very debatable one. It is a recognised principle of patternmaking that the print should be of dimensions suitable to support the core and maintain it in its correct position. It is very surprising to notice, when visiting various foundries, the vast difference there is in the size of coreprints. Some foundries produce satisfactory castings with what other foundries would consider very insufficient coreprint. This is another detail that must be left with each individual foundry to decide.

Coreprint Sizes

A very satisfactory method is to make the coreprint and corebox the same size, as pattern and corebox " rap " will produce a satisfactory clearance for the assembly of the core. By this method a correctly-made core to crush through fouling the mould has never personally been known. One patternshop of a production foundry known to the author made all coreprints to fit inside the corebox, and very successful results were obtained. Crushed moulds, due to cores being larger than the print, were very rare.

Metal Coreboxes

A metal corebox is either cast from a wooden master box or from a plaster of paris master box. Wooden master boxes are generally used when the necessary shape can be economically constructed by this method, but sometimes it is cheaper to construct a wooden matrix, of the shape of the required core, and to use this to produce a plaster corebox. This method is used to construct the corebox suitable for an exhaust manifold.

Both methods of construction are shown in Fig. 15. The wooden corebox has been lightened out to give a uniform metal section and the wooden matrix is shown in one half of the plaster box. The other plaster corebox illustrates how this method of construction is used in the production of a corebox with a very intricate joint.

Machining allowances are incorporated wherever possible to assist the metal patternmaker. As an exceedingly good finish is necessary on the unmachined surfaces, all loose pieces should be so formed that they are unmovable whilst the core is being rammed. The metal section must be strong enough to withstand the service conditions, but as light as possible to reduce the fatigue of the core makers.

Cast iron and brass are very suitable metals for the construction of metal coreboxes. Aluminium is too easily defaced, although when carefully used a corebox of this material gives useful service.

Blown Cores

The core-blowing machine is now a recognised part of the coreshop equipment, and it has necessitated the introduction of a special corebox. As core-blowing is primarily to assist production, it is not the slightest use having one of these machines unless it can be worked to capacity. Therefore, it is essential to have sufficient coreboxes continually to maintain the working of the machine, and the coreboxes must be made so that they can be stripped and assembled in the quickest possible time. Obviously, if one corebox requires one minute to strip and assemble, twice as many cores will be made with a corebox that can be stripped and assembled in one half-minute. The time taken to blow the core is only a matter of seconds.

A very satisfactory method, shown in Fig. 16, has been evolved for speedily assembling and stripping the corebox when the core has been blown. The joint faces of the two halves are extended, and the outer surfaces machined with taper in the form of a slide; a tapered wedge engages over these slides, and the assembly action of the wedge is more or less instantaneous, the release being much the same. The two halves are securely held when the core-blowing is in operation.

Rough usage cannot be entirely eliminated, and it is essential that the wedges and slides be as strong as possible. Quickness of assembly and stripping is necessary; consequently it is impossible to be too critical of how the corebox is used to obtain the quickest production.

The majority of coreboxes used on the blowing machines are of cast iron, and care must be taken in their construction, as it is important that smooth surfaces be produced. This considerably assists in reducing to the minimum the tooling of the cores, as speedy production is the main feature. Defective cores must be scrapped rather than attempts be made to rectify them by tooling.

The two faces of the corebox joint must be a perfect fit, or trouble will quickly be experienced due to the sand blowing through the joint. In a very short time there will be worn in each face a groove through which the sand will pass. All loose pieces should be a good fit in their seatings, because the pressure at which the sand is blown very quickly reveals defects of bad jointing.

Experience has proved that deep recesses or pockets at right angles to the flow of the sand into the corebox are sometimes loosely rammed. To overcome this defect an exhaust hole is placed at the end of the recesses to allow any excess air to escape (Fig. 16). To retain the sand the hole is covered with very fine gauze, and this method has very successfully overcome trouble caused by air pockets.

Constant examination is necessary to check at the commencement all defects that develop, because an undetected defect can very soon be the cause of a new corebox being needed.

Another method of increasing core production is to construct a number of coreboxes within the same framework, this number being dependent on the foundry's requirements.

The example in Fig. 16 illustrates the method of construction. The core-producing unit is of cast iron and is made from a plaster cast. All working surfaces are machined and the outside surfaces are lightened out to produce a uniform metal section of approximately ¼ in., which greatly reduces the weight. This core is very simple in design, but more intricate designs are produced with ease. The cores are produced on a "bumper," machine, and the time taken is very little greater than if one core was produced.

For production purposes, it is not always advantageous to produce a core in one piece; sometimes it is necessary because of core-drying space or equipment to produce a core in two or more portions. The problem must always be considered before commencing to construct a corebox. It is usually cheaper and easier to construct two separate coreboxes for a given core than to construct one corebox and afterwards find, when the casting is in production, that the corebox must be altered and sectioned to produce the core in two parts.

These remarks are illustrated by the examples shown in Fig. 17. The core would occupy a considerable amount of room in the core stove because of its height, and if made to dry horizontally it would still occupy an appreciable amount of space. Therefore, this core is produced in two portions, the base being dried as it stands on the plate and the cylindrical portion in a core drier. After drying, the core is assembled and checked by a standard gauge.

Consideration of the best possible method of producing a core can very materially assist even flow of production. For example, if four cores are necessary to produce a certain casting and one core through difficulties of production cannot be supplied to complete the set, casting production is spasmodic. Such trouble is sometimes caused through unsatisfactory core-producing equipment.

Similar cores which are likely to become mixed and mistaken for each other should always be made slightly different so that it would be impossible for the wrong core to be assembled in a mould. This at first may seem a difficult proposition, but actually it is not. The moulder with constant practice is used to assembling the correct cores, and if he receives a consignment of similar cores there need only be a very slight variation, *i.e.*, difference in length or size of coreprint, and he instantly knows the wrong core is being assembled. By this method a considerable amount of scrap can be saved. The author has had experience of wrong cores being assembled through similarity of shape and the same size of coreprint.

When, for purposes of accuracy, locations in the corebox are necessary, they should always be so placed to form a location that will not require tooling. In the majority of instances a core location that has been tooled is never as satisfactory as one produced by the corebox, and core misplacement can have a very serious effect on casting production.

The ideal pattern equipment is one that is continually in production producing perfect moulds and cores. A colleague, who has studied production moulding in the U.S.A., has stated that the pattern equipment used in that country is the finest he has ever seen, and that the mould, when the pattern has been withdrawn, requires no hand working. If a bad lift be experienced the mould is knocked out; from observation, however, bad lifts are very infrequent and, moreover, the moulders had no moulding tools.

He was informed that the patternshop always endeavoured to construct the finest possible equipment. Of course, there is a considerable difference in the number of castings produced from an individual design in this country compared with U.S.A.; hence, one cannot afford to lay out as much money on pattern equipment in this country, but with the general skill of the foundry deteriorating through the introduction of semi-skilled labour, the pattern equipment will have to be of a high standard to compensate for the loss of moulding skill. The patternshop must endeavour to supply the foundry with equipment so constructed that moulding skill of a high degree is not necessary, and in this manner will maintain within the craft the skill which the majority of other crafts are gradually losing.

In conclusion, the author wishes to thank the directors of Ley's Malleable Castings Company, Limited, for permission to photograph certain pattern equipment and for supplying the facilities used in the production of the illustrations, and Messrs. R. W. Williams, A. E. Peace and W. C. Marshall for their assistance in producing the lantern-slides.

DISCUSSION

The Branch-President (Mr. W. T. Evans), remarked that Mr. Horton had given the members a very full Paper, illustrated by many examples. The author's method of building a pattern of hardwood and facing it with metal resulted in a lighter pattern, which made it easier for the moulder to get a good clean draw. A pattern must be of reasonable weight.

Mr. A. E. Peace said he did not think Mr. Horton had referred to aluminium pattern-plates. Mr. Peace had seen these used, and it occurred to him that they would reduce the weight. Was there any serious objection to aluminium pattern-plates? He knew that corrosion was a problem. A pattern with a number of fingers on it had been shown. Had those fingers been made in brass or wood? If made in wood they would be very weak, he imagined. In connection with coreboxes for core-blowing machines, and the method of quick removal by a wedge, Mr. Peace said he had seen a method adopted, where stiff wire, or rod, was used, which was snapped over and sprung. Had Mr. Horton any comments on that method?

Mr. Horton, referring to aluminium pattern-plates, said it would certainly be advantageous if one could have such pattern-plates, but there was the obstacle of cost. In production moulding it was a great advantage in reducing weight. As to the plate-pattern with fingers around the outside, the lecturer pointed out that a master pattern had been made of the small fingers, and they were cast in brass and secured in their correct position around the plate. He doubted whether wire clips for coreboxes would be a success on core-blowing machines, because a very tight joint was essential, or sand would escape through the joint.

Mr. F. Dunleavy said that the current impression that the patternmaker was there to construct, and the moulder to destruct, was wrong. The skilled moulder did not misuse patterns, and he would like to have Mr. Horton's assurance that the damage referred to was done by unskilled or semi-skilled workers who did not appreciate the value of patterns. He asked Mr. Horton if all the castings illustrated were malleable. A few years ago he made a pipe 7 ft. 6 in. long, and used a plain board, the shape of the pipe, and strickles. That would be a far better and cheaper way than the method which had been illustrated in the Paper.

Mr. Horton agreed that his foundry in general was dealing with semi-skilled labour. Those were the conditions ruling in the foundry, and one had to impose conditions suited to that foundry. He reminded Mr. Dunleavy that the Paper dealt with patternmaking for production moulding, and he considered his method for making a pipe core, which was for production moulding, far superior, and suitable for the conditions. For a one-off job, he agreed that the strickles would be fitted for the job. All the castings illustrated were of malleable iron.

Mr. R. H. Buckland was pleased to hear the view stressed that it was the "casting" which was required. Some patternmakers insisted that a pattern was right, yet a pattern often had to be made incorrect to make a casting right. He asked if Mr. Horton had any records relating to the number of castings made from hardwood patterns, as he believed it possible to obtain thousands of moulds from such patterns.

Mr. Horton said the number of castings produced from a hardwood pattern did run into thousands. On one particular job, they produced between 9,000 and 10,000 from this material. It was in production a long time and periodically was sent to the pattern shop to be renovated, or varnished. One section, which the moulder had continually brushed and painted over, was reduced by $\frac{1}{16}$ in.

Rapping Plates

Mr. H. G. Cochrane said he had hoped Mr. Horton would mention some kind of rapping plate. He thought that strong rapping plates were necessary.

Mr. Horton agreed that a number of patterns which were sent in would be much better constructed if the rapping plate was incorporated. Rapping plates were not used on production patterns, as these are generally vibrated by machine.

Mr. F. Butters considered a wooden pattern mounted on a wooden board was a frail thing to send into a foundry.

Mr. Horton replied that he had plates which had produced thousands of castings.

Mr. C. D. Pollard said a patternmaker was not a man who had to make something to look nice. He must know really more of the moulding side than the moulder himself. Unless a patternmaker, on receipt of a drawing, could visualise the moulding throughout, he could not usefully discuss that job with the foreman moulder. Mr. Pollard declared that, as a maker of steel castings, he much preferred properly-made hardwood patterns to metal patterns. They would last, providing they had proper use, for many thousands of castings.

Mr. T. Goodwin said Mr. Horton had shown them the better way to build a pattern, and how to make a corebox so that it would have a long life, as well as the easiest way to do it. Aluminium pattern-plates could be worked successfully, and for flask work they were ideal.

Pattern Compounds

Mr. H. A. Redshaw asked if the pattern compound expanded at all. When they made a mould from the pattern compound, was there any trouble with the mould, and did the pattern have to be eased at all? Referring to the box pattern of wood, faced with brass, he thought a metal pattern would have been better, and, in his opinion, it could be made just as quickly.

Mr. Horton said he had no experience of expansion of stone compound. Sometimes there was a sagging, but that was not actually due to the material, but to the mould into which the stone was poured. The box illustrated was lighter with a wooden base, and if made with a cast-iron section, a master pattern would have to be made first.

Patterns for Machine Moulding

Mr. J. Lucas pointed out that much had been said about metal pattern fitters. These operatives ought to be divided into two entirely different classes—metal pattern filers and metal pattern fitters. One class would be called semi-skilled, and the other skilled workers of the first order. Referring to hardwood patterns, in the course of many years' experience, Mr. Lucas had found these would last exceptionally well if properly made and adequately filleted, and would give good service in actual work. He had expected Mr. Horton to say something about machines of various types, for patterns nowadays had to be made to suit moulding machines. The author, he said, made a model of the casting he was going to produce, and from that model was made a plaster cast for the contour of his core, which he said gave perfect matching of core and mould. There might be a variation in the core, and several times he had noticed a core would turn out bigger than the corebox.

Mr. Horton said that the subject of patterns to suit various types of moulding machines was well worth a Paper. Regarding matching up of cores and moulds, one had to revert to the old system of trial and error, when trouble was due to variation in cores. In connection with cores which were bigger than the corebox, the lecturer said that when they had a core made and found a sag, this was allowed for; they provided extra depth of corebox to allow for that sag, and this again was a matter of trial and error.

Pattern Wear Control

Mr. Lewis asked whose job it was to control the wear of patterns in use.

Mr. Horton, in reply, observed that the moulder could not be relied upon to tell where the pattern was wearing, since it wore so slowly and was hardly noticeable. He suggested the return of patterns to the pattern shops periodically, where templates could be kept; it would be quite easy to run over the patterns to see whether they were worn or not.

Mr. Holland asked whether the cost of renovating a wooden pattern would not be more than making a metal pattern. By the time a complaint was received from a customer, many castings would be made and spoilt.

Mr. Horton pointed out that, when they were given a job, they did not always know how many castings would eventually have to be made. If a particular job was initially a rather small order, a wooden pattern was used. The difficulty arose when repeat orders came in, but this could be overcome by making a metal pattern when larger quantities were required.

Mr. B. Gale referred to coreboxes on core-blowing machines, and said that one point not mentioned by Mr. Horton was the action of the compressed air and the sand on the corebox directly beneath the blowing hole. His experience was that one very quickly detected wear in that part of the corebox. He would like to know if Mr. Horton had any method of overcoming that trouble when making the corebox. He regretted that Mr. Horton had no experience of the question of the expansion of artificial stone. Mr. Gale had had cases with castings having very fine limits for location, and he had found that the entire pattern had grown. The growth might be only 0.010 to 0.015 in., but that was serious when on machine locations

Mr. Horton agreed that the coreboxes on core-blowing machines did wear, but he knew of no definite method of preventing that wear. Regarding the stone compounds, he used them in a number of production pattern-plates without having any troubles due to variation.

Pattern-Plate Details

Mr. P. A. Russell said, from his experience, one frequently received customers' patterns which required duplicates. White-metal non-shrinking patterns were the best in such cases. He asked whether Mr. Horton had ever experimented with different types of aluminium alloys for pattern-plates. He would also like a few more details of the construction of pattern boards. Unless a pattern board was very accurately constructed, it would not keep its flatness; the size and number of battens were an important factor. When securing split metal patterns to plates, it was necessary to use screws and bolts; what method had Mr. Horton of filling up the screw heads, so that the marks were not obvious?

Mr. Horton agreed with Mr. Russell that there was no shrinkage with white metal. They could not use a pattern supplied to produce an aluminium pattern, and would have to use a master pattern. They very seldom made white-metal patterns. Regarding the filling of screw heads, for brass patterns the slots in screw heads were soldered over; for an aluminium pattern aluminium solder was used, and for the iron patterns wax was used for the screw head slots. A metal board was usually preferred for the building up of pattern-plates.

On the proposition of Mr. Niven, seconded by Mr. Orme, a hearty vote of thanks was accorded to the lecturer.

Lancashire Branch

THE PRODUCTION OF SOME INTRICATELY-CORED IRON CASTINGS*

Paper No 647

By T. R. HARRIS (Associate Member)

The demands of modern engineering for intricate castings embracing what previously had been separate components may be ideal from the engineer's point of view, but is a considerable source of anxiety to the foundryman, especially when he is called upon to produce cylinders and other pressure vessels. Often a casting can be made which looks perfect, but which, on the application of the hydraulic pressure test, weeps at a number of places due to porosity—one of the foundryman's greatest troubles.

Post-War Changes

The following examples of intricately-cored castings are typical of many others that are produced regularly in a shop which, in pre-war days, was chiefly producing larger and heavier castings for pumping, winding and air-compressing engines. In the post-war period a re-organisation took place, and a speciality was made of smaller air-compressing and pneumatic plant which called for very intricate castings. The technique necessary for producing these castings varies considerably from that in vogue in the days of heavier work. Then, loam moulds were the order of the day, produced by the minimum of pattern work, and a "dull" iron was ideal for casting the heavy jobs.

To-day, all this is changed. Castings with walls of $\frac{5}{16}$ in. thickness demand the use of "hotter" iron, and the mould and cores have to be well made. The production of intricately-

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* This Paper was the winning entry to a Prize Competition organised by the Lancashire Branch.

cored castings calls for the closest co-operation between patternshop and foundry, and only wood of exceptional quality should be used in the construction of the pattern and coreboxes. The introduction of oil-sand cores was one of the biggest benefits which has come the way of the founder in modern days, and the following examples owe much of their success to the use of this medium. Great care has to be exercised in the choice of workmen for these jobs, and in many cases it takes a considerable time properly to train a man to be capable of producing this class of work, particularly the first example to be considered. Expert supervision is necessary in the coreshop producing these cores, and care has to be exercised in their proper drying. Oil-sand technique differs from that required in naturally-bonded cores, both in making and drying. The older type of cores needed ramming, and on drying the combined water was evaporated, while artificially-bonded cores need not be rammed, and the drying process is essentially chemical. Oil-sand cores are dried by oxidation, and it is not a question of moisture removal. Best results are obtained with low-temperature stoves with good air circulation, a suitable temperature being about 205 deg. C.

L.-P. Cylinder Moulding

The first example chosen to illustrate the theme of the present thesis is a low-pressure cylinder for a two-stage air compressor. From the illustration, Fig. 1, it will be seen that it is a fairly complicated cylinder. The views are a number of sections through the various planes indicated, and are self-explanatory. In the first place, it will be observed that the design is not ideal from the founder's point of view, as there are thick and thin sections of metal in juxtaposition, and many lumps occur where the metal has been bossed-up to receive a stud. These all tend to produce " draws " through which the water will leak on test. Then, again, the water-jacket core is a source of trouble, for it is very thin in some places and also has only a very limited outlet for the gases generated on casting, and unless proper precautions are taken, it will " blow " and thus tend to cause porosity.

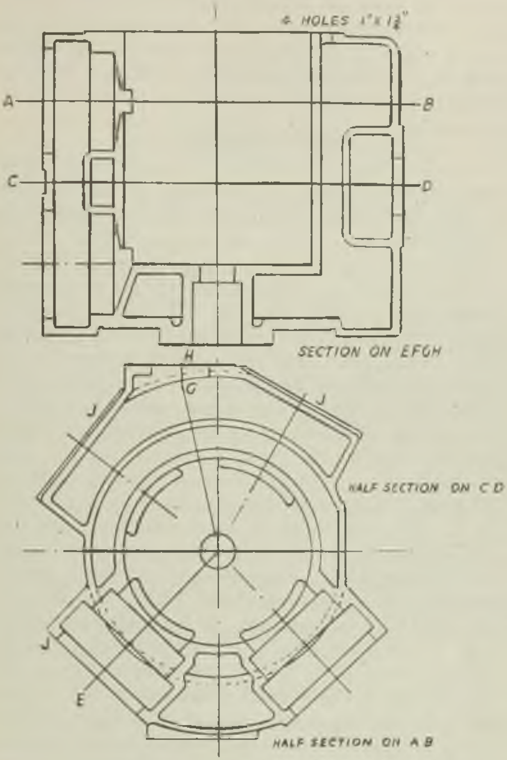


Fig. 1.—Low-Pressure Cylinder for Two-Stage Air Compressor.

Castings such as this example can only be produced successfully after the most careful planning beforehand of both the moulding and core-making technique, while the choice of a suitable metal mixture for the job is of the greatest importance. The normal procedure in work of this nature is for the patternmaker, on receipt of the blue-print, to lay the job out full size on a suitable drawing board, with space between the views to mark in the necessary machining allowance, core prints, etc. Before any patternmaking is done, a consultation between the patternmaker and foundry superintendent decides on the method of moulding which will be adopted.

Mould Construction

In the present instance it was decided to cast the job open end up, or in a similar position to the illustration, the joint of the mould being taken on top of the pattern. On a cursory examination of the drawing it might be thought by some that a better plan would be to split the pattern along the line CD, thus moulding in two boxes, the object being ease in assembling the cores. This, however, is unnecessary, and results in a fin of metal around the joint, which while not taking away from the usefulness of the casting detracts from its appearance, which is sometimes worth a little extra care, especially on high-class engine work. The pattern is "boxed" up, and the various facing pieces, J, J, etc., each carry a core print and are kept in position by dovetails. These dovetails extend the full length of the pattern and carry all the facings, which rest on them. Also the dovetails are made of aluminium, it having been found that no matter how perfectly fitting a wooden dovetail may have been made originally, or how well seasoned the timber from which the pattern has been constructed, invariably after a little while a wooden dovetail "sticks" and tears up a portion of the mould, a trouble not experienced with the use of aluminium.

Core prints are placed on each facing, and are made a little on the big side to allow of the easy insertion of the core on assembly, it having been found with dry-sand work that if both core print and corebox be made the correct size, the moulder has to resort to the use of a file to allow of the cores entering their respective prints. Also, the side prints are "guided," that is they each have a distinct difference imparted to them which is reproduced in the corebox, and so on assembly of the mould this can be proceeded with, without the necessity of the presence of the patternmaker in the foundry with blue-print. Especially is this wise in the present case, as the job is not symmetrical but the cores have a similar appearance which would need trying in position if no distinctive mark was given them.

The centre core is supported on the print L and the chaplets, as shown in Fig. 2, while two $1\frac{1}{2}$ in. dia. prints are placed in the bottom to locate and take off some of the gases from the jacket core at M, these holes being subsequently plugged. It will be noticed from Fig. 2 that no head is incorporated in this cylinder, although it is cast open end up. The reason is that no useful purpose is served by the employment of a head in this instance, as the results do not justify the extra expense incurred in moulding and subsequently removing it. Like most other jobs of an intricate nature, the coreboxes are more difficult to produce than the pattern, and great care has to be exercised in their production to ensure the resulting cores fitting one another and being of the correct hand.

A *resumé* of the assembly of the cores in this mould is necessary to understand the reason for the various boxes making up this set.

Core Assembly

The first cores to be inserted are the four making the air-ways and valve pockets Z, Fig. 2. It will be observed that it would be impossible to insert water-jacket core Y after Z was in position or *vice versa* if the cores were made as in Fig. 1, because of the portion X, Fig. 2, forming the port. Consequently portion X has to be made as a separate core, and is secured in place after water-jacket core Y is in position. The four cores Z are therefore placed in position.

next the jacket Y, and then the four small cores X, which are located by a print on Z, and wired back in position. These port cores and the top ones are kept back $\frac{1}{8}$ in. clear of the main core to avoid a "crush." To allow of the top jacket core being placed in position, core Z has to be made off to the line W, Fig. 2, and the portion V carrying the valve pocket and port is subsequently wired in position.

To connect the air-way cores Z, a bridge piece is necessary at U, the whole being shown diagrammatically in Fig. 3, which shows various sections of the assembled cores and is self-explanatory. The air-inlet core T is made separate from the bridge-piece core, and is placed in its print before the bridge piece is inserted in impression in core Z. The boxes for cores Z are made as frames, with the interior filled in to shape, the top of the box being the print portion, these being loose in the frame, and also in halves for convenience in making the cores. The water jacket, as was suggested, is made as two cores jointed in the centre of the cylinder CD, Fig. 1, each piece of which is made in a frame box. To facilitate making this core, all pieces must be easily accessible and the box made accordingly with a large number of pieces, all of which suit in their respective positions. The cylinder bore is made in a full box while the bridge pieces U are made in suitable frame boxes, the top side being strickled off.

The boxes in which are made cores that abut against others have suitable places marked for the making of the necessary arrangements for the evacuation of the gases on casting. Such a case would be the bridge core-boxes, these being marked where the round core T suits, this being a means of venting core U. Places are also marked in the jacket boxes where cores for the sludge doors fit (these sludge doors are not shown in the illustrations to avoid complications).

Casting Desiderata

All the pattern work being finished, a start is made in the foundry and a number of important

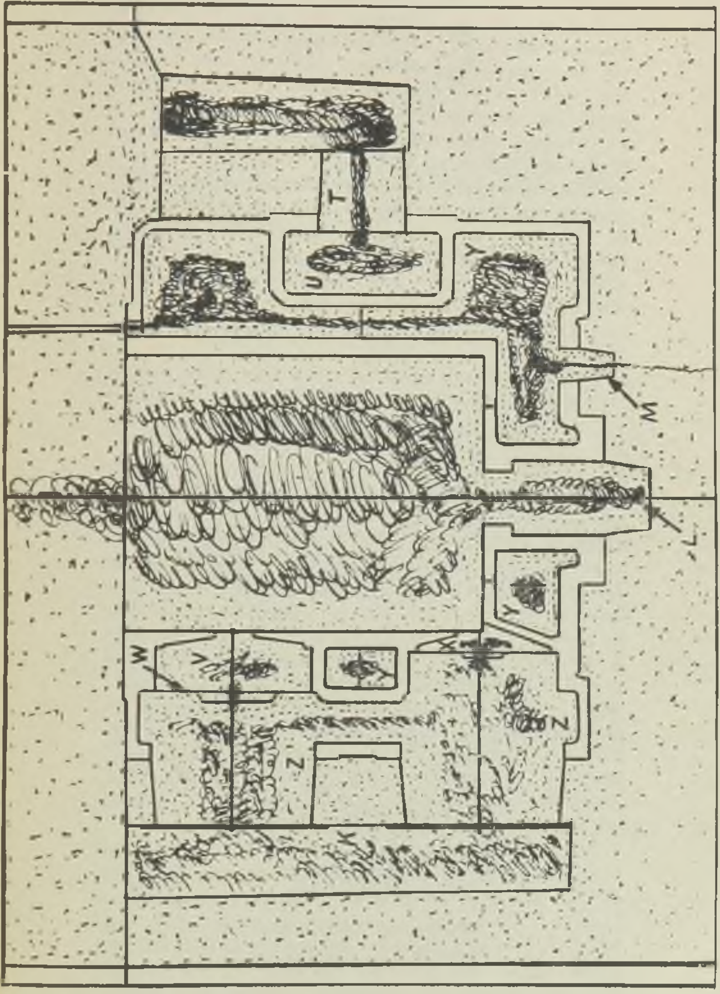


FIG. 2.—LOCATION OF CORES FOR LOW-PRESSURE CYLINDER.

points given due consideration. Among these considerations are the questions: where is the best place to run the job; the number and disposition of risers; the venting arrangements for the easy exit of gases from the cores, etc. Dealing with these considerations in order, this particular cylinder is run from the bottom by two inlets connected with two downgates, these being connected at the top joint and fed by a common downgate. A great advantage of bottom pouring is that the fall of metal is broken, first at the top joint, then at the bottom, and can thus be gently led into the mould, and so save scabs, etc., which otherwise—if top-poured—would be caused by the erosion of the metal over certain parts of the mould and cores, with disastrous results.

Two risers are situated over the main barrel and between the water connection holes from the water-jacket core. The gases are taken off from the various cores in as many places as possible. The jacket core is the most difficult to make because of the restricted outlets for the gases generated on casting; it is made of a sea-sand mixture with a proprietary binder. This core is very delicate and is held together by wires (which are not shown in the illustration, but which are both circumferential and vertical), the objection to a cast-iron grid being that the size of the core is not sufficient to allow of a suitable-width grid and a layer of sand each side. Also, if a cast-iron grid were used, great difficulty would be experienced in extracting it from the casting. Some of the gas from the jacket core is taken off through the two bottom prints, but the bulk comes through the top " pods," and a little goes off through the sludge drain cores.

The method of taking off the gas through the top is to make the core $\frac{1}{8}$ in. shallow, and to mark on the pattern the centre of these various holes. In the top mould a number of vent holes are pierced through before the job is dried, corresponding to the position the hole in the jacket core will occupy on assembly. When the jacket

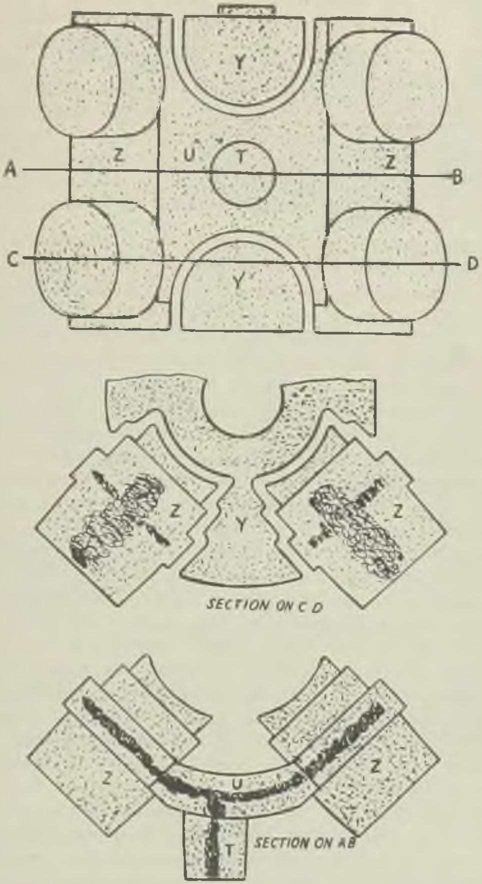


FIG. 3.—SECTIONS OF ASSEMBLED CORES FOR LOW-PRESSURE CYLINDER.

core is in position, a ring of loam is built around the vent, and the top is placed on and seals it. In this way there is a free vent from the core to the atmosphere. Very fine ashes are used in this core to assist the venting, particularly of the larger masses of sand, which, if not artificially vented in this manner, would evolve an excessive amount of gas on casting. The vents would be inadequate to deal with this quantity of gas, and thus the gases would strike back into the metal and cause violent blowing, resulting in a waster casting.

The gases from the valve cores Z are taken off through the prints, as shown in Fig. 2. Space K is made during moulding by four patterns placed against each of the prints on the facing pieces J, J. The spaces left by these patterns are large enough to allow of the moulder placing his hand in and wiring the small port cores in position. The spaces afterwards are filled with fine ashes which lead the gases direct to the atmosphere. All the cores are made of a sea-sand and a proprietary binder. The best results are obtained by first drying the sand and then mixing a definite quantity to a proportion of binder in a "Rotoil" mill. The jacket and valve cores are made of a straight sea-sand mixture, but the centre core is made of a mixture containing a proportion of used moulding sand. All the cores have to be well made and "burnt out" to ensure safety on casting, because, the exits (especially from the jacket core) being rather restricted, an excess of gas is a great danger. Nevertheless, care has to be exercised that the core is not burnt over much and becomes "rotten."

The choice of a metal mixture for a casting such as this is very important, because, although the mould and cores are well made and carefully assembled, the use of an open iron would be conducive to "wasters" through weeping, etc. After much experimenting a steel-mix iron was evolved for this type of cylinder, and gave good results; porosity was reduced to a minimum and the bore was even throughout, no hard spots being encountered. This particular cylinder was 13½ in. diameter, and the rough casting weighed 8½ cwts.

Making a Water-Cooled Casing

Another example that might be classed as an intricately-cored casting is illustrated in Fig. 4, and is a water-cooled casing. A number of features make this interesting, one of them being the thickness of metal compared to its surface area, which necessitates hot metal to run it successfully. On the other hand, the job would be safer if " duller " metal could be used to allow of the gases from the jacket core easily escaping. The job is cast face-down or, as Fig. 5, by three pencil runners, which ensures hot metal being used and also avoids excessive erosion. The pod of sand A is rammed with the bottom and is well stayed. It is also filled with ashes to assist in drying and venting and to avoid scabbing on the plate of metal. Joints are taken in the mould at YY and ZZ, the former to allow of inspecting the mould after the middle portion of the job is in place and the water-jacket core secured.

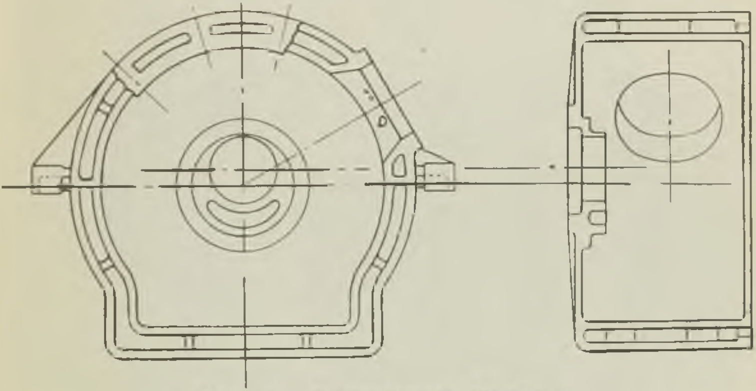


Fig. 4.—Water-Cooled Casing.

Core Assembly

The water-jacket core is assembled in a number of prints around the bottom. These prints should be on the large side to allow of the core being easily inserted, and can be stopped around subsequently to keep the metal from entering the vents. This core is secured by wiring in position through the bottom, and is made in two pieces, being divided by the baffle plate in Fig. 4. Being only 1 in. wide and 11 in. deep, it would be a difficult matter to make these cores

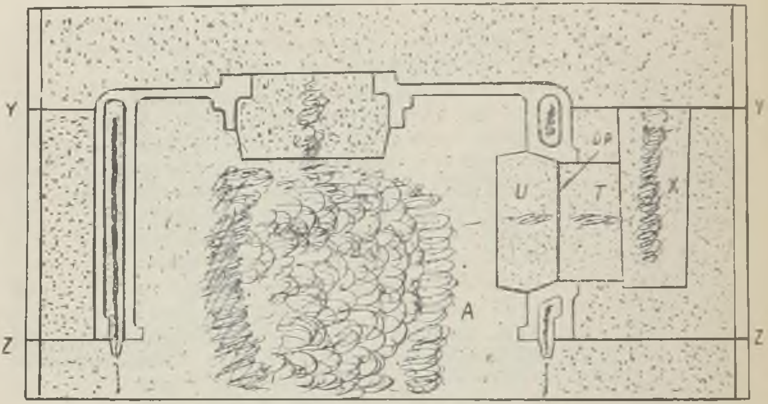


FIG. 5.—MOULDING AND CORING OF WATER-COOLED CASING.

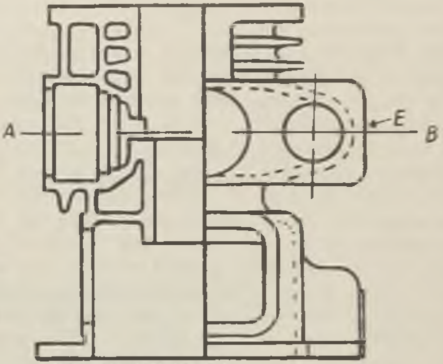
on end and handle them for drying, so they were made on the flat on aluminium coreboxes with the top scraped over, the aluminium boxes being utilised as driers. These cores are difficult to make, because of their narrowness, and great care had to be exercised in their production. Wires were the medium used to hold the core together, and a sea-sand mixture was used. Venting was accomplished by means of bars rammed up in the core and then withdrawn, leaving a number of exits to the atmosphere by way of the prints. Care had to be exercised to counteract the tendency of the core to spring on drying, and thus cause thin places on the casting.

A complication in assembling was occasioned by the inspection-hole core D (Fig. 4). As can be seen from the illustration, it is impossible first to place core D in position and then assemble the jacket or *vice versa*. The method adopted to surmount the difficulty was to make the core D in two pieces, divided at line DP, Fig. 5, with a coreprint in " pod " A and the other in the middle mould T, Fig. 5. When the middle was being rammed up a space was made at the back of the print T, as in the previous example, and on assembly part T of the core was placed in its print. The core being somewhat shorter than the print, it was pushed back clear of the edge of the mould. The water jacket being in position the part U of the core is placed in position through the jacket. It will be observed that the joint of this core is within the jacket.

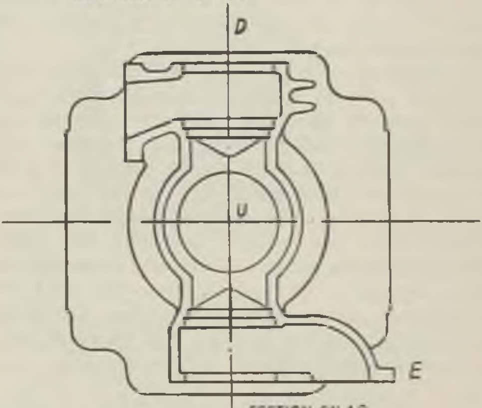
The middle—with the core well back—is now assembled, and the moulder then places his hand in the space X provided (already referred to), and pushes the core tight against its other portion and secures it in position with core gum. The space is then filled with ashes and the vents made good. The feet on this casting were moulded with the middle portion, the space underneath being cored out and the cores built in before drying. Of course, the feet and all facing pieces, etc., were carried on dovetails. This casting was subject to a hydraulic test, and was a rather difficult job to handle.

Air-Cooled Air Compressor

The next example is an air-cooled air-compressor cylinder with a fairly complicated exterior, the valve pockets, ports and cooling fins complicating moulding operations. From a foundry point of view this casting is not as formidable as the previous examples, but is included as an example of intricately-cored castings because it illustrates the use of cores as an aid to moulding. Fig. 6 shows some sections of this casting, which consists of two cylinders



HALF SECTION ON CD



SECTION ON AB

Fig. 6.—Cylinder for Air-Cooled Air Compressor.

of different diameter bore together with the crankcase portion and valve receptacles, etc., on either side; the cylinder and the ports being suitably ribbed. Because of the design it is impossible to split a pattern for this in any plane so as to allow of direct moulding from two halves, and thus the alternatives presented are either to mould from a pattern split along the centre line of the cylinder with the underlay portion cored out, or to make the whole of the exterior in cores.

From a summing up of the possibilities it is found that a better and cheaper job can be obtained by making the exterior in cores. In this connection it may be well to notice one great advantage in making complicated work in cores as against moulding the job direct from a pattern, and that is in the method of withdrawing the pattern. A pattern can be withdrawn from the mould in only one direction, and any loose pieces must be small enough to enter the cavity formed by the main portion of the pattern and withdrawn later. The limits thus imposed by the method of direct moulding from a pattern are entirely eliminated in coremaking. A corebox can be stripped from either of its six sides, or any position intermediately; in fact loose pieces can be drawn out anywhere. Not only does this make for ease in withdrawing the pattern work but also in dressing the subsequent core.

Made as a Core Assembly

A mould with ribs and loose pieces that have been withdrawn after the main pattern is usually difficult to blacken, a disadvantage not found in cores. Thus the example shown was made in cores. The pattern consisted simply of a large rectangular prism with a coreprint for the cylinder bore core. Into the cavity formed by the pattern—which was in essence a print—the various cores were assembled. The moulding box in which the large print was rammed up is jointed so as to correspond to the joint necessary to insert the valve cores. The outside is made in four pieces, two from the face of the mould to the centre of the valve ways and the other two from this joint to the top, embracing the crankcase portion. The cores are made from a proprietary oil-sand mixture and care has to be exercised in drying to avoid the thin section of sand being " burnt." Assembly begins by placing the two bottom cores in position and then the valveway cores. The remainder of the mould is then placed on, and the other outside cores are assembled. The cylinder-bore core is next inserted, and the two hand-hole cores placed in position; the crankcase core then completes the coring of this mould. The job is run on one flange, as at E, and also on top, this arrangement ensuring that no gas is trapped on top; flow-off risers are situated on the opposite side to the runner on the top flange.

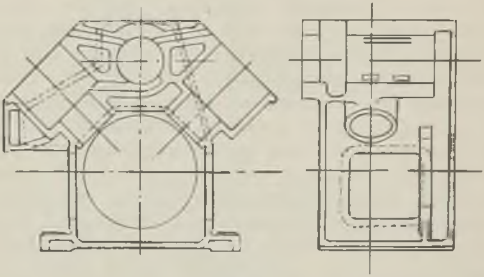


Fig. 7.—Cylinder Block for Compressed-Air Engine.

A Cylinder Block Casting

A further example, and one that illustrates the modern trend towards the elimination of separate components and the incorporation of a large number of pieces in one casting, is illustrated in Fig. 7. It shows the cylinder block of a compressed-air engine, and as will be seen from the illustrations it is a twin cylinder of the trunk type with the cylinders at an angle—sometimes known as a " Vee " engine. This particular casting embraces two cylinders, the valve chest for rotary valve, the air ports, the crankcase and the air inlet and filter chamber. The mould is jointed through the centre line of the cylinder and the assembly of cores is a fairly straightforward matter.

The feet cores are first assembled, then the air inlet core and the filter chamber core. Next the half of crankcase core is assembled in the bottom mould and into this the cylinder-bore core and two small lightening cores are placed, while over these the top core forming the crankcase portion is assembled. The separate core forming the chamber in which the gear wheels driving the valve are contained is then assembled, and the top lowered in position. The set of cores forming this casting are straightforward and are made of a sea-sand mixture. The job is run into one of the feet on the joint, and is a typical example of the complicated type of casting which engineering design now demands from the foundry.

DISCUSSION

Mr. H. V. Grundy, proposing a vote of thanks to the author expressed the opinion that the Paper was novel in that it dealt with certain specific castings rather than general foundry practice. The lecturer had gone into great detail in describing the manner in which the patterns and moulds were made, but the slides were deficient in dimensional description, and he would be glad if Mr. Harris would give some further information regarding this point. The first casting shown was 13½ in. in diameter and weighed about 8 cwts. What were the other sizes and thicknesses which were being dealt with?

He would like to congratulate the speaker upon the excellence of his Paper, and upon winning the competition organised by the Lancashire Branch. The competition had been open to all, and it was a credit to Mr. Harris that he should be declared the winner, particularly in view of the fact that he came from such a distant part of the country, where personal foundry contacts were very infrequent, and in consequence it was so difficult to exchange ideas.

Mr. Grundy also expressed the thanks of the Institute to Mr. Jones, whose interest in the Institute and whose generosity had made this competition possible. Mr. Harris was making his *debut* before them, and no doubt he would become one of the Institute's future lecturers. This had been made possible by Mr. Jones, and he would like him to accept their appreciation of his efforts.

Mr. A. L. Key seconded the vote of thanks and associated himself with the remarks Mr. Grundy had made. The vote was carried with acclamation.

Mr. Harris, responding to the vote of thanks, expressed his appreciation of the way in which he had been welcomed by the members of the Lancashire Branch. Referring to Mr. Grundy's question as to the size of the casting used, the 13½ in. referred to the diameter of the cylinder bore (Fig. 1). The core of the casing was 1 in. wide and 11 in. deep, and all other dimensions were to scale. Mr. Harris then explained further points by means of slide illustrations.

Steel-Mix Changes

Mr. Grundy asked for further information upon the steel mix which the lecturer had evolved. He would also like to know whether Mr. Harris had found it necessary to have recourse to chills in dealing with the varying thicknesses, or what method had been adopted to overcome this tendency of the metal to "draw." They all knew that this differed in regard to the steel mix. He also noted Mr. Harris' reference to the "necessity to ram cores less heavily," and would like to know if he used semi-solid core oil on all the cores in that particular job. Was it not possible to use more efficiently a liquid oil?

Mr. Harris explained that the steel mix consisted of about 25 per cent. mild-steel scrap, 35 per cent. cast-iron scrap and 40 per cent. pig-iron with low-phosphorus content. He was not responsible for the original oil-sand mixture, and although he had been in charge of the foundry for some time, he had not had occasion to alter the mix; but he would ascertain if a thinner oil could be used with some of the cores.

Body Core Making

Mr. Grundy pointed out that with the liquid core oils there was practically no necessity to ram in regard to some of the less intricate cores—the body core, for instance. He noted Mr. Harris' reply to his question referring to the semi steel, but asked for details of the analysis, and what ultimate analysis of the metal was aimed at.

Mr. Harris said that the body core was not made with the semi-solid core oil, but with a thinner oil. The jacket cores would be made of a semi-solid in order to get green-bond to withstand drying. The bottom part, the little pods would be made of a more naturally bonded sand in order to withstand erosion and drying. If the small pods were made of the same sand as the bulk of the core, during the drying they would probably all crumble up. He could not say very much about analysis, as it was only recently that a chemical control had been installed in the laboratory of the works with which he was associated. The carbon content would be about 3.2 per cent. In reply to a further question by Mr. Grundy, Mr. Harris stated that his firm did not use any chills now.

Casting Temperature

Mr. F. Andrews asked at what temperature the metal was poured.

Mr. Harris replied that his firm used an optical pyrometer, and he found that everybody's opinion was not identical with regard to temperatures. Above a certain temperature they seemed to vary 50 deg. up or down. The pyrometer was used more for day to day comparison, and they tried to get it as near 1,320 deg. C. as possible. Whether this was correct as applied to anyone else's method he could not say, but as a method of comparison it was satisfactory.

Oil to Sand Ratios

Mr. Key raised a point with regard to oil-sand mixtures. During the past few years he had experienced difficulties in making awkward cores in oil sand. A fundamental point to consider was the proportion of oil used to the amount of sand. What proportion of sand to oil was used by Mr. Harris in respect to jacket cores, and what was the proportion of sand to oil in respect to casing cores and the larger cores such as those used for valves?

Mr. Harris said he had not the information available at the moment but he would probably be able to supply it later.

Mr. Key said that it might be interesting for the members to learn that, to achieve success with a certain type of core, it was necessary to use 70 parts of sand to one part of oil. If there was more oil the job would be unsuccessful. Fifty parts of sand to one part of oil was the strength necessary for certain other cores. Another point was that he assumed Mr. Harris used all wrought irons for his jacket cores.

Ensuring Equal Section Thickness

Mr. Harris having agreed that this was so, Mr. Key continued by inquiring whether the lecturer had ever sectioned a casting to determine whether a core was expanding unequally or otherwise. He had had considerable experience with jacket cores, say, 1¼ in. thick, 3 ft. dia., and 6 ft. long. Cast-iron rings were placed in them, although they were only 1¼ in. thick. All the rest was wrought iron. This had to be done because, down the front of the core, there was left more or less of a broken circle. If they had had wrought irons in those jobs they would have had the jacket core through on the outside of the mould. Cast iron was used to obviate this tendency.

Dimensional Changes and Their Cure

Mr. Harris said he had not noticed any such difficulty on casting, but he had on drying. Care had to be exercised in order to keep the cores from distorting. The necessary correction was made by making the core box " wrong " in order to get the job " right."

Mr. Key said he would not be surprised if there was found to be a difference in section.

Mr. Harris admitted that there would probably be a difference of $\frac{1}{16}$ in. in thickness on one side, compared with the other.

Mr. J. Masters asked whether it was not possible that in drying the core the core plate expanded when it went into the stove and pulled the core with it. **Mr. Harris** agreed that this was so.

Mr. Masters suggested that there was a larger expansion on the aluminium core plates than there was with the core. He further explained that if the core plate had been made in cast iron it would not have taken the expansion so quickly. The expansion could also have been negatived by piercing the core plate in various places. A firm in the Manchester district had hundreds of dryers, all of which were perforated, and their cores had to be within a few thousandths of an inch of the truth, or otherwise they were discarded. Every mould was tried every day, and a minimum of about 150 moulds was cast daily. If a core were a couple of thousandths out of truth it was discarded.

Mr. Harris said he would look into the point, and ascertain whether it was advisable to have a cast-iron dryer, instead of an aluminium one, and perforate it.

Mr. Key said it was a simple matter of trial and error, with regard to the dryers or the jigs, to keep the core exactly to shape. The point was that in bending wires in building up a jacket core two men could make cores which would act entirely differently when the metal got round them. It was merely a question of camber.

Mr. F. Andrew said he had noticed that with pipe cores made on barrels without hay band, if the runner played on the one side of the core, this had the effect of expanding one side of the barrel and pulling the core out of centre.

Gas Evolution

Mr. S. G. Harrison remarked that the author had stated that, owing to the very thin section of the job, the casting had been effected at a very high temperature, but that, in future, the temperature would be lowered. The speaker was of the opinion that the high temperature would be better practice, as at a low temperature any gases generated would not have an opportunity to escape before the metal set. Had Mr. Harris experienced any trouble with the metal getting into the vent over the jacket core where a little ring of loam was used? Personally, he would have been inclined to ram a tube into the core and then carry it through the top part of the mould, which would eliminate any danger.

Mr. Harris admitted that he referred to the use of lower temperature and getting the gases away, but he qualified it subsequently by stating that pencil runners were used which gave a slow filling in the mould. This afforded the gases a chance to escape as the mould was filling. To use pencil runners it was necessary to use very hot metal. Sometimes with very small cores they did bring tubes up, but not through the top. He brought the little ring of loam up more than was really necessary, and as the top came down it sealed the vent.

Mr. Masters stated that there was a "ricket" scratched round the vent. The pressure of the top part sealed the vent. The moulds were too hot to bear the hands upon when assembled, and the heat dried the loam and oil.

Mr. Harris stated that the top box was quite hot and dried itself. It went down and made a seal.

Standardised Runners

Mr. R. Turner asked for information concerning the size of the down runners. Were the in-gates bigger than the down runners or the down runners bigger than the in-gates?

Mr. Harris replied that he was not responsible for the designs and could not answer the question straightaway. The patterns were got out and the runners were standardised and made a part of the pattern. It was necessary to emphasise the importance of good patternmaking for this class of work. An effort should be made to produce coreboxes as accurately as possible, in order to save the moulder the trouble of having to rub his cores.

Mr. Turner asked whether the runners entered from underneath or direct into the body.

Mr. Harris replied that the runners went into the body. There was a well at the bottom.

Mr. J. R. Platt observed that no doubt Mr. Harris had experienced the difficulty of keeping up the metal level in the runner box due to vortex immediately over the down-gates. Had he ever used anything in the nature of a square runner instead of a round one, in order to obviate this vortex?

Mr. Harris said that the down-gates used on a number of jobs in the foundry at Camborne were rectangular, with a stopper on top.

Mr. R. A. Miles asked what was the type of studs referred to in the Paper.

Mr. Harris said that they were tinned, and that they were merely used under the bottom of the cylinder core.

Paper No. 648

London Branch

SOME ASPECTS OF THE CASTING OF COMMERCIAL INGOTS*

By W. A. C. NEWMAN, B.Sc., A.R.S.M., A.R.C.S., F.I.C.

Three Classes of Ingots

Commercial ingots may be conveniently divided into three classes:—(1) Ingots of pure metals obtained as the final products of the extraction plants; (2) ingots of alloys, manufactured according to specification, for sale, or for the primary object of obtaining metal of uniform composition to be remelted for special purposes, and (3) ingots—of pure metals or alloys—which are intended for mechanical working such as rolling, forging, drawing, etc.

The conditions which must be met in the production of these three classes are not all similar nor of equal importance. In the first group guaranteed purity is essential; the ingots must be in a form which is easily handled, and it is preferable if they are acceptable in appearance. Yet as they are not to be employed in any structural part or similar product without further treatment and are rarely used alone, they are not subject to mechanical tests, nor are foundrymen particularly interested in the internal soundness or structure except as these indicate impurities. Similar considerations apply in the case of the second group, except that here uniformity of make-up and of ultimate composition is superimposed on purity. In the third group, however, the demands are more stringent, for on the characteristics—physical, chemical and mechanical—of the original ingot depend, in a very

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* Slightly abridged.

great measure, the success and efficiency of the succeeding manufacturing operations. It is, therefore, to this class that most attention has been directed, and some knowledge has been gained—by no means yet completely—of the influence of such factors as method of casting, temperature, mould material and shape and mould dressing on crystal structure, segregation, soundness and surface condition, and of the further influence of these latter on the behaviour of the material during mechanical working.

The casting of pure metal ingots occurs after the final refining operation and usually consists either in tapping direct from the furnace into chill moulds or through an intermediate ladle or kettle where final skimming may be done, or by simply ladling out by hand from some such kettle in small quantities at a time. It is important that the refined metal shall not absorb excessive impurities in transit to the mould and that precautions should be taken, especially in the case of easily oxidised metals, to prevent contamination from the air.

Such methods are adequate for what one may term the minor base metals, tin, zinc, etc., where the production is comparatively small and the temperatures concerned are not high, but in the case of copper, lead, etc., where the amounts involved are considerable, and relatively high temperatures are necessary, modern practice in the largest plants demands mechanical aids.

The Case of Copper

Copper from the reverberatory furnace is cast into moulds—for anodes, wire bars, flat cakes or ingot bars—which in large-production work are carried on some type of continuous conveyor, most commonly a casting wheel. The metal passes from the tapping spout of the reverberatory to a launder which slopes into a pouring ladle. This holds about 1,000 lbs. of copper, and has a lip 6 in. above the casting surface of the mould. A bridge piece keyed into place about $1\frac{1}{4}$ in. above the bottom of the ladle and 14 in. back from the lip gives a measure of bottom pouring and keeps back scum. The casting wheel is usually situated in a pit below the floor level on which the furnace is built.

Mould Materials

The moulds into which the metal is cast were originally made of cast iron, but their poor thermal conductivity, combined with the comparatively short life before cracks developed, and the consequent high cost, inspired investigations into other mould materials. Eventually copper moulds were adopted, and in most recent practice these are, in addition, water-cooled.

The discovery of the effectiveness of copper itself in this connection offered a means of internal manufacture which was economical. Refined copper is used as the mould material, as even small amounts of impurity lower its thermal conductivity sufficiently to impair its efficiency.

Life of Moulds

Sand casting of the moulds was first employed, using a wooden pattern. More recently collapsible cast-iron mother moulds have been installed on a separate platform near to the tap hole, so that the stream from the refining furnace may be diverted in part whenever moulds are to be made. The collapsible frame is set on a heavy copper base and is stationary beneath a press on which copper dies are mounted. The exterior surfaces of the latter correspond to the interior surfaces of the copper mould required. When the frame is full of molten copper the latter is cooled slightly and then skimmed, the dies or cores are lowered into it and remain there until the metal is set. They are then raised, the copper mould allowed to cool and afterwards accurately machined all over. For moulds intended for wire bars or flat cakes, water-cooled cores are used; for moulds for ingots and ingot bar moulds, solid copper cores are sufficient. The cores should not remain in the molten metal too long or excessive shrinkage develops and may cause transverse cracks in the pockets. On the other hand, lifting the cores before solidification is complete may result in a run of molten metal. A series of perfect moulds is in this way always available; no mould need be used after it has developed a fault. Usually 50 to 200 tons of finished ingots per mould are obtained, though, on rare occasions, a mould may last for up to 60 heats or 300 to 400 tons of ingots.

Scrapping of moulds is usually due to the development of cracks where the stream of metal first hits them. They also tend to sag in the centre. Discarded moulds are returned to the furnace, thereby reducing charges to the mere cost of making the moulds on the spot.

When a new mould is introduced, or a wheel is starting from cold, a small charge of copper about ½ in. thick—"a warmer"—is run into each mould to warm up the latter and expel moisture. These are then returned to the furnace. The temperature of the moulds is carefully controlled by a surface pyrometer.

Mould Dressings

A common dressing is a wash of very finely ground (93 per cent. passing 200 mesh) silica or bone ash mixed with water, which is sprayed on with a gun and then dried by a blast of hot air. The consistency of the dressing is important. It is usually mixed in a tank and its specific gravity checked by a hydrometer immediately before application. Where the moulds are water-cooled the life is considerably longer. The face plates are cast in special mother moulds on the site.

Quality Control

The testing of the copper—whether it be for wire bars, anodes, or ingots—is performed regularly by taking small dip samples from the stream at short intervals, say every 30 minutes. These are examined for fracture and by visual inspection for oxygen content. Any undue oxygen absorption is quickly detected by the appearance of blackish spots on the surface of the small test-bars. There is a tendency for the oxygen content of the metal in the furnace to increase as casting proceeds. This is countered by renewed poling or by placing a small quantity of charcoal in the intermediate ladle. Billet samples are also obtained during the run and drawn into wire for the determination of conductivity in a standard apparatus. Drill samples at appropriate intervals are used for chemical analysis.

Common Defects

Faults which may appear in the ingots and the causes to which they are normally attributed may be summarised as follows:—

(1)	"Set" too convex.	Poling carried too far or temperature too high.
(2)	"Set" concave.	Poling not carried far enough or too low a temperature.
(3)	Irregular holes containing moisture.	Dressing of mould not dried sufficiently.
(4)	Deep seated holes especially at contact point of metal and mould.	Too high temperatures of metal and mould being employed.
(5)	Severe porosity.	Oily dressing used in too large a quantity.

Recent practice has tended rather to the use of vertical moulds for anodes and wire bars instead of the former flat ones. Less surface is thereby exposed to atmospheric oxidation. It is found, too, that the average oxygen content is lower in a vertically cast bar than in one cast in the horizontal position. Greater density is obtained in vertical cast bars—8.64 to 8.83 against 8.59, but the densities of the wires drawn from the two kinds are approximately the same. Vertical bars have also higher electrical conductivity and elongation, but their tensile strength is somewhat lower. Their general workability, however, is greater. Horizontally-poured bars give a superior rolled product if the upper wrinkled surface is planed away.

Making Alloy Ingots

Ingots of the second class to which reference has been made are mainly cast (1) for sale or (2) to ensure uniform composition, before being melted in larger bulk preparatory to being poured into large castings.

The melting is usually done in crucible furnaces of any of the well-known types fired by gas, coke or oil, and the ingot moulds, made usually of grey iron, are arranged side by side or on a small turntable. Suitable arrangements are made for temperature control, for deoxidation, for the skimming of the metal and for prevention of oxidation while the metal is passing from crucible to mould and whilst it is solidifying in the mould, preferably using bottom pouring and by pouring through a gas flame.

The melting of large batches is done in small reverberatory furnaces which are tapped into ladles, whence the metal is poured into sand moulds. Attempts have been made to manufacture alloys of the brass and bronze type for casting into small ingots for sale, in such reverberatory furnaces but with indifferent results, especially where the metal content is strictly specified. Mixing and the control of composition are not obtainable to the same high degree as when crucible melting—implying smaller batches and more efficient stirring—is practised. Remelting, however, serves to adjust small differences and to yield a product which is reasonably uniform in bulk.

Ingots for Rolling

The casting of ingots which have to be rolled or otherwise worked involves the production of material of the highest chemical, physical and mechanical character. Such ingots range from the thin strip castings suitable for cold rolling to the large 5-cwt. or 10-cwt. slabs of non-ferrous alloys and the still larger steel ingots weighing up to nearly 200 tons.

So far as non-ferrous ingots are concerned, melting of the alloys is carried out in crucible furnaces of all types and in the well-known electric furnaces such as the Ajax-Wyatt, the Ajax-Northrup and certain rotating barrel types.

Ingot Moulds

The casting of ingots implies casting in chill moulds, regular in shape with no intricacy of design, but through which the heat from the casting is transmitted and afterwards dissipated by radiation. The days of the old stone moulds are far past, and since the 19th century metal moulds have been common, but the nature of the metal which should be used is a question still in the forefront of foundry practice and has, within recent years, been the subject of much investigation. It is now no longer understood that a mould is merely a container into which molten metal is poured and then allowed to cool. It has been realised that the mould has a significant effect on the character and the structure of the ingot formed within it. Too much attention cannot be given to securing good moulds of the best material.

Until comparatively recently the normal type of chill mould used for non-ferrous ingots was made of cast iron, preferably of close-grained hematite iron, having a composition within the following ranges:—Graphitic carbon, 2.5 to 3.6; combined carbon, 0.1 to 0.4; silicon, 1.5 to 4.0; manganese, 0.2 to 1.2; sulphur, 0.06; and phosphorus, 0.23 to 0.5 per cent.

A high phosphorus content is conducive to fluidity and the production of good castings. On the other hand, some aver that the compound Fe_3P is deleterious and conducive to a shortened mould life. These manufacturers thus prefer a low percentage of phosphorus.

In general such iron is cheap, durable and can be cast with a smooth surface. The moulds themselves should be cast face downwards and with sufficient inclination to carry any slag upwards. As nearly as possible the metal in the mould should be equalised so that it should suffer no distortion and the ingot cast in it should have uniform cooling all round. It is usually found that the hard casting skin on such moulds is beneficial, and that where it is machined away, in order to improve the surface somewhat, cracking occurs earlier. Annealing or "blueing"—heating the moulds to a dull red heat—counters this to a certain degree and in any case relieves casting strains.

Iron moulds for cast-iron castings have a somewhat different composition from that employed for ingots in non-ferrous work. An analysis would show total carbon, 3.5 to 3.6; manganese, 0.6 to 0.8; sulphur, 0.05 to 0.06; and phosphorus, 0.4 to 0.6 per cent. In casting the mould itself in dry sand, the interior surface is formed by a nearly cold steel core to give chilling. Chills are also used around the outside. The life of such a mould—as indeed of all moulds—depends, apart from the correct composition and proper casting, on the casting temperatures of the ingots, the time the cast ingot is in the mould, the temperature of the mould during casting and the coating used on the mould surface.

In non-ferrous work parallel sided moulds are almost universally used, whereas in steel practice tapered moulds are employed. The former have a good many disadvantages from the point of view of producing sound ingots, but they form ingots which are more suitable for rolling. In general, more solid metal is obtainable from tapered ingots and in those in which the larger section is uppermost than from those cast the reverse way. There are fewer gas holes, but contraction cavities still persist. Increasing the taper increases the soundness and, at the same time, in the average ingot, the columnar crystals become larger. The surface quality, however, is not materially changed.

Ingot moulds fail principally in two ways by (1) major cracking, due to factors of design or casting or to changes in properties produced by structural changes following heating, and (2) minor cracking or crazing, attributable to oxidising and stress effects, including growth. This type of failure is increased by a high silicon content of the mould material.

The cracks, both transverse and network, which sooner or later appear on the surface of a mould transmit the defect to the ingot, and this is fatal where the latter is to be rolled. because it results in overlaps and an imperfect rolled surface, only removable by planing or scalping. Such a crack in a mould holds a certain amount of dressing and almost invariably results in a "blow," due to the sudden vaporisation of volatile oil. It is found, too, that the cracks most readily occur in a mould whose section is variable, *e.g.*, in strip moulds which have lugs to support them on the cross bars of the mould carriage or frame, cracks invariably occur first opposite the lugs. Various methods have been tried to overcome this cracking—filling them in with an iron cement, filing them down at the proud edges and filling daily with china clay, but none is really effective in prolonging the life.

The expedient has also been tried for strip moulds of introducing mild steel strips, $\frac{1}{8}$ in. thick and cut to the shape of the moulds, in between the latter to give an artificially new surface to replace a cracked back. These plates are held tight when the moulds are screwed up in the carriage. The results so far are promising. Some plates now in use have survived 700 heats and show little sign of deterioration.

It is invariably found that unless cast-iron moulds have intermediate treatment during their lives a very hard skin forms, which results in the ingots being pimply or even short. A treatment which has been recommended is to scrub the surfaces with a stiff wire brush, and follow this with an application of thick tar. The mould is then annealed, when the mould surface recovers most of its original condition. In the casting of brass ingots in cast-iron moulds it has been found advantageous to clean the latter daily by first soaking them in a hot 10 per cent. solution of caustic soda, which softens and partially dissolves the hard skin—containing some 60 per cent. zinc—which forms on the surface, and then scraping them with a sharp tool.

Inherent Disadvantages

Three of the serious disadvantages of cast-iron moulds are: (1) the gas evolution during pouring; (2) the growth of the cast iron, and (3) their low heat conductivity and high thermal stress during casting.

The gassing which has been attributed to the iron is probably primarily due to overheating by contact with the molten metal. Contributory causes are the porosity of the iron and the reaction between the superficial oxide on the metal and the carbon in the iron—probably the combined carbon rather than the graphitic—which is accentuated by the effects of the mould dressings.

The substitution of mild steel for cast iron diminishes the blowing and cracking effects, but two other serious defects arise, viz., distortion of the mould and the liability of the molten metal to weld on to the steel. This latter trouble has been met somewhat by aluminising the surfaces of steel moulds.

In all usual types of cast iron one has to contend with so-called " growth." This has been attributed to the precipitation, then solution and afterwards reprecipitation of the graphite in the matrix of the mould, and more latterly by Carpenter to the repeated oxidation of iron silicide. The presence of nitrogen and hydrogen increases the amount of growth, while P and S and

Mn appear to diminish it. In large ingot moulds as much as $\frac{1}{4}$ in. decrease in internal measurements due to this cause has been observed after 150 heats. Incidentally it has been found that moulds made from cupola iron can with advantage be made initially more accurate, with a reasonable chance of remaining so, than moulds made from straight (or direct) metal. The latter, however, generally have the longer life.

Nickel cast-iron moulds have been used in order to try and reduce some of the ill effects of grey iron, but personal experience is that, apart from being more costly, they are not altogether satisfactory and show defects of their own.

In the case of moulds for steel ingots, which are usually much larger than for non-ferrous work, it has also been shown that for each kind of steel there are special—almost critical—conditions which the mould has to fulfil. Shape, taper, diameter, length, and proportion of wall thickness to ingot body are all important. The material mainly used is low in S and P, with a high total carbon content. Some recent results, however, have revealed the greater durability of ingots containing high percentages of phosphorus. Thus:—0.240 per cent. P, 120-130 heats; 0.170 per cent. P, 130 heats; 0.070 per cent. P, 115-120 heats. The Si is such as to yield a soft grey iron, for a mottled or white structure would probably cause premature cracking. So many factors intervene, however, that it is almost impossible to correlate mould life with composition. Pearce, as the result of an extensive survey, suggests the following ideal specification for a mould for steel ingots:—Total C, high $\nless 4.3$ per cent. $- 0.3 \times$ Si per cent.; Si, sufficient to yield a grey all-pearlite iron; Mn, $1.7 \times$ per cent. S $+ 0.3$ per cent. min.; S, < 0.1 per cent.; P, < 0.1 per cent.

Pearce also is of the opinion that a suitable *structure* for an ingot mould for steel would be that of a high-carbon iron to confer resistance to the hot stream of metal, with a very fine graphitic structure to prevent the entry of oxidising gases and thus delay growth. This particular combination is normally not easy to obtain, if at all. But the B.C.I.R.A. has tried a process involving the addition of a small quantity of titanium to a melt of high-carbon iron (No. 3 hematite iron), and then a treatment of the latter with carbon dioxide. While retaining the high-carbon content the structure obtained is of a fine graphite type approaching that originally suggested.

During its life the composition of the mould material changes somewhat—the total carbon falls (due to decarburisation at the working face); combined carbon falls due to conversion, under heat, of pearlite to ferrite.

Cracks and faults which occur in steel ingots are frequently due to bad mould design. Where, for instance, the section of the wall is too heavy (especially in the case of ingots of small diameter) circumferential cracks may be produced near to the hot top. The metal may, moreover, solidify too quickly, causing the rate of pouring to be increased in order to prevent premature freezing, with the consequent ill-effects on the structure and internal soundness. With thick moulds their life may be prolonged as a whole, but in the long run great age and the temptation to use the moulds beyond an economic limit may be a disadvantage, giving cracks—or hangers—on the internal surface, and this yields faulty ingots. Recent results in steel practice have shown that, generally speaking, with moulds made from similar classes of iron, thick walls fail by disintegration of the surface and give a low total weight of ingot per unit weight of mould metal. As the thickness decreases a figure is reached at which this latter ratio attains a maximum value, afterwards decreasing, and the tendency to major cracking increasing, as the wall thickness becomes less.

The cooling of a casting within a mould is a thermal operation, involving considerations of thermal conductivity, specific heat and density of the mould. It should be as uniform as possible, consistent with the heat being removed quickly in order to give rapid chilling. In the old type of hematite iron box this could not readily be obtained because of the high thermal resistivity and low heat capacity of the material and because also of its complex internal structure. Thoughts then turned to other materials, particularly copper.

The Use of Copper Moulds

In order to obtain the highest efficiency from copper moulds the copper itself should be of high purity, otherwise the conductivity is considerably diminished and the essential advantage is lost. For instance, 0.4 per cent. As, 0.15 per cent. P or 1 to 2 per cent. Sn reduces the thermal conductivity by over 50 per cent. The thickness of the walls should be sufficient to carry away enough heat, aided possibly by circulating water, to maintain the inner face cool and keep pace with the rate of heat outflow.. If such means are not provided welding of the molten metal on to the copper will ensue. The danger is greater with the higher melting-point alloys and therefore the counter provision must be more extensive and water-cooling is imperative. With lower melting-point alloys, non-water-cooled moulds are employed and are adequate for removing quickly the smaller amount of heat in the molten mass. It may also be noted that there is a considerable decrease in the amount of heat transferred to the water-cooled copper mould once it is filled, for by that time the ingot is solid and has shrunk, leaving an air gap which acts as an insulator. At the same time, however, the ingot may safely be withdrawn much sooner, while it is exceedingly hot, thus lessening the working cycle.

A comparison between cast-iron and copper moulds on similar types of work may be summarised as follows:—

	Cast iron.	Water-cooled copper.
(1) *Life* ..	Replacement after about 1,000 heats. (They might, however, be re-machined for the next larger size.)	Copper lining renewed after 3,000 to 5,000 heats. Instances have occurred up to 15,000 heats.
(2) *Casting cycle*	10 mins.	2 mins.
(3) *Lay-out*	Each casting unit requires up to six moulds because of preparatory work (heating up, etc.).	One mould will serve two or three casting units. Minimum of preparation.
(4) *Structure*	Beyond any adequate control.	Uniform structure. Surface does not require machining.

A further advantage of the copper mould is that it is only slightly elastic but very ductile. Any strains, therefore, which are produced during casting are relieved by normal plastic flow on cooling.

The Erical Process

Of almost opposite character to the copper mould is the one designed by Ericsson and used in the Erical process of casting. In place of high-conductivity copper Ericsson uses low-conductivity nickel iron which has also low thermal expansion. Hence the solidification rate is much lower, the temperature gradient through the mould wall is steeper and the difference between the temperature on the front and back of the mould is considerable. Due to expansion, the wall becomes slightly convex inwards and the face pressure thus exerted forces the metal which is still molten in the centre up into the pipe cavity above, thus yielding a larger percentage of sound metal.

In addition, piping is avoided without the necessity, or inconvenience, of feeding in, and a fine structure is obtained. Any tendency there may be to crack in the middle constricted region, due to contraction effects within the area restricted by the inward pressure of the plates, may be countered by giving the plates an initial set outwards by means of adjustable screws. The final result is, of course, that the sides of the ingot are almost parallel. A thin clay wash, followed by a thin oil dressing is recommended for the Ericsson mould. The latter is also provided with an accurately centred tun dish.

It is recognised, as will be shown later, that casting in normal practice is accompanied by much turbulence of the molten metal. Bottom or upward casting, such as is widely practised in the case of steel, wherein the metal is fed down a feeding tube, along a horizontal channel and then up into one or more moulds, reduces this factor considerably but not entirely.

The Durville Casting Method

The most successful attempt to overcome turbulence is the Durville method in which, in effect, the mould slips round the molten metal instead of the latter splashing into the mould. In this process, used principally for copper-aluminium alloys, the metal from the melting furnace is transferred via a hand-carried ladle to a container which is attached permanently to the mould. The metal is carefully skimmed and the mould and container then rotated around a horizontal axis until their positions have been reversed.

Mould Dressings

Mould dressings are common in all classes of ingot casting. The functions of a dressing may be summarised as follow:—

(1) To prevent the molten metal from adhering to the mould material by providing a protective film.

(2) To enable the ingot to be removed easily when solid.

(3) To assist in providing a reducing atmosphere as far as possible during the transit of the molten stream down the mould.

(4) To afford lubrication.

Of the many types of dressing none is ideally suitable to meet all circumstances and, indeed, one generally finds a pet nostrum in every foundry. In the common mixtures oil of some kind or another finds a large place. Refractory inorganic washes are mostly confined to ferrous practice. In any case, there should be no reaction between the dressing and any constituent of the ingot or mould.

One point about which there is doubt is the desirability of having a heavy oil with a high flash-point which will not readily ignite or decompose, or a light oil with a comparatively low flash-point so that it will burn easily as the metal rises in the mould. The deposition of much soot or carbonaceous deposit from a fully cracked oil is to be deprecated, as this gives rise to blemishes on the bar surface. In general, experience seems to point to the use of a light dressing of a heavy oil, either alone or in mixtures, for most non-ferrous work. There is no clearly defined preference for a mineral as against a vegetable oil.

Common dressings include lard oil, olive oil, melted resin, mixtures of graphite and lard oil; graphite and olive oil; resin and turpentine; tallow, resin and turpentine, and a well-known one consists of lard oil, tallow, china clay and french chalk in the proportion 3:2:1:½ and finally stiffened by the addition of graphite.

Genders and Bailey found that a volatile dressing causes in general a decrease in crystal size, an increase in the columnar crystallisation normal to the mould face and an increase in depth of the layer of chill crystals between the mould and the columnar ones. Volatile dressings have, moreover, the disadvantage of giving off gaseous products which may become entrapped or dissolved in the metal. Porosity thus produced is mostly just under the skin. In instances where the metal solidifies before all the dressing has volatilised—*i.e.*, mostly in narrow moulds—contraction cavities are prevalent. In larger moulds the passing of the escaping gases tends to promote greater temperature distribution, and therefore more uniform cooling, coupled with a more extensive dispersion of gas porosity.

Soot from burning acetylene or turpentine has been recommended, but in personal experience, so far as strip casting is concerned, has proved ineffective. Such a soot dressing is in reality inferior to the usual oil as a thermal insulator. As a result, local heating and blowing may occur, especially if the metal impinges on the mould side.

For cupro-nickel and similar high melting-point alloys, lard oil mixed with a little fine graphite appears to be effective, and if the alloy is being cast into thin strip ingots a little dry graphite scattered over the mouth of the moulds after the primary dressing prevents sticking at that point and promotes the formation of a better and more economical top to the ingot. For precious metals simple lard oil or olive oil without admixture is effective.

Mould Dressings for Ferrous Work

In ferrous work washes of finely ground clay, or ganister, with and without frequent applications of oil, oil and graphite, etc., are commonly used. A wash containing a mixture of carborundum and fireclay powders in the proportions of about 6 : 1 has also been employed. Clay-washed moulds have a tendency to flake at temperatures exceeding 300 to 350 deg. C. The application of oil alone or mixed with graphite increases the life and reduces sticking appreciably. Such a coating would operate up to a mould temperature of about 400 deg. C. A mixture of kaolin and water-glass would appear to have advantages, but unfortunately it tends to flake readily. A few drops of machine oil from a can immediately before casting is very effective.

General Considerations

The subject of ingot casting cannot be confined solely to the actual methods which are adopted. Some consideration must be given to the processes that are operative within the metal during pouring and solidification. The physical and chemical laws which are invoked work in many diverse ways that are even now but imperfectly understood. A number of observed facts, however, merit close attention.

Perhaps the most significant observation is that during casting the molten metal is in a state of turbulence. If it were possible to transfer molten metal from crucible to mould without such turbulence much of the foundryman's trouble would be solved. Transference imposes difficulties of its own and to their suppression much ingenuity has been applied. The nearest approach to quiescence is in the Durville process, and in those rare instances, *e.g.*, in accurate precious-metal work where the material is melted and allowed to solidify in the same crucible or in a special type of electric furnace, yet in each of these instances there must almost inevitably be some disturbance due to convection currents. The production of a sound casting depends primarily on the union of moving molten particles. Ideally, each layer in succession should coalesce with the nearly solidified layer preceding it, and thus gradually fill the mould. In other words, the bottom part should be solid before the casting is completed. If sand moulds are used the transfer of heat through the walls is so small that it is difficult to pour slowly enough for this state to arise, and indeed it may not be desirable. In actual fact, what happens?

(1) The incoming metal causes that already within the mould to rise, by simple pressure, basin shape towards the side. The stream also acts as a minor injector drawing air in with it which disperses as bubbles. These effects are accentuated when a single stream is used. Where, however, a tun dish is employed, and the metal flows in in several smaller streams, though the total force may be the same it is distributed, and displacement and splashing are on a much lesser scale, giving a secondary but important effect of more uniform temperature,

while the injector effect is considerably reduced. Time in feeding is also saved, less care is needed to fill the mould, the top end waste is a minimum and there is an increase in the general soundness of the ingot. In bottom or upward casting, too, there is little lateral displacement. Both these devices result in much more equable conditions throughout the ingot.

(2) Crystallisation commences from the mould, first as small, regular equiaxed crystals then as columnar ones, and finally in the interior, small crystals again form. This change of crystalline form has been variously attributed to (*a*) undercooling; (*b*) the separation of the ingot from the mould due to contraction; (*c*) the attainment by the mould of a constant temperature and a consequent decrease in the rate of outflow of heat; (*d*) the overstepping of a critical ratio between the amount of solid crust and the still molten liquid. In general the higher the casting temperature the higher is the temperature gradient and the longer become the columnar crystals. The longer the solidification range the greater the relative amount of equiaxed crystals.

(3) As solidification proceeds, contraction occurs simultaneously: (*a*) of the cooling liquid metal (this can be minimised by attention to feeding and pouring temperatures); (*b*) during the transition from solid to liquid, and (*c*) of the solidified material.

(4) The still liquid metal flows, as far as it is able, having regard to the obstruction offered by the growing crystals, into the gaps still left, including those small ones produced by the contraction of the material already within.

(5) The last of the liquid solidifies and contracts, giving the usual pipe in the upper part which may or may not be bridged by solid matter excessively quickly cooled by exposure to the atmosphere. Contraction cavities form more readily in long, thin ingots than in thick,

fat ones. If feeding is not continuous, other deep-seated cavities may be left to which the feed has not penetrated.

It is advantageous in chill ingot casting to induce chilling from the bottom. To this end large copper blocks have been used as bases for steel ingot moulds, thus conducting the heat away quickly. One of the most important results arising from the use of copper stools in the casting of steel ingots is the increased life of the cast-iron moulds. Such blocks have also been used for casting nickel alloys. In all cases advantages lie in ensuring solidification from the bottom. A process—R.W.R.—has also been developed on the Continent in which, after the metal has filled the mould, a water-cooled copper plate is fixed over the top and then the whole assembly is inverted so that the copper plate is at the bottom during solidification.

There is, then, a general picture; but it does not illustrate the whole story, for, in addition, there are:—(1) The presence of gases—dissolved, entrapped from the atmosphere or derived from the mould dressing; (2) the segregation of impurities either at the crystal boundaries or in the last metal to solidify down the centre, whither they are forced by the solidifying metal which rejects them; (3) the movement of some constituents in certain alloys inward or outward, according to apparently regular laws (though the mechanism is still a matter of controversy), which is termed variously segregation, inverse segregation (if the movement is contrary to what might be expected from normal solidification) or liquation. This results in enrichment of the ingot as regards a particular constituent at one part and an impoverishment at another.

Molten metals dissolve gases in increasing amount with an increase in temperature, and much gas is also entangled mechanically. Further, there may be chemical combination between the furnace gases and some gas already in the metal. For instance, Allen has shown that hydrogen from flue gases readily combines with oxygen in the cuprous oxide in copper to yield steam to which the ultimate unsoundness is due in great measure. As the temperature falls a certain amount of gas is liberated, and on solidification evolution is very active. A certain amount of the residual gas is driven into the central portion of the ingot, some is distributed in minute globules, but with a concentration just under the outer skin, and some may remain, in an unsound ingot, in large cavities in the metal, probably causing blisters during subsequent rolling and annealing. Moreover, in their formation they displace liquid metal, and thus reduce the size of the shrinkage cavity itself.

The reduction of the gas content of ingots has been widely investigated, and among the processes found effective to a certain degree are:—

(1) Control of pouring temperature and rate of pouring. In general, unsoundness in an ingot is the additive effect of contraction and gas content, and depends largely on the casting temperature and the rate of pouring. A measure of super heat in the molten metal is desirable, and on the whole it is better to err in having the melt too hot than too cold, provided it is combined with a slow rate of pouring. Usually soundness increases as the rate of pouring decreases, but with too low a casting temperature unsoundness results whether the pouring rate be fast or slow. The measurement of density is a good criterion of soundness.

(2) Deoxidation.

(3) Rapid stirring, especially with a graphite rod.

(4) Allowing the melt to solidify in the crucible, thus passing through the most active gas evolution stage, then remelting it again quickly and casting.

(5) Introducing the vapour of volatile chlorides or the chlorides themselves. For aluminium castings chlorine, boron

trichloride and titanium-tetrachloride have been used.

(6) Passing a neutral gas, *e.g.*, nitrogen, though the melt, which results in the contained gas being driven out. Perfectly sound piped ingots have been obtained in this manner from unsound aluminium and killed steel.

(7) Melting as a last refining operation and casting *in vacuo.*

The last, which has attained some prominence on the Continent, relies partly upon the withdrawal of the gases under reduced pressure of 2 to 5 mm. of Hg, partly on the ordinary evolution of gas during solidification, and partly on the dissociation of gases chemically combined with the metal under the influence of temperature and reduced pressure. It permits the melts to remain quiescent for unlimited periods out of contact with the air, allowing full deoxidation to take place and solid contaminating impurities to rise to the surface. It is costly, and although large furnaces *have* been built, their use is confined to the treatment of material whose ultimate value in a de-gassed state warrants the expense. The furnace used is of the low-frequency induction type, and the charge is slowly heated to the melting temperature in 6 to 7 hrs. It is then allowed to become completely liquid at a temperature not much above the melting point during 2 to 3 hrs. Much gas is given off during this period, and then the temperature is raised considerably—in the case of steel to 1,700 deg. C.—and maintained at that point for 6 to 8 hrs., during which the principal and final refining occurs. Subsequently the temperature is allowed to fall again nearly to the melting point and the metal is cast into ingots, still under the influence of the vacuum and of the heating medium. In this manner a small controlled stream of degassed metal may be poured into a mould out of contact with air or other gases, and at such a rate that it follows up the metal just solidifying, thus being allowed to fill any gross or even intercrystalline cavities. For ingots weighing 700 lbs. and 4 tons casting times of 15 min. and 40 to 60 min. respectively have been employed.

Such special methods have the possibility of only a limited field. For general work reliance must still be placed on simple modifications which can readily be adapted. These in the main are:—

(1) The use of copper moulds and vertical central feeding from a tun dish arrangement.

(2) Bottom pouring (although this is partially supplied by the tun dish).

(3) Quick transit of the metal into the mould at a relatively high temperature.

(4) The lowest possible amount of dressing on the mould.

(5) Protection of the stream of metal from atmospheric contamination, *e.g.*, by a ring of flame.

Segregation, as has already been indicated, may occur in three ways:—(1) Of impurities to the centre or at the crystal boundaries where the effect is to reduce the mechanical strength of the material; (2) general dispersion throughout the mass; some impurities may actually be dissolved; and (3) of certain constituents—towards the interior or towards the outside.

Flowing Power

Unclean metal may arise from the doubtful character of the original charge, especially if secondary metals have been used, or from oxidation during the pouring operation. The films of oxides—or nitrides—formed on the melt and on the pouring stream when such constituents as Al, Mg and Zn are in the charge, cause an apparent increase in the viscosity of the liquid, though this, in reality, is not the case, for the viscosity of molten metals is little greater than that of water. The fall of the film into the mould as it breaks off at once introduces foreign material which has a deleterious effect, preventing coalescence. Moreover, that characteristic which has been variously termed fluidity and castability, but is perhaps better called flowing power or "flowability," is prevented from having full play in the mould, resulting in imperfect surfaces and internal contamination. In good work nothing should prevent the even flow of liquid metal into the portion which is solidifying. Another cause of an apparently thickened stream is the presence of a large quantity of gas which is restrained by the surface tension of the liquid metal and has had no opportunity of being released.

In some cases the oxide or nitride is soluble in the basis metal, as in copper, nickel and iron, and there is then every chance of the metal pouring cleanly although the oxides are still entangled in the stream. If perchance a flux is used or the product of deoxidation, say with phosphorus, has a low melting-point, then the film is carried almost invisibly on the surface of the stream as a fluid layer.

Generally speaking, flowability is greatest for single metals and eutectics. It varies with the extent of the solidification interval, *i.e.*, between the time the metal just starts to solidify and the end of solidification.

In general, the segregation of impurities and undissolved material is towards the centre of the ingot, having been rejected by the growing crystals. Some, however, becomes entangled and remains in the main body of the ingot. The aim is so to disperse these small quantities of foreign matter that they become innocuous or else, if in large quantity, to gather them together in the last portions to solidify when they may be removed. There is a tendency for the metal solidifying in the central portion to draw the impure liquid down by the force of contraction and thus yield an impure region some way down the ingot.

The so-called inverse segregation has been attributed to the flow of still liquid metal between the dendritic crystals, to the operation of gases within the metal, and to the repulsion of primary crystals away from the chill surface. Whatever be the true explanation the results may be expressed quite simply—the enrichment at the surface of the ingot of that constituent which solidifies last and not, as one might expect, of that which solidifies first. The enrichment in the interior, on the other hand, is of that constituent which solidifies first. Differences in assay between centre and outside, amounting to 2 to 3 per cent., have been observed, especially in low-grade silver alloys. Such differences do not normally give rise to any serious difficulties in working, but must certainly be taken into account in sampling and in the manufacture of alloys to close specifications as regards composition.

DISCUSSION

The discussion was opened by Mr. G. L. Bailey, who observed that the author had done extremely well to emphasise so strongly the importance of making good castings. The extra expenditure involved in making first-class castings was very well justified, for the expenditure of even an extra 1d. per lb. of castings might result in a serious saving of expense in later stages, due to less rejects for defective wrought material.

Steel-Lined Moulds

The use of copper moulds would, he suggested, increase rather than decrease, because the iron mould, with all its conveniences and advantages, was certainly open to serious objection on the grounds mentioned by Mr. Newman. A reasonable life for a cast-iron mould was 1,000 heats, as mentioned in the Paper; but in the latter 500 of those heats, the mould was probably not turning out first-quality castings, because it was beginning to deteriorate, and the stage at which it should be rejected must be decided upon according to the expense which its continued use involved. On one occasion he had tried the experiment of lining a cast-iron mould with a thin plate of steel, but his results were altogether different from those of Mr. Newman, and he would like an expression of opinion as to where he had gone wrong. For lining the mould he had used plates $\frac{1}{8}$ in. thick. and had cut some grooves down the side of the mould for the plates to slip into, leaving ample room for the expansion of the plates and hoping that they would expand into the grooves. The plates, however, had expanded away from the face of the cast-iron mould, with the result that the ingots produced were much thinner in the middle than at the edges. The plates would not expand in the direction in which provision was made for their expansion.

Phosphorus Content of Ingot Moulds

The Branch-President (Dr. A. B. Everest) commented that Mr. Newman was obviously a great authority on ingot moulds, and that some of his ideas were rather refreshing and possibly a little unconventional. For hematite moulds Mr. Newman had mentioned phosphorus contents of 0.4 to 0.6 per cent.; the Branch President wondered whether he had meant 0.04 to 0.06 per cent. The reference to the Ericsson mould was particularly interesting, and he asked what was the composition of the special strips used in that mould and what expansion characteristic was aimed at.

Mr. A. H. Squire asked whether copper moulds were used only for the production of ingots of copper or of copper alloys, and whether attempts had been made to use ingot moulds made of the alloys which it was intended to cast in them. For instance, if a bronze ingot were to be made, could one use a mould made of the same bronze?

Perlit-Iron Ingot Moulds

Mr. J. A. Smeeton, M.I.Mech.E., recalled that five or six years ago a company with which he was associated, and which was manufacturing

Perlit iron, had made a number of moulds in Perlit iron for several non-ferrous metal manufacturers in Birmingham, who had stated that the Perlit moulds had stood up appreciably longer than any other quality of cast-iron moulds that they had used previously. It was fair to say, however, that Dr. Everest had not at that time developed the nickel irons to the extent to which they were now developed. Perlit moulds did, however, show a minimum growth and had the all-pearlitic structure and close grain which retarded cracking and other faults which were so obvious in the ordinary qualities of cast-iron moulds used previously.

With regard to moulds for steel ingots, he said that at a works on the Rhine recently, he had been amazed to find that after a number of ordinary ingots of open-hearth steel had been poured, the surplus metal in the ladle was used to pour into other moulds for the casting of ingot moulds. They were collapsible moulds which were opened immediately after they were cast, and had normal sand cores. As ordinary open-hearth steel of sheet steel quality was poured into the moulds a workman threw into it some handfuls of ferro-silicon from a bucket, which silicon was said to improve immensely the quality of the metal and render it suitable for such moulds. It was stated that the average mould made of hematite cast iron of the usual quality would last for 65 to 85 fillings, whereas the moulds made of open-hearth steel to which the ferro-silicon was added had lasted 120 to 140 fillings.

Top and Bottom Running

He did not know how far bottom running was applied to non-ferrous metals, but bottom running was considered essential for any good-quality steel ingot. A number of years ago he had been associated with a company in France which had a process for manufacturing cast-steel hollow ingots for the manufacture of tubes. When following up that process in Scotland he had visited a large works in which the men were bottom pouring round steel ingots, using the same process of runners in the base of the mould as was used in the French works for casting the hollow steel ingots. In making the circular hollow steel ingots a refractory core was used, so that when the metal rose and filled the mould it began to contract on cooling, and the core collapsed and permitted the splitting of the cast hollow ingot. The effect of this process was to squeeze all impurities to the top of the ingot, and when a number of the ingots were cut up their whole length there was not a pinhole or a fault of any kind anywhere on the surface. Those ingots were never made in this country, but the experience showed that in 90 cases out of 100 the bottom-run ingot was superior to the top-run ingot because turbulence in the mould was not nearly so great when bottom pouring and there was less tendency to piping than when the ingot was run from the top.

Finally, he said he had not had the pleasure of hearing before any Paper which contained so much valuable and concrete information, and he suggested that the author should be invited to read it again before a combined meeting of the Iron and Steel Institute and the Institute of Metals, because it must be of immense interest to the members of those bodies. He desired to thank the author for having prepared and read a Paper of such vital interest to the foundry industry.

Mould Temperatures

Mr. H. O. Slater (Past Branch-President) asked for information concerning the desirable temperatures for moulds used for copper-nickel, 70/30 brass, aluminium-bronze, and so on, and emphasised also that the pouring rate and the cooling rate were very important. A very old and sound foundry principle was that the equal distribution and solidification of metal was essential to the production of a sound casting.

It was perhaps surprising that the author had achieved a certain amount of success by inserting a steel plate into a mould; he personally had not been able to achieve success in that direction. It would appear that the necessary machining of the mould and the insertion of the plate might cost more than a new mould.

"Bellied" Moulds

Mr. J. O. Hitchcock referred to the practice adopted in many brass rolling mills of bellying cast-iron moulds, *i.e.*, of bulging them in the centre, and said he understood the idea was that the superficial impurities were thereby collected together in the bellied portion and could be planed off; in that way the amount of scrap was reduced to the minimum.

He had noted that frequently cast-iron moulds were made with front and back of different thickness; indeed, he did not remember having seen any that were of uniform thickness. The varying thicknesses seemed to be irrational, and he asked what was the reason for adopting that practice. One advantage of water-cooled copper non-ferrous moulds was that greater regularity of melting schedule was obtained as compared with cast-iron moulds.

Mr. E. H. Brown, asking for more information with regard to segregation in the silver and copper alloys, said that in the graphs the silver-rich alloys showed a very much slower movement from the segregation point than did the copper-rich alloys. He asked whether there was any critical range, in the case of any particular alloy, within which that effect could be minimised.

Superiority of Crucible-Cast Ingot Moulds

Mr. A. J. Murphy, referring to specifications of iron for chill moulds, expressed the opinion that the main point was to ensure a uniform structure throughout the casting, and believed that for this reason a crucible-melted iron casting gave a better life as a mould than one which was cast direct from the cupola.

It was by no means easy to secure a sound casting in high-conductivity copper, and for normal production the use of 2 per cent. of zinc in the copper greatly facilitated casting. Of the common metals zinc had the least deleterious effect on the conductivity of the base metal. By simple means such as those one could retain good conductivity with reasonably easy casting.

He was in great sympathy with the reference to the troubles arising from the use of excessive amounts of dressing. It had been suggested, however, in that connection, that by means of a heavy dressing with certain copper alloys, provided the entrapping of vapour bubbles could be avoided, an appreciable grain-refinement was obtained. No doubt the reason was the fairly intense vibration which occurred in the metal just as it was on the point of solidification. This probably lay behind the preference of some casters for heavy coatings of dressing.

AUTHOR'S REPLY

Mr. W. A. C. Newman, B.Sc., replying to the discussion, first paid tribute to the tremendous amount of work done by Mr. Bailey and Dr. Genders in the investigation of ingots and ingot moulds, and said that anyone who had any connection at all with ingot casting was extremely indebted to them for their work.

The decision as to the exact stage at which it paid to reject a mould was always difficult. The management wanted the maximum life from a mould, but the men who were working with it wanted to scrap it as soon as it deteriorated to a stage at which it appeared to affect the ingots produced. An advantage of the casting of copper moulds on the spot was that the scrapped mould castings provided the material for new moulds, and they went back into the furnace at the ordinary price, whereas an ordinary cast-iron mould which was scrapped would command only scrap price.

Steel-Lined Moulds

With regard to the use of plates for lining moulds, he said he had mentioned it provocatively, with a view to getting ideas. In ordinary strip moulds, which were placed back-to-back, the back always deteriorated first, probably due to the stresses produced in casting the mould itself, so that the efficiency of the mould was impaired before the internal recessed part deteriorated to any appreciable extent. Frankly, he had not expected that the fitting of a very mild steel plate would assist in any degree at all, and so far he had used only about half a dozen. The experiment had been tried with ordinary strip moulds, the sheet metal being cut into plates to conform to the shape of the moulds and placed next the backs. The moulds were not screwed up tight, but were given just a grip fit, so that a certain amount of play was left to accommodate movement both vertically and laterally. It was surprising to find that there was not much buckling of the plates, and after 700 heats the surfaces had remained reasonably good, so that the lives of the moulds were prolonged considerably. The moulds themselves cost about £1 each, and the cost of the fitting of a plate was about 3s. 6d. The life of a mould was from 1,000 to 1,400 heats ordinarily, but by fitting a plate, at a cost of 3s. 6d., a mould could be made to give another 600 or 700 heats, which was reasonable economy. He did not claim that the experiment was completely successful yet, but a certain amount of progress had been achieved and the work was continuing.

Phosphorus Content

The phosphorus content of the hematite iron referred to by the Branch-President was from 0.4 to 0.6 per cent., the phosphorus being added specially. There was great controversy between the advocates of high-phosphorus content and of low-phosphorus content. The chief advantage of high-phosphorus content was that it gave the metal greater flowing power, and it was also felt generally that the structure was somewhat more uniform.

B.C.I.R.A.'s Research

The British Cast Iron Research Association had recently tried a process involving the addition of a small quantity of titanium to a melt of high-carbon iron—No. 3 hematite iron—and the treatment of that material in the molten state with carbon dioxide. That was quite an unusual procedure, and the structure obtained was said to be of the very fine graphitic type, approaching the one originally suggested by Pearce as being most suitable. That work, and a great deal more useful work of a similar character, had been done under the ægis of the Committee set up by the Iron and Steel Institute to consider the heterogeneity of steel ingots.

Replying to Mr. Squire's question as to whether it would be possible to use moulds of the same composition as that of the alloys cast in them, he suggested that that would be impossible, for the reason that alloys generally had inferior thermal properties, their conductivities were very low, and the heat would not be conducted away sufficiently quickly to prevent the adhesion of the ingots to the moulds in which they were cast.

Steel Moulds

The remarks of Mr. Smeeton concerning Perlit iron moulds were of particular interest, because it was an accepted opinion in some quarters that a pearlitic structure was desirable in a mould. It was rather surprising to hear that satisfactory results were obtained with steel moulds. For non-ferrous ingots, steel moulds were taboo, because of the probability of the welding of the ingots to the steel. He had seen silver-base alloys attach themselves to the steel when it and cast iron were used together in a mould. In one instance the bottom plugs in the strip moulds were accidentally made of steel instead of iron, and all the plugs had pulled.

With regard to horizontal *versus* vertical moulds, he said the tendency was to cast wire bars and anodes in vertical rather than horizontal moulds, because there was less danger from contamination from the oxygen of the air, and the properties of the bars were better generally.

Ingot-Mould Temperatures

Dealing with Mr. Slater's question concerning the proper temperatures of moulds for casting various alloys, Mr. Newman said he could not at the moment go through the whole series of alloys, but for most base metals and precious metals he liked to heat the moulds to about 150 to 180 deg. C. Strangely enough, unusual circumstances were experienced three or four weeks ago, when the moulds used for casting bronze were actually red hot at about the fourth cast. The strips cast in those moulds were placed on one side and were rolled separately, and to his surprise there was not much difference between the rolling properties of those strips and of strips which were cast in moulds the temperature of which did not exceed 200 deg. C.; the only real difference was that the strips cast in the red hot moulds tended to split a little.

He agreed with Mr. Hitchcock that it had been the practice to "belly" cast-iron moulds, with the idea of segregating the impurities in the bellied portion, and planing that portion away. The point against it was the expense of producing the moulds in the first place with the bellied portion. Another reason for the use of bellied moulds was that the bellied portion should take up the contraction which occurred along the length of the ingots made of certain alloys, thus ensuring that the ingots produced would be parallel-sided. He preferred that the thickness of a mould at front and back should be uniform, in order to secure uniform heating all round.

Silver Alloys

Replying to Mr. Brown, he said that in silver-copper the minimum segregation occurred in the eutectic alloy, where there was a single melting point and the whole of the metal solidified at one temperature. In the silver-rich alloys, containing more than the eutectic composition, there was enrichment in the centre, and in the copper-rich alloys, containing less than the eutectic composition, there was enrichment at the edge.

With regard to Mr. Murphy's reference to crucible-melted *versus* cupola iron, he said that an advantage claimed by some people for cupola iron was that it would retain its characteristics longer than the directly-melted metal. He agreed with Mr. Murphy that the addition of a small amount of zinc to copper assisted the casting of the copper moulds themselves; indeed, the effects of small proportions of impurities on the casting of pure metals was remarkable. It was difficult to produce a sound casting in pure silver, by reason of the extreme absorption of oxygen by the silver; but if only ½ per cent. of copper were added it was quite possible to produce a perfectly sound casting.

Vote of Thanks

Mr. A. J. Murphy, proposing a hearty vote of thanks to Mr. Newman for the charming and easy way in which he had dealt with the casting of commercial ingots, emphasised that the subject was of fundamental importance because a very large proportion of the metallurgical industry must stand or fall by the quality of the material it received in the form of ingots.

Dr. L. B. Hunt, seconding the vote of thanks, said that while the problems of ingot casting were in some ways simple, in other respects they were very involved, particularly in connection with rate of cooling, turbulence and mechanical pouring. Very much thought had been given to these matters and many of the ideas developed could very well be applied to certain aspects of foundry work. That was a further reason for gratitude to Mr. Newman for his very interesting Paper.

The vote of thanks was carried with acclamation.

Sheffield Branch

Paper No 649 THE CLASSIFICATION OF FOUNDRY SANDS

By T. R. WALKER, M.A. (Member)

During recent years in industry the requirements from the products have been gradually increased. This applies to almost every phase of manufacturing activity, including that of castings manufacture. In the foundry, larger outputs are required of castings with improved physical properties and a better surface. The increased requirements have made it necessary to control industrial operations more closely, and nowhere is this more evident than in the foundry. In a modern foundry, to obtain success every operation and every material must be controlled. These materials include sand, and it is a matter of common knowledge that during recent years the testing of sand on a scientific, or semi-scientific, basis, has made rapid progress. The apparatus used in sand testing is finding its place in more and more foundries, and the results obtained from such testing are understood throughout the foundry world.

Sands to Specification

In considering the results of sand testing, it is necessary to remember that uniformity is quite as important as the actual result obtained. In order to obtain uniformity in the sands coming into a foundry, from which the sand mixtures used for moulding or core making will be made up, it is necessary for someone, either the supplier or the consumer, to test the sands to ensure that their properties do not differ more than a reasonable amount from the average of the supplies. This means that in time a consuming firm will wish to receive sands within a certain range of properties, the range having been found as the result of foundry experience with the raw sands supplied. More than one supplying firm is, in fact, now prepared to supply sands to specifications.

If the construction of these specifications is left to the consuming firms, each one would in time evolve close specifications of sands to meet their requirements, and it is very unlikely that foundries even engaged in manufacturing the same class of casting would hit on identical specified ranges for the properties of the sands they require. There would thus gradually be constructed a large number of specifications, many of them differing only very slightly, and this would involve the supplying firms in considerable difficulty, since sands which would meet the specification of one foundry would not quite meet that of another foundry, even though actually the same sand would be equally suitable in the two foundries.

In order to avoid this prospective state of confusion and difficulty, it would be far better to classify the foundry sands available as raw materials, or supplied ready for use, by dividing them into groups. If the range of properties within each group was not too closely specified, the selection of a group would be quite as valuable as the meeting of a specification, since it would cover the requirements of a number of specifications varying very slightly in details. If the range of properties within each group was not too wide, sands in the same group would for many foundry purposes be equivalent, so that the choice of a sand would be simplified and not complicated.

Variety of Properties

Most of the important properties which affect the foundry behaviour of a sand can now be assessed with comparative ease and rapidity. They include the chemical analysis, the size, shape and surface of the grains, the green and dry strength, and the permeability. Since the strength and permeability are greatly affected by the amount of water present, the water content is an important property to be determined. It must be emphasised that the results of the tests itemised are not sufficient to determine completely the foundry behaviour of a sand, but precisely the same remark applies to any more complete examination which can be carried out at present. The final evaluation of a sand must

TABLE I.—*Classification*

Group No.	0.	1.	2.	3.
Chemical Analysis—				
SiO_2 .. .. per cent.	Up to 81	Over 81 To 83	Over 83 To 85	Over 85 To 87
Al_2O_3 .. .. ,,	Up to 2	Over 2 To 4	Over 4 To 6	Over 6 To 8
Fe_2O_3 .. .. ,,	Up to 2	Over 2 To 4	Over 4 To 6	Over 6 To 8
Optimum water content .. ,,	Up to 2	Over 2 To 3	Over 3 To 4	Over 4 To 5
Grading—				
V.C.S. .. .. per cent.	Up to 5	Over 5 To 10	Over 10 To 15	Over 15 To 20
C.S. .. .. ,,	,,	,,	,,	,,
M.S. .. .. ,,	,,	,,	,,	,,
F.S. .. .. ,,	,,	,,	,,	,,
Silt .. .. ,,	,,	,,	,,	,,
Clay .. .. ,,	,,	,,	,,	,,
Green strength (lbs. per sq. in)	Up to 1	Over 1 To 5	Over 5 To 10	Over 10 To 15
Dry strength .. (lbs. per sq. in.)	Up to 20	Over 20 To 40	Over 40 To 60	Over 60 To 80
Permeability No.	Up to 25	Over 25 To 50	Over 50 To 100	Over 100 To 150
Grains clean	Not clean	Rounded smooth	Rounded rough	Rounded pitted
Grains with secondary bond	No bond	,,	,,	,,

be made as the result of foundry experience, but sand testing gives very valuable assistance in the choice of a sand likely to give good results.

In the proposed classification each significant property of the sand is divided into ten groups, each group covering a definite range of values, the ten groups covering the usual properties of sand, ranging from strong natural moulding sands to silica sands, and the proposed system of classification is set out in Table I.

A Simplified Classification

In the classification, the properties specified have been cut down in number to a minimum in order not to make the scheme complicated. The chemical analysis, for example, includes only silica, alumina and ferric oxide, these being the principal constituents which determine the foundry behaviour of a sand. The water content of a sand alters its properties enormously.

It is not possible to fix a water content which

of Sands into Groups.

4.	5.	6.	7.	8.	9.
Over 87	Over 89	Over 91	Over 93	Over 95	Over 97
To 89	To 91	To 93	To 95	To 97	
Over 8	Over 10	Over 12	Over 14	Over 16	Over 18
To 10	To 12	To 14	To 16	To 18	
Over 8	Over 10	Over 12	Over 14	Over 16	Over 18
To 10	To 12	To 14	To 16	To 18	
Over 5	Over 6	Over 7	Over 8	Over 9	Over 10
To 6	To 7	To 8	To 9	To 10	
Over 20	Over 30	Over 40	Over 50	Over 60	Over 70
To 30	To 40	To 50	To 60	To 70	
,,	,,	,,	,,	,,	,,
,,	,,	,,	,,	,,	,,
,,	,,	,,	,,	,,	,,
,,	,,	,,	,,	,,	,,
,,	,,	,,	,,	,,	,,
Over 15	Over 20	Over 25	Over 30	Over 35	Over 40
To 20	To 25	To 30	To 35	To 40	
Over 80	Over 100	Over 120	Over 140	Over 160	Over 180
To 100	To 120	To 140	To 160	To 180	
Over 150	Over 200	Over 250	Over 300	Over 350	Over 400
To 200	To 250	To 300	To 350	To 400	
Sub-angular smooth	Sub-angular rough	Sub-angular pitted	Angular smooth	Angular rough	Angular pitted
,,	,,	,,	,,	,,	,,

would suit all types of sand, but fortunately there is an optimum, or best water content, at which any sand will develop the best green strength, and this optimum water content has, therefore, been chosen as the property to be specified. It is understood that the maximum permeability will, in general, not coincide with the water content at which the green strength is a maximum, but usually the two water contents are reasonably close together. The water content has been included in the chemical analysis group of classification, since its determination is essentially a chemical matter.

For the mechanical grading, Boswell's classification has been adopted as being the minimum which can be utilised to supply useful information regarding the distribution of grain sizes. The particle sizes corresponding to the grades are as follow:—

Very coarse sand ..	1 to 2	mm. dia.
Coarse sand	0.5 to 1	,,
Medium sand	0.25 to 0.5	,,
Fine sand	0.1 to 0.25	,,
Silt	0.01 to 0.1	,,
Clay	less than 0.01	,,

The green strength grouping calls for no particular mention, except that it must be remembered that the green strength is the maximum which can be obtained, this, of course, depending on the water content. The dry strength depends not only on the nature of the sand, but also on the water content; the dry strength figure mentioned in the classification is that obtained by drying a green sample containing the optimum water content. It is naturally possible to obtain higher dry strengths than this by increasing the green water content, this at the same time diminishing the green strength. The grouping of permeability figures offers no particular difficulty.

Grain-Shape

In considering the grains, the important features are the shape, which may be rounded or angular to different extents; the nature of the surface, which may be either smooth, rough or pitted; and the presence or absence on the washed grain surfaces of a thin film of secondary bond tenaciously held. These points have, therefore, been covered in the classification, whilst the size distribution of the grains has already been covered in the mechanical grading.

In writing down the classification of a sand from its determined properties, the results are set out in three rows of figures. The first of these, called for convenience A, refers to the chemical analysis, including water content. The second, called B, refers to the mechanical grading, and the third, called C, covers green and dry strength, permeability and nature of the grain. If the properties of a sand are known, to determine the number of the group to be allocated for a given property, it is necessary only to compare the determined value for that property with the range covered by the different groups of that property. For example, if the silica content of a sand is 92 per cent., then, since the group covering the range of 91 to 93 per cent. silica is group 6, this 6 is the first figure to be set down in row A. Similarly, if the alumina content is 7 per cent., then the second figure in row A will be 3, since group 3 covers alumina contents of 6 to 8 per cent. The figures for the other properties are obtained in precisely the same way, so that finally all the properties covered in the classification are expressed in three rows of numbers.

Practical Examples

One or two detailed examples will make the application of the system quite clear. Suppose a moulding sand, as the result of examination, gives the following results:—

Chemical Analysis—

SiO_2	91.5	per cent.
Al_2O_3	6.7	,,
Fe_2O_3	1.4	,,
Optimum water content ..	6.2	,,

Grading—

V.C.S.	2 per cent.
C.S.	3 ,,
M.S.	48 ,,
F.S.	27 ,,
Silt	6 ,,
Clay	14 ,,
Green strength	5.5 lbs. per sq. in.
Dry strength	110 ,, ,,
Permeability No.	130
Grains	Clean, sub-angular, rough.

Comparing these properties with the table, they can be written down as follow:—

A	6	3	0			
B	0	0	6	4	1	2
C	2	5	3	5		

Supposing now that one is given the figures in rows A, B and C above and works backwards, it is found that the figures describe a sand having the following properties:—

Chemical Analysis—

SiO_2	91 to 93 per cent.
Al_2O_3	6 to 8 ,,
Fe_2O_3	Not more than 2 per cent.
Optimum water content	6 to 7 per cent.

Grading—

V.C.S.	Not more than 5 per cent.
C.S.	Not more than 5 per cent.
M.S.	40 to 50 per cent.
F.S.	20 to 30 ,,
Silt	5 to 10 ,,
Clay	10 to 15 ,,
Green strength	5 to 10 lbs. per sq. in.
Dry strength	100 to 120 ,, ,,
Permeability No.	100 to 150
Grains	Clean, sub-angular, rough.

This range of properties indicates at once the type of sand described. It is evidently a moulding sand suitable for facing purposes on medium size castings. If a supplier were asked to supply such a sand, he would probably be unwilling to reduce the range of values indicated, so that in effect the range given embodies a specification.

A Second Example

As another example, supposing one is given the classification of a sand as follows:—

A	9	0	0	0		
B	0	1	8	4	0	0
C	0	0	9	1		

The first row A tells us that the silica content is over 97 per cent.; the sand is evidently a silica sand with little iron or alumina present. This is confirmed by the optimum water content, which is not more than 2 per cent. From the grading it can be seen that since the medium sand grade is between 60 and 70 per cent., the sand is a coarse silica sand. The fact that it is a silica sand is again confirmed by its green strength, as shown in row C, which is not more than 1 lb. per sq. in., and its dry strength, which is not more than 20 lbs. per sq. in. The fact that it is a coarse silica sand is also confirmed by its permeability, which is indicated as being over 400. It is also revealed that the grains are clean, rounded and smooth. Setting out the information deduced from the classification gives us the following table:—

Chemical Analysis—	
SiO_2	Over 97 per cent.
Al_2O_3	Not over 2 per cent.
Fe_2O_3	„ 2 „
Optimum water content	„ 2 „
Grading—	
V.C.S.	Not over 5 per cent.
C.S.	5 to 10 per cent.
M.S.	60 to 70 „
F.S.	20 to 30 „
Silt	Not over 5 per cent.
Clay	„ 5 „
Green strength	„ 1 lb. per sq. in.
Dry strength	„ 20 „
Permeability	Over 400
Grains	Clean, rounded, smooth.

From the figures given there is no doubt whatever of the kind of sand described, and there is equally no doubt that for all practical purposes in the foundry such a sand could be obtained from more than one supplier and from more than one district.

The advantages of a classification of this kind need no elaboration. Its adoption would assist suppliers and consumers alike. The supplier would, in effect, be supplying sand to meet a specification not to suit a single consumer but acceptable to a number of foundries, and the examination of his raw materials to ensure that their properties complied with the particular groups selected would give him timely warning of any change in the nature of the deposits. The consumer would receive sands the variation in whose properties was limited to known amounts, whilst the knowledge of the variation in properties permissible in a particular sand would allow the selection of alternative sources of supply which might be more economically situated.

APPENDIX

On reading through his Paper at a late date, the author found that he would like to add the following further information:

Sand grains are classified into ten groups in which the grains have no secondary bond, and ten in which they have secondary bond. The numbers referring to both sets of groups should be included to avoid any possibility of error.

In the first example, described on page 638, the figures on line C are given as 2 5 3 5, the final 5 describing the grains as being clean, subangular and rough. A fifth figure, 0, should be added to show that the sand has no secondary bond, this being evident from its group number of 0 in the classification of sands with secondary bond. If instead of being clean the grains had possessed a secondary bond, then the figures in line C would have read 2 5 3 0 5.

Precisely the same remarks apply to the figures given in line C for the second sample.

For a sand with clean rounded smooth grains, the figures should read 0 0 9 1 0. If the sand had possessed secondary bond instead of having clean grains, the figures would have been 0 0 9 0 1. Since any sand must either have secondary bond or not, it is evident that one of the last two numbers in line C must always be 0. In the case of clean grains, the final 0 should always be added in order to avoid any uncertainty.

Sheffield Branch

Paper No. 650. SOME NOTES ON THE PROPERTIES OF CHILLED METALLIC SHOT AND GRIT USED IN SAND BLASTING

By J. E. HURST (Past-President) and J. H. D. BRADSHAW (Member)

The operation of cleaning castings for various purposes by sand- or shot-blasting has steadily grown into a process of major importance in many sections of the foundry industry. All the various types of plant designed for this purpose use abrasive materials in a granulated form, of which the most important are the various forms of metallic and silica abrasives. The metallic abrasives in the form of metallic shot and grit are now used extensively in place of sand or flint grit in all the various forms of sand-blasting machinery.

By metallic shot is understood the rounded more or less spherical particles of metallic material in contradistinction to the angular or cornered particles possessing a multiplicity of cutting edges which are referred to as metallic grit. In spite of the extensive replacement of sand and flint by metallic shot and grit the generic title " sand-blasting " as applied to this cleaning operation and the machinery used in it, still remains, and is used indiscriminately with the more recent and probably more satisfactory term of " shot-blasting." In addition to its use in cleaning operations in the foundry chilled metallic shot and grit find extensive use in the preparation of the surfaces of castings, forgings and sheets, for such purposes as enamelling, painting, cellulosing, electro-plating, galvanising, tinning and metal spraying. It is used also in the operations of stone sawing and cutting, rock and well boring, and in the concrete industries for the production of dustproof hard wearing surfaces.

Commercial varieties of metallic shot and grit appear to be described by some form of appellation including the word "steel," as for example "*chilled steel shot and grit*"; "*chilled alloy steel abrasives.*" This same practice persists in other countries. In Germany, for example, such phrases as "*Stahl-Sand*" and "*Diamant-Stahl*" are used, and in France this material is frequently referred to as "*Grenailles d'Acier.*" It may be that the inclusion of the word "steel" in the commercial description of this material can be justified on the grounds that a proportion of the metal mixture used in its manufacture may be steel.

Performance of Chilled Metallic Shot and Grit

Both shot and grit are manufactured in a range of sizes from finely powdered material less than 100 mesh in the case of grit, up to coarse grades, and it is found in practice that different sizes are suitable for different classes of work and for the production of different types of finish. For example, in general foundry cleaning operations the coarser sizes are recommended for large-size steel castings; the intermediate sizes for iron castings; and the finer grades for brasses, bronzes and the softer metals. Whilst both shot and grit are used for these general cleaning purposes it does appear that the use of grit is the more extensive, and it is probably found that owing to its angularity and the presence of cutting edges, grit is generally more efficient than shot. In the preparation of the surfaces of castings, etc., for enamelling or metal coating, grit is normally used.

It has been shown by Neville[1] and also by Bradshaw[2] that the character of the cleaned surface differs considerably, according to whether shot or grit is used. In the case of the former a surface which is described as a "peened"

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[1] FOUNDRY TRADE JOURNAL, March 21, 1935, p. 200.
[2] Proc. I.B.F. 1935-36.

surface is obtained, in contrast to what is described as an etched surface obtained with grit. This latter is the surface finish desired by enamellers, as, in addition to providing a key for the enamel coat, it is found greatly to minimise defects which occur in the enamelling process. Exactly as in other operations, such as grinding, in which abrasive material is used, the size and character of the abrasive may have a very great influence on its performance both from the point of view of quality of work and also the service life of the shot and grit itself. In so far as the performance of shot and grit is affected by its size and character, this is in the hands of the user of the material. The shot and grit manufacturer produces a range of sizes and characters and the selection of the most suitable of these is in the hands of the user to meet the requirements of his particular class of work. In this, of course, the manufacturer of the shot and grit is able to assist by advice based upon the general knowledge that he has accumulated of the use of the material in its many applications; but it is clear that the final selection must depend upon trial and experiment to meet the user's exact requirements.

Performance Data

Two aspects of this question of the performance of metallic shot and grit which have attracted attention in the application of this material to the operations of cleaning castings, forgings and other articles are: (1) the comparative value of metallic and silica abrasives, and (2) the comparative value of different varieties of metallic abrasives. Experimental data and figures relating to these two factors are not only scarce in foundry literature, but are extremely difficult to obtain. According to Bradshaw,[2] from an economical point of view, chilled metallic shot and grit are distinctly advantageous when compared with sand, quartz or flint. Although more expensive in first cost, metallic grit has from 10 to 20 times the life of sand, and its use is accompanied by various other advantages, not the least being the reduction in the immense amount of dust which accompanies the use of sand. For some purposes metallic shot has a life of as much as 60 times that of sand. When cleaning castings for enamelling purposes it is usually estimated that 1 ton of chilled metallic grit will do the work of 16 tons of quartz.

Some detailed experimental results obtained from the cleaning department of a large Continental works handling from 2,500 to 3,500 tons per month of steel forgings and iron castings have been published ("Revue de Fonderie Moderne"). This class of work, of course, is entirely different from that of cleaning castings for enamelling purposes. The experience over a period of ten months, during which a total of 32,000 tons of material were cleaned by blasting, using metallic grit, proved the quantity used was less than 100 tons. It was stated that for the cleaning of a similar quantity of mixed forgings and castings, using sand, approximately 3,800 tons of sand would have been required. On the basis of these figures 1 ton of chilled metallic grit is approximately equal to 38 tons of sand. The saving in handling and storage charges in

TABLE I.—*Results of Tests on Metallic Grit Used in the Preparation of Iron Castings for Enamelling.*

Test no.	Grit used per 100 lbs. of castings blasted.
1	2.016
2	3.412
3	3.083
4	2.909
5	2.958
6	2.629
7	3.688
8	3.176
9	4.522
10	3.923
11	3.429
12	7.756
SS	2.551

TABLE II.—*Chemical Composition of Chilled Metallic Shot and Grit.*

Sample no.	T.C. Per cent.	C.C. Per cent.	Gr. Per cent.	Si. Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.	Cr. Per cent.	Origin.
1	3.30	3.30	Nil	1.95	0.45	0.097	0.85	0.15	British.
2	3.32	3.32	,,	1.83	0.36	0.098	1.24	0.14	,,
3	3.11	3.11	,,	1.88	0.30	0.092	1.28	0.14	,,
4	3.00	3.00	,,	1.95	0.34	0.165	1.31	0.10	,,
5	3.21	3.21	,,	2.07	0.38	0.125	1.19	0.087	,,
6	2.90	2.90	,,	1.50	0.35	0.15	1.20	0.10	,,
7	2.95	2.95	,,	1.23	0.41	0.155	1.09	0.45	,,
8	3.11	3.11	,,	1.87	0.40	0.119	1.19	0.07	,,
9	3.00	3.00	,,	1.10	0.33	0.166	1.09	0.33	American.
10	3.40	3.40	,,	1.48	0.33	0.044	1.00	0.07	German.
11	3.18	3.18	,,	1.64	0.33	0.106	1.15	0.11	,,
12	3.14	3.14	,,	1.30	0.33	0.162	0.93	0.19	Continental.
13	3.40	3.40	,,	1.68	0.38	0.109	0.54	0.03	Unknown.

favour of metallic grit will be readily apparent from the figures quoted in this manner.

It is also stated that in addition to the economies realised by the use of metallic grit, much better results in appearance and finish were obtained, and in fact articles which presented difficulties in cleaning with sand were cleaned easily when metallic grit was used.

Nozzle Wear

A point of considerable interest regarding the wear of nozzles was recorded also. This was much less in the case of metallic abrasives than when sand was used and on an average the wear of nozzles with metallic grit was only one-fifth of that obtained with sand. Some results were obtained also which showed a saving in compressed air in favour of metallic grit. Over a period of two successive years with a correction for tonnage treated a saving in air consumption of 15 to 20 per cent. was obtained over that used in the case of sand. A further interesting point was brought out in these results, to the effect that the consumption of metallic grit was slightly greater in the cleaning of iron castings than in the case of cleaning forgings. This was attributed to the design of the castings treated and the fact that some of the abrasive remained in the interior portions of these and was not wholly recovered.

Life of Chilled Shot and Grit

It is clear that information regarding the comparative life of different varieties of metallic abrasives would be of great value. In the case of silica abrasives it is known that the properties of silica sand can vary in sands of different origin, and that there is a substantial difference between the hardness and toughness of sand and such materials as quartz and flint grit. These differences in properties in different varieties of silicious materials probably have a large influence on their behaviour when used in sand-blasting. Similarly in the case of metallic grit, metallurgical knowledge indicates that the properties of hardness, toughness, and in fact

Fig. 1.—Grit, mounted for Testing.

Fig. 1a.—Grit, mounted for Testing. × 4.

all the physical and mechanical properties are capable of substantial variation according to the composition and the thermal treatment to which the metal is subjected. For these reasons it is to be expected that different varieties of metallic grit may show differences in life and service values according to their composition, treatment during manufacture, and physical and mechanical properties resulting therefrom.

There do not appear to be any reliable data published giving figures referring to the comparative life of different varieties of shot and grit. For this reason the figures given in Table I will be of value. These figures have been obtained from actual full-scale long-period tests in the shot-blasting of the same class of work using different varieties of metallic grit. The class of work was the preparation of cast-iron stove-grate castings for enamelling and every effort was made in each test to ensure comparative conditions. The many difficulties associated with tests of this description will be appreciated by all those familiar with sand-blasting operations, and it will be quite clear that no significance can be attached to the actual magnitude of the figures outside the particular class of work on which the results were obtained. Their significance lies in their comparative value, and they do show that under comparative conditions it is possible for different varieties of metallic grit to show differences in results. Obviously further experimental work of this character will constitute an important section of future research into the improvement in the character, properties and service value of metallic shot and grit.

The performance of metallic abrasives must be intimately connected with the mechanical and physical properties of the material, the grain size and shape, in addition to the efficiency of the particular design of blasting machine in which the abrasive is used. In connection with the mechanical properties it will be clear that the hardness and strength properties, including the toughness, will be of major importance, and may be expected to bear some relation to the behaviour of the material in regard to its cutting and wearing properties in addition to its resistance to disintegration. In so far as mechanical properties are concerned, these may well be the major properties in determining the life of any given size of metallic abrasives in service. In their turn the mechanical properties will depend upon the chemical composition and character of the material itself and the thermal treatment to which it is subjected during its manufacture. Both the grain size and shape are of importance also, and in their turn these are intimately connected with the manufacturing procedure.

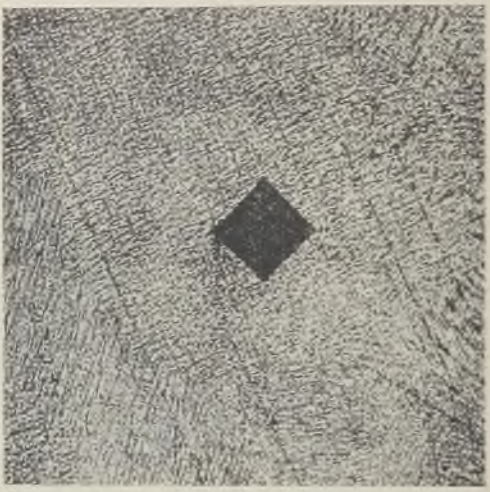

Fig. 2.—Grit showing F.D.H. Impression. Etched in Picric Acid. × 50.

Chemical Composition

The chemical composition of a number of samples of commercial varieties of both metallic shot and grit have been assembled in Table II. These have been selected from analyses made over a period of several years, and of specimens of different origin, and for this reason may be regarded as representative of the commercial varieties of this material available to-day.

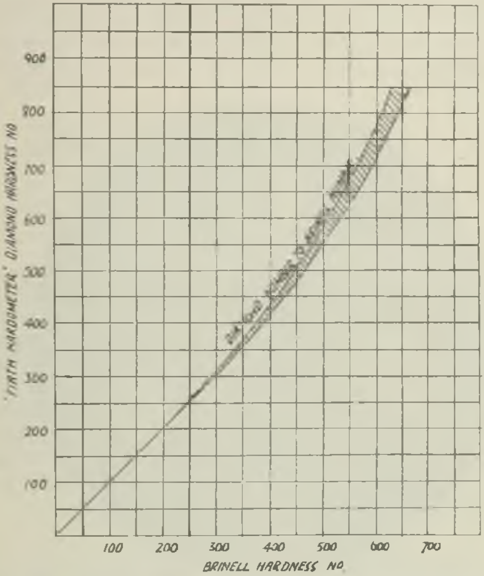

FIG. 3.—APPROXIMATE COMPARISON BETWEEN BRINELL HARDNESS NUMBER AND FIRTH DIAMOND HARDNESS NUMBER.

(A definite comparison cannot be given, but the comparative values within the shaded area shown will serve as a general guide.)

On strict metallurgical grounds all these specimens of commercial chilled metallic shot and grit are more properly described as chilled white iron. Mention has been made already of the fact that this material is most generally described as steel.

In all cases graphite is completely absent and the whole of the carbon is in the combined form. The total carbon contents in the analyses given range from 2.90 to 3.40 per cent., with amounts of silicon, manganese, sulphur and phosphorus which show clearly that the material is correctly classified as chilled white iron. All these analyses show that the material contained chromium, but with the exception of specimens Nos. 7 and 9, the amount of this element is small and cannot of necessity be regarded as having been added intentionally. The amount present in No. 7 and No. 9 is substantially larger, and in one case it is known to have been added deliberately.

TABLE III.—*Firth Diamond Hardness of Chilled Metallic Shot and Grit.*

Specimen no.	1	2	3	4	5	Origin.
1	882	882	882	882	882	British.
2	902	824	882	824	824	,,
3	724	824	681	724	—	,,
4	824	681	1,081	882	882	,,
5	946	882	824	824	824	,,
6	946	724	824	824	824	,,
7	824	882	946	882	882	Continental.

Hardness

The hardness of actual shot grains can be measured best by diamond hardness testing, using either the Firth, Vickers or Rockwell hardness testing machines. The two former methods are recommended for the reason that they enable low indenting pressures being applied, thus

TABLE IV.—*Firth Diamond Hardness of Sand-Cast White Irons.*

	T.C. Per cent.	Si. Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.	Cr. Per cent.	F.D.H.
300	3.14	0.62	0.64	0.136	1.21	0.04	464/500
325	3.30	0.92	0.56	0.186	1.10	0.68	606/588

avoiding the breaking of the small grains which is the difficulty associated with the use of larger indenting loads. The Firth diamond hardness machine using a 10 kilogramme load is used in the authors' laboratories. A recommended procedure in mounting specimens is to press a number of grains of shot to be tested into a small cake of white metal alloy. Embedded in this matrix the grains can be ground and polished to leave flat surfaces suitable for diamond hardness testing. A typical test specimen prepared in this manner is illustrated in Fig. 1, and a magnified view of the diamond hardness impression obtained with the Firth hardness testing machine using a 10 kg. load is shown in Fig. 2.

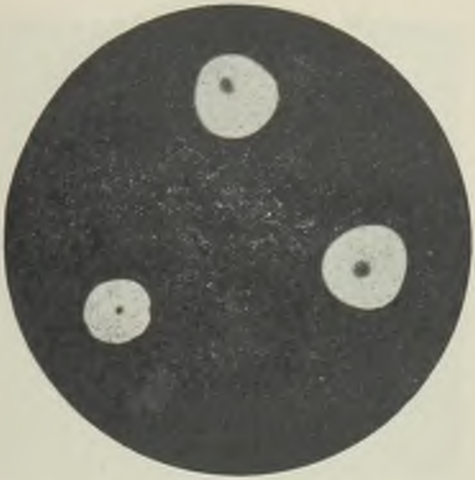

Fig. 4.—Round Shot showing Central Shrinkage Cavity. × 4.

A collection of hardness results determined in this manner on a number of specimens of grit obtained from different sources is assembled in Table III. The results for each specimen in the table are given on separate grains of shot from the same sample and in some cases, as for example samples Nos. 3 and 4 in the table, a substantial variation in the hardness value is revealed. Results of this kind emphasise the need for testing a number of grains from any one sample in order to obtain a representative hardness figure for the sample as a whole. Diamond hardness numerals in their range of hardness differ slightly from ordinary Brinell hardness numbers obtained

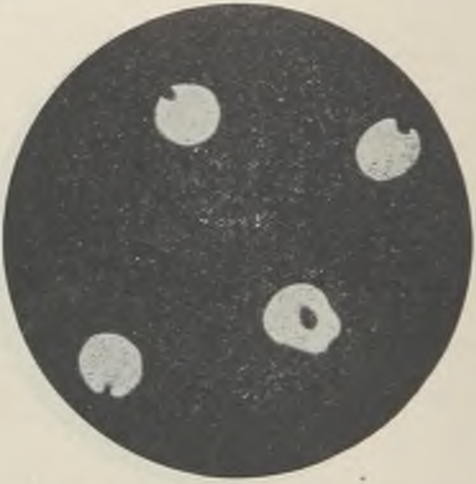

FIG. 5.—ROUND SHOT SHOWING ECCENTRIC SHRINKAGE CAVITY. × 4.

with hardened steel ball indenters. The extent of this difference is illustrated by the graph in Fig. 3, and it will be seen that the diamond numerals are slightly higher than the ordinary Brinell figures. It is probably true to say that the Firth diamond hardness results obtained on shot or grit lower than 750 may be considered to be on the soft side and samples showing irregularity, including results lower than this, may be regarded as soft in character.

These hardness results are substantially higher than those obtained on the general varieties of hard white iron in the sand-cast condition. For the sake of comparison the results in Table IV were obtained on two commercial varieties of hard white iron grinding plates. Plate No. 1 is an ordinary quality of white iron and No. 2 a special quality of chromium alloy cast iron, both in the sand cast condition. The difference in hardness value is substantial and this is due almost entirely to the drastic quenching effect to which shot and grit material is subjected during its manufacture.

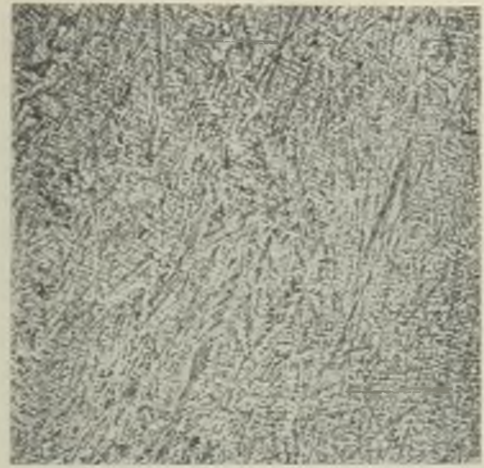

Fig. 6.—Grit A. Etched in Picric Acid. × 120.

Strength Properties

No really satisfactory method has been devised yet for the measurement of the strength properties on actual samples of shot or grit in the granular form, and it is difficult to conceive of a method for the direct determination of the simple strength properties on the material in this form. The strength properties that are likely to be of interest are the ultimate breaking strength either in tension, bending or compression, the resilience value, and perhaps the modulus of elasticity. The study of these properties in material for shot and grit will prove of value in the study of the resistance to disintegration of this material in service. It is of course less difficult to imagine some comparative method of measuring resistance to crushing or even to disintegration. For example, a predetermined quantity of shot or grit of known grade analysis might be blown in a form of shot-blast machine under standardised conditions and the differences in grade analysis after a treatment of this kind used as an index of the resistance to disintegration. Methods of this kind involve the standardisation of a number

FIG. 7.—GRIT B. ETCHED IN PICRIC ACID. × 120

of arbitrary conditions, but of course they do not possess the advantage of affording a comparative measure of the very property in which both shot users and manufacturers are interested.

Work has been done in the authors' laboratories on the direct determination of the strength properties of chilled white irons using small annular ring formed specimens, permitting of the direct determination of the modulus of rupture, elasticity, permanent set, internal stress and resilience values. This has enabled some knowledge to be gained of the influence of the composition and thermal treatment on the strength properties of chilled white irons. The utilisation of data of this character involves an assumption that its comparative value holds for the same materials converted into much smaller masses such as particles of shot suitable for crushing into grit.

FIG. 8.—GRIT C. ETCHED IN PICRIC ACID. × 120.

Knowledge of these various attributes of the mechanical strength properties in materials used for the manufacture of shot might prove of considerable value in dealing with some of the considerations which arise in service. For example, it is noticed that metallic grits vary in the tendency with which they lose their sharp edges by bending over and becoming rounded. This fact may be associated with the facility with which the material will undergo plastic deformation.

Fig. 9.—Grit D. Etched in Picric Acid. × 120.

Specific Gravity

The determination of the specific gravity of metallic shot and grit may prove extremely useful. In the case of shot it may prove a useful guide as to the extent of unsoundness. In such round shot formed by the solidification of small molten drops of metal there is always a tendency for the formation of a shrinkage cavity near the centre of each shot. Typical examples of this sort of thing are shown in the illustrations Figs. 4 and 5, which reveal the cross-sections of a number of round shot ground and polished after embedding in white metal. The occurrence of this shrinkage cavity in small round shot of iron and steel was utilised by Ericson[3] in his studies of the volume changes of iron on solidification. Except in very small diameter shot there is always a tendency for the internal shrinkage cavity to be present, or alternatively a slight local depression of the surface probably due to the solidified crust not being strong enough to resist the suction effect involved in the progressive contraction on freezing. As a rule the cavity is regular and situated in the centre, but several cavities may sometimes appear

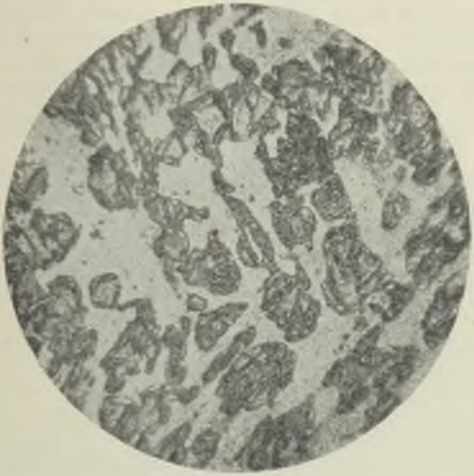

FIG. 10.—GRIT A. ETCHED IN PICRIC ACID. × 1,200.

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[3] Carnegie Scholarship Memoirs, Vol. XXIII, 1934.

in the same shot, and their shape may also be irregular and their position eccentric.

The solidity of round shot and the absence of cavity will be intimately connected with the speed of freezing, and in the ordinary methods of shot production it is probable that the freezing speed is very much quicker than that used by Ericson. Accordingly shot of larger diameter is very frequently found to be quite sound. In the method used by Ericson shot having a diameter of below 0.6 mm. was generally found to be sound. Completely hollow shot are sometimes encountered, consisting of a thin shell only. In this case these are formed after the manner of bubbles, and are actually solidified metal bubbles. Occasionally where water has been used as a quenching medium, such hollow shot are found completely filled with water, an effect very much akin to the compound bubbles or drops which have been studied by various physicists, as for instance Boys.

Table V.—*Specific-Gravity Determinations on Different Specimens of Chilled Metallic Shot and Grit.*

Specimen no.	Specific gravity.
1	7.50
2	7.53
3	7.50
4	7.40
5	7.48
6	7.44
7	7.53
8	7.42
9	7.52

In the case of crushed shot the specific gravity may be a rough and approximate guide to the strength and toughness of the material. Broadly speaking, the higher the specific gravity, the higher the strength properties. A higher specific gravity also indicates a proportionately higher energy content in moving particles of shot of identical size at the same velocity. The results of a number of determinations on samples of grit obtained from different sources are summarised in Table V. The variation from the lowest to the highest result is of the order of approximately 2 per cent. The determinations in each case were made by the ordinary density bottle method.

Microstructure

The examination of the structural characteristics of shot and grit under the microscope presents a number of interesting features. The procedure followed in the preparation of specimens for micro-examination is similar to that for the hardness determination in which a number of grains are embedded in white metal and polished suitably for etching and examination. This procedure affords the opportunity of examining a number of grains picked at random from the same sample, thus providing a greater opportunity of detecting the presence of any variability in character of the material.

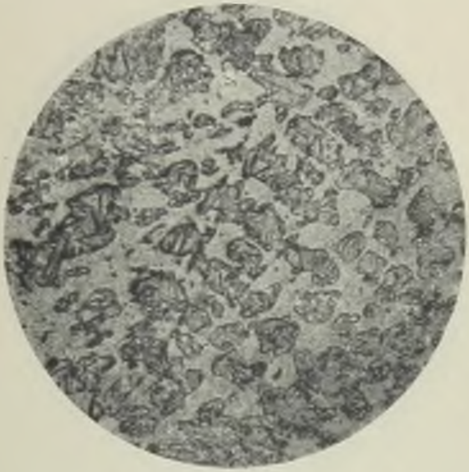

Fig. 11.—Grit B. Etched in Picric Acid. × 1,200.

It is, of course, well known that in its preparation metallic shot and grit is chilled, and the knowledge of this, together with the details of the chemical composition, lead one to anticipate structures of the white iron type. A group of photographs of different makes of shot are included in Figs. 6 to 9. These show the etched structures etched with picric acid at a magnification of 120 diameters, and have been chosen to illustrate the wide differences in structure revealed by grit of different manufacture. At this magnification the specimens, Figs. 6 and 7, show a structure which appears to be a finely divided eutectic structure, specimen 7 showing, if anything, a little more of the darker etching solid solution background.

FIG. 12.—GRIT C. ETCHED IN PICRIC ACID. × 1,200.

In Figs. 8 and 9 much more of the darker etching background appears and in Fig. 9 this background may be regarded as predominant. All the specimens show at least 1 per cent. of phosphorus, and the white etching constituent may be regarded as both the iron carbide and the phosphide eutectics. It is quite rational to suggest that a lower proportion of these constituents in the structure would be accompanied by increased strength and toughness characteristics, and it would not cause any surprise to know that the photograph, Fig. 9, is typical of the structure of the material which gave result No. 1 in Table I, the best result of these tests.

FIG. 13.—GRIT D. ETCHED IN PICRIC ACID. × 1,200.

The structure of the solid solution ground mass, dark etching, generally requires a high magnification to resolve it, and the photographs, Figs. 10 to 13, are the corresponding photographs taken at a magnification of 1,200 diameters. All these show the ground mass to be martensitic in character, and in some the quenching has been so severe as to retain some austenite. The specimen, Fig. 12, showed portions of the ground mass ture which readily etched dark and was apparently unresolvable at 1,200 diameters, suggesting that the structure may be regarded as troostite and possibly indicating not nearly so effective chilling and quenching as has been received by the other specimens.

The martensitic character of the solid solution portion of the structure is probably the reason for the greater hardness of this material than that of ordinary white cast iron, which in the sand cast condition has the solid solution portion of the structure in the pearlitic condition. The general character of the structure shown in Figs. 9 and 13 is of special interest in view of the fact that this represents a sample which has given very good results in service. This consists of approximately half eutectic and half solid solution, this latter being predominantly martensitic. As already indicated, it is unreasonable to suppose that in material of this general composition, the adjustment of the actual composition, the quenching and thermal treatment conditions to yield a structure of this character would be accompanied by the highest degree of toughness and strength simultaneously with the highest degree of hardness. It is also clear that the micro-examination of chilled shot and grit may be usefully employed in the study of this class of material with the object of further improving its properties and characteristics.

Grading

The grading of both shot and grit has been referred to already as a factor of considerable importance in determining the performance of this material in any particular set of circumstances. In addition to the actual particle size, grading can be considered to include the particle shape, and it will be obvious that both particle size and particle shape will be governed largely by the methods used in manufacture. The requirements both as to shape and size vary to a large extent according to the purpose for which the material is to be used, and it cannot be too strongly emphasised that the selection of the most suitable quality from this point of view is largely in the hands of the user himself. The shot and grit manufacturer produces a range of sizes and characters, and in general places himself in a position to match the requirements of the user.

In the case of round shot, for example, the degree of approach of the particles to the truly spherical and also the uniformity of size is definitely more important in some applications than others. In the case of some of the stone-cutting and polishing operations, a greater degree of precision in these respects is required than in some of the applications of this class of material to rough cleaning operations in sand blasting. In the case of grit there are some operations, such as the cleaning of castings for enamelling purposes, where the maximum degree of angularity is required, and the presence of rounded surfaces is regarded as undesirable. On the other hand, there are users who prefer angular grit to show a certain extent of rounded surfaces.

It will be readily understood that owing to the wide variety of uses and requirements there are no hard and fast standards either as to size or shape. In general all manufacturers of shot and grit identify their grades by numbers, the lower numbers indicating the larger sizes and *vice versa*, to this extent following the system of numbering wire-mesh screens based upon the number of meshes per inch length. Even although there are no standards of grit size it is of some general interest to study a standard system of grading which has been drawn up in the U.S.A. for application to non-metallic abrasive grains. This system is evidently designed to exercise some degree of control over the extent of the spread of sizes which always occurs in the grading of material consisting of irregular shaped particles. (Table VI.)

For the majority of sizes control is exercised through five consecutive standard screens, and the spread of the sizes is over four screens. The majority of the material in a given size is that retained on two screen sizes, and this is at a maximum in the coarser grades at slightly

TABLE VI.—*Allowable Limits for Sizing Abrasive Grain.*

Grit no.	Screen through which 100 per cent. must pass.	Control screen.		Maximum of oversize on control screen.	Minimum retained.	Cumulative minimum retained.	Maximum of 3 per cent. through screen no.
		No.	Opening.				
			Ins.	Per cent.	Per cent. on screen no.	Per cent. on screen no.	
10	7	8	0.0937	15	45 on 10	80 on 10 and 12	14
12	8	10	0.0787	15	45 on 12	80 on 12 and 14	16
14	10	12	0.0661	15	45 on 14	80 on 14 and 16	18
16	12	14	0.0555	15	45 on 16	80 on 16 and 18	20
20	14	16	0.0469	15	45 on 18	80 on 18 and 20	25
24	16	20	0.0331	20	45 on 25	75 on 25 and 30	35
30	18	25	0.0280	20	45 on 30	75 on 30 and 35	40
36	20	30	0.0232	20	45 on 35	75 on 35 and 40	45
46	30	40	0.0165	20	45 on 45	75 on 45 and 50	60
54	35	45	0.0138	20	45 on 50	75 on 50 and 60	70

60	40	50	0.0117	30	45 on 60	65 on 60 and 70 ..	80
70	50	60	0.0098	15	45 on 70	70 on 70 and 80 ..	100
80	60	70	0.0083	15	40 on 80	70 on 80 and 100 ..	120
90	70	80	0.0070	15	40 on 100	70 on 100 and 120 ..	140
100	80	100	0.0059	15	40 on 120	65 on 120 and 140 ..	200
120	100	120	0.0049	15	30 and 140 ..	60 on 140 and 170 ..	230
150	100	140	0.0041	15	40 on 170 and 200	75 on 170, 200 and 230	270
180	120	170	0.0035	15	40 on 200 and 230	65 on 200, 230 and 270	—
220	140	200	0.0029	15	40 on 230 and 270	60 on 230, 270 and 325	—

NOTE I.—These specifications shall not apply to abrasives used in the manufacture of abrasive paper and cloth products (coated abrasives).

NOTE II.—The screens referred to above are those of the United States Standard Sieve Series certified by the National Bureau of Standards.

NOTE III.—The allowable limits set forth in the above table are based on the shaking of a 100-gramme sample for 5 minutes on a "Rotap" machine operated at a speed of 290 revolutions per minute and 156 taps per minute. Where more than one screen is used they are to be agitated simultaneously.

over 80 per cent., a maximum limit being placed on the oversize and fines. It is of importance to note that the sieving conditions, using a "Rotap" machine, require to be standardised also. This standard system of grading does not apply to metallic abrasives—chilled shot and grit—and it is included in this Paper purely as an illustration of a system of grading as applied to non-metallic abrasives which in many respects are akin. The importance of this lies in the recognition of the spread in screen grading of material of this character made up of irregular sized and shaped particles.

With the increasing importance of both metallic shot and grit in foundry cleaning operations it becomes more and more desirable to study the character and properties of this material with the object of improving its efficiency in operation. Very little information on this subject has found its way in the technical Press, and it is hoped that this short study will correct this deficiency and serve as a kind of basis and also incentive for further work in the development of the properties of this material.

The authors wish to take this opportunity of thanking the Directors of Bradley & Foster, Limited, Darlaston, for permission to utilise the data presented in this Paper, most of which has been obtained in their research laboratories.

DISCUSSION

Changing Conditions

The Branch-President (Mr. J. B. Allan), said he was particularly interested in the comparative results from the air-projected shot and the mechanically-projected shot. The latter was a modern development within the last few years. Another point was that of the embedding of the shot in a white-metal matrix for use in determining the hardness. All the very high degrees of hardness probably meant that in the white metal there was some slight give, and the actual hardness might be even higher than the one shown. Perhaps Mr. Hurst would give them some information on that point.

Compositional Influences

Mr. J. Roxburgh remarked that, as usual, the members had learnt something of interest from the authors, and, as was also usual, they had been given details of investigational work that pointed the way along which further research could be done, and from which something very useful could be obtained. The question of the composition of the metal of the chilled metallic shot appealed to the speaker as being interesting. Apparently the properties depended on low manganese, high sulphur and high phosphorus contents. As one who made chilled castings, and referring to hardness figures, Mr. Roxburgh said he had more or less to make comparisons with a Shore number. The figures mentioned seemed to him very high, and he wondered if the authors had made any investigations with other materials, for instance, a high-manganese iron with low sulphur—say a manganese content of 1.5 per cent. or thereabouts. He thought the authors would in that way get strength and hardness as well. He wondered if there would be any objections to an iron of that composition.

He was also interested in the question of the solidity of the little chilled shots, and wondered if there were any means of overcoming this phenomenon. He would like the authors to describe how the shot was made. Apparently the metal was quenched in water, and he wondered, if the metal was submitted to some pressure or other process before being ejected into the water, whether that would make any difference. Another point to which the authors had referred was in connection with the comparison between a metallic shot and a silica grit, where it was claimed that the wear of nozzles with the metallic shot was much less than that with the sand. He wondered in that instance of what material the nozzles were made. He also wished to know if the authors' investigations as regards iron castings had been carried out on the various types of material. For instance one could get a hematite casting of very soft material, or on the other hand, one of high hardness value, and he wondered if the life the authors obtained with their metallic shot varied on that account.

Hardness Determinations

Mr. Hurst first dealt with the Branch-President's sugestion that, perhaps, had the specimens been embedded in something harder than white metal, they might have shown a still higher hardness. He pointed out, however, that in investigating the hardness variations of a shot they used a very low load. The pressure was only a 10 kilogramme load. With that load on the particle size of shot they had investigated they did not anticipate that there had been any deficiency introduced into the determination due to the metal in which it had been embedded. With smaller grain they would find it necessary to use a still lower load. The figures given could be regarded as reasonably accurate. In regard to Mr. Roxburgh's question of composition and strength, Mr. Bradshaw, in his notes, had suggested that some of the experimental work they had done so far with high manganese tended to give a shot of a brittle character, and consequently a short life. He did not think that Mr. Roxburgh's suggestion of submitting the metal to some pressure before it was ejected into the water would overcome the question of solidity. Surely it was inevitable that the grains of shot, like steel ingots, must start to solidify from the outside surfaces first, the last portion of the material to solidify being in the centre. This resulted in an openness of character in the grain which was equivalent to the amount of shrinkage in the small volume of the shot. Respecting the type of nozzles used, they had no information beyond the fact that they were hard white-iron nozzles. It was customary to use hard white-iron nozzles such as were made by the malleable ironfounder; it was presumed that the nozzles used in the experiments were of that type.

Nozzle Life

MR. BRADSHAW said that, since the compilation of the Paper, he had come across a concrete example in regard to the comparative life of nozzles. The experiments were carried out with hard white cast-iron nozzles of 9-mm. diameter working at a pressure of 35 lbs. When using sand the average life of a nozzle was 16 hours, but when using flint the life was reduced to 7 or 8 hours under the same conditions; yet when they changed over to chilled iron grit the life was then of the order of three weeks. It really made a serious difference to the life of the nozzle.

Elastic Limit and Abrasive Qualities

PROFESSOR J. H. ANDREW said that the possibility of the hard particles being pushed into the white metal during hardness testing had struck him also, as it required very little pressure to do so. Did Mr. Hurst find any difference between the hardness of the large and small particles of shot? If not, this supported his contention that his method was sound.

The micrographs were most interesting. One which was shown on the screen suggested that the metal had been cast at a high temperature as compared with the others. The structure of the shot described by Mr. Hurst as being particularly good indicated that a considerable amount of austenite present acted as a reinforcement for the hard carbide and martensite. Was it a fact that, in using spherical shot, after a certain amount of use the shot became of the angular type and therefore better for its purpose?

Could the authors tell him whether a high elastic limit was a valuable property to be sought in the material for shot? One would expect that a high value for the elastic limit would be associated with better abrasive qualities.

Round and Angular Shot

Mr. Bradshaw, dealing with Professor Andrew's question concerning the efficiency of the material, said that the round shot as described in the Paper was in contradistinction to the grit. The shot was less efficient than a grit, and in use it often broke up and became irregular. When it did that it virtually became more efficient than it was in the first place. Without going back to the genesis of the manufacture of grit or shot, it was, of course, known that in the beginning the first experiments were made on a round material, which was essentially a shot. It was then thought that that material was quite efficient, but as the majority of people who used that material did so with the object of covering the work treated with some other substance, or coating it according to some other process such as enamelling or painting or even galvanising, it was found in those days that the shot was not as efficient as the sand then used, the reason being that the shot in use gave what was called in the trade a "peened" surface—that was to say that if one examined the surface of the work treated one would find it was quite smooth. From those days the tendency in the trade had been to move away from shot and now people liked to use what was called grit, which was actually a form of crushed shot. The grit was essentially a material that contained a number of irregular pieces. These caused it to have a very rapid action, in addition to which a furrowed surface was produced. The greater part of the production of material made to-day and sold in this country was what was called the angular or grit type. Round shot was not so much used.

Nature of Working Conditions

Mr. Hurst, speaking of casting temperature, said that this was found to be a very important matter, not only from the structural point of view, but also as it affected shape. He hoped that the time would come when this would be investigated further. He was in agreement with Prof. Andrew in his interpretation of the effect of microstructure on the behaviour of the shot. In regard to the qualities of the round shot, there was probably an optimum period in its life; that was to say, its efficiency varied along a sort of curve. It passed through an optimum period in use and finally wore away and was useless. As Mr. Bradshaw had stated, round shot seemed to be out of favour in the castings' cleaning department. The largest use of round shot to-day was in stone-cutting and polishing. He believed that in this case, also, there was an optimum period, and that it was not necessarily at its best when it was new. After some use it gradually got better and then fell off. The elasticity of the material was very important as distinct from plasticity.

Replying to further points raised in the discussion, Mr. Hurst said that in the range of sizes they were able to deal with, under a 10-kilogramme load they did not find any difference in hardness when investigating the hardness of samples of shot of different particle sizes. In pressing the particles into the metal, they used a specific pressure. A pressure of several hundreds of pounds was required to press and hold them in position. He only mentioned this to give some idea of the fact that the particles were really firmly supported in the metal. The only difficulty they had was that sometimes they came to a size of particle that, with a 10-kilogramme load, simply did nothing else but split up. They regarded that as the criterion. If they could get a firm uniform impression, they were satisfied. Over a range of sizes below about 18's, they could not test at all with their present apparatus, because this was limited to the 10-kilogramme load. One of the lantern slides exhibited showed fragments of shot broken by being pressed in.

Nozzle Wear and Efficiency

Mr. H. Wharton said that users of material could not fail to be interested in the experiments that had been brought to their notice. In following these experiments, it had struck him that more of them would have to be undertaken if anything like reasonable results were going to be obtained to help Mr. Hurst and Mr. Bradshaw in their conclusions on the merits of angular grit or any other abrasive. The velocity at the nozzle was certainly one of the things chiefly to be considered. The velocity was governed by the power behind the air. Once the nozzle started to wear away, the blasting efficiency diminished very quickly. Another point was that the abrasive, when it was new, worked quicker than when it had been in operation for some time, not only because of it tending to break down, but because it got dirty. They then got dust which was not carried away by the dust exhaust system, and it became embedded in the surface of the abrasive. Another thing that had to be watched was the fact that in compressor plants condensation was a bugbear, as a fruitful cause of stoppages. These stoppages took up the time of the foundryman who always measured the value of abrasives by the tons of metal castings cleaned in a specified time. Thus stoppages were something that must be taken into consideration. The operator had always to be considered. When the operator was plying the nozzle to a casting, he must strike at the right angle in order to get the most efficient cutting angle. This depended to some extent on the skill of the operator himself. Some operators were much better than others. Thus, in making comparative tests, it was advisable to have the same operator all the time.

Mechanical Projection Suggested

Mr. Hurst said he appreciated Mr. Wharton's remarks and the significance of controlled conditions. He (Mr. Hurst) ought to have taken the opportunity of paying tribute to the work done by Mr. Neville. Perhaps the only comprehensive investigations done on sand-blasting were those done by Mr. Neville. He carried out very comprehensive tests on the question of nozzle size, nozzle velocity and angle management of the shot, and showed the very great importance that these factors had in economical sand-blasting. Since that time very little further work had been done, and Mr. Bradshaw and he (Mr. Hurst) took the view that there was considerable room for further improvement, both in the direction of the quality of the material itself as used for the abrasive and in plant design. A lot of what Mr. Wharton had said might be used to support the mechanical sand-blasting machine in contrast to what he would call the pneumatic sand-blasting machine. They all appreciated the significance of nozzle wear. Not only did nozzle wear have the effect of reducing the efficiency of each operation but it put up the cost. It was in that way a sort of double-edged weapon.

Rubber Nozzles

Mr. S. Leetch said it was very gratifying to those who had to make steel castings to know that people like Mr. Hurst and Mr. Bradshaw were going thoroughly and scientifically into the question of the best type of shot to use; frankly, it was amazingly difficult to get adequate material in this connection for steel castings. It was very difficult also to make a non-smooth surface against a runner. If they could get a shot that was satisfactory from those two standpoints alone a big step forward would be made. On the question of the merits of angular shot and round shot he always felt that the advantage to be obtained from the former was that they were able to get a larger area in contact. With a spherical shot they just got the impact at one point, whereas with an angular shot they were able to hit either the edge or the face. He felt that sand had a more purely abrasive action, whereas with the shot they got an impact action and perhaps a cutting action. Most of the points had been mentioned, but it would appear that if they could get a shot that would work-harden on contact they would be making a further saving of money. So far as nozzles were concerned he had a feeling that the trouble caused by wearing might be overcome by the use of rubber. He felt that the use of rubber for the resistance of abrasion was something that was likely to develop more and more.

Mr. Hurst said he knew from experience that steel pipes conveying shot from screens into bunkers wore out very rapidly. It was no uncommon thing for a pipe to wear out completely in seven days. Rubber pipes would appear to stand up very much better. He was told that rubber nozzles had been tried, but that the difficulty was to keep them cool. If some means could be devised to keep them cool, rubber nozzles would, he thought, be very satisfactory.

Scale Removal

A Member said he had found that angular shot removed scale from castings quicker than round shot, but his experience was that the loss of angular shot was much greater than the loss of round shot. Angular shot cost about £2 a ton more than round shot, and this was an item that had to be taken into consideration.

Speaking in regard to the question of the size of shot and its effect on scale removal, Mr. Hurst said he imagined that a great deal would depend on the type of scale. It was, of course, difficult to compare experiments in one works with those carried out in other works, because conditions varied so much. He was interested to hear of the member's experience on the advantage of angular shot over round. There was certainly a difference in price, the round shot being cheaper, but he thought, from his own experience, that the amount of round shot used in cleaning was substantially less than it was a few years ago. Mr. Bradshaw and he (Mr. Hurst) were anxious to know whether there was any real intrinsic value in the angular shot as distinct from the round. It certainly seemed that there was.

Speaking again in the discussion, the **Member** said he was not sure in his own mind that toughness of shot was an advantage. On the contrary, he felt that it required to be fairly brittle. If they had a shot with sharp edges, they were going to get less effect from it as time went on.

Mr. Hurst said there might be some confusion of thought as to what toughness was. What he visualised by toughness was measured in terms of energy to break the material, disrupt it and disintegrate it. It was quite possible to have a hard and tough material that would yet not have a tendency to bind over at the edges. He imagined that if they used diamonds, probably the hardest thing that could be imagined, they would not have much success, because of their brittleness.

Sheffield Branch

Paper No. 651

TIME AND MOTION STUDY IN THE FOUNDRY*

By C. D. POLLARD (Member)

There are many and varied systems for working time and motion study schemes in the factories and works in the country, and the author will not make any attempt to compare the advantages or disadvantages of one scheme against another, but will confine himself to the working of the one with which he is in daily contact.

The work commences with the usual routine office work of entering the receipt of an inquiry for the price of castings, and the sales department make out an estimate sheet, which, along with the drawing and inquiry, passes to the drawing office for the preparation of what is called a layout sheet. The draughtsmen calculate the weight of the proposed castings and discuss with the foundry manager the suggested methods of coring, jointing, etc.

The time and motion study men are then drawn into the discussion regarding those features of the job which affect the cost of production, such as how many patterns per box, type of moulding machine, flasks or moulding boxes, etc., and a rough layout of the job is prepared.

Fig. 1 shows a typical layout giving all the details which govern the working-up of the moulds for the job. Sizes of boxes or flasks, weight of core material required per casting, etc., are always given. This layout is submitted to the foundry manager for approval, and unless he wishes to make some alteration to the instructions shown thereon, he signs and accepts it

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* Slightly abridged.

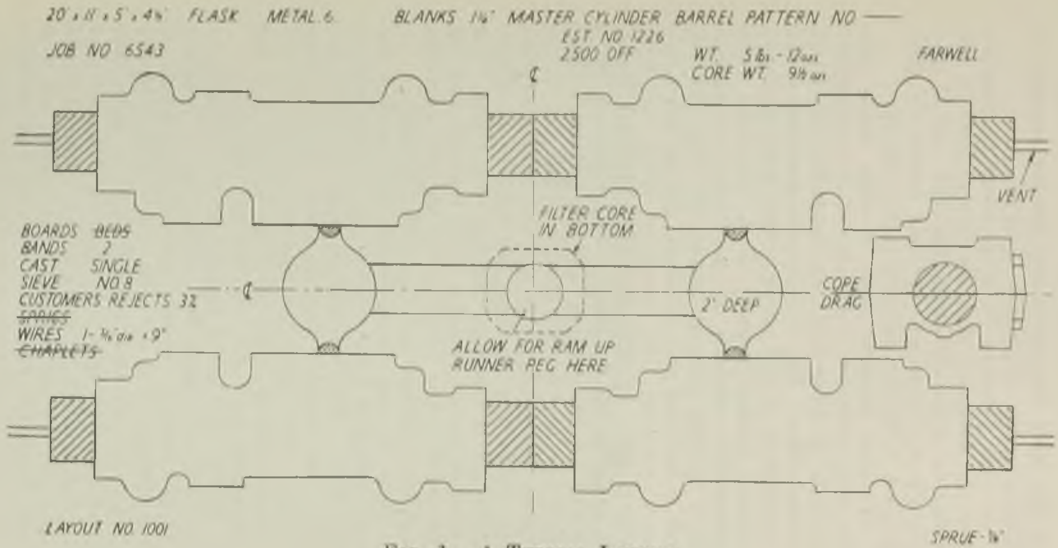


FIG. 1.—A TYPICAL LAYOUT.

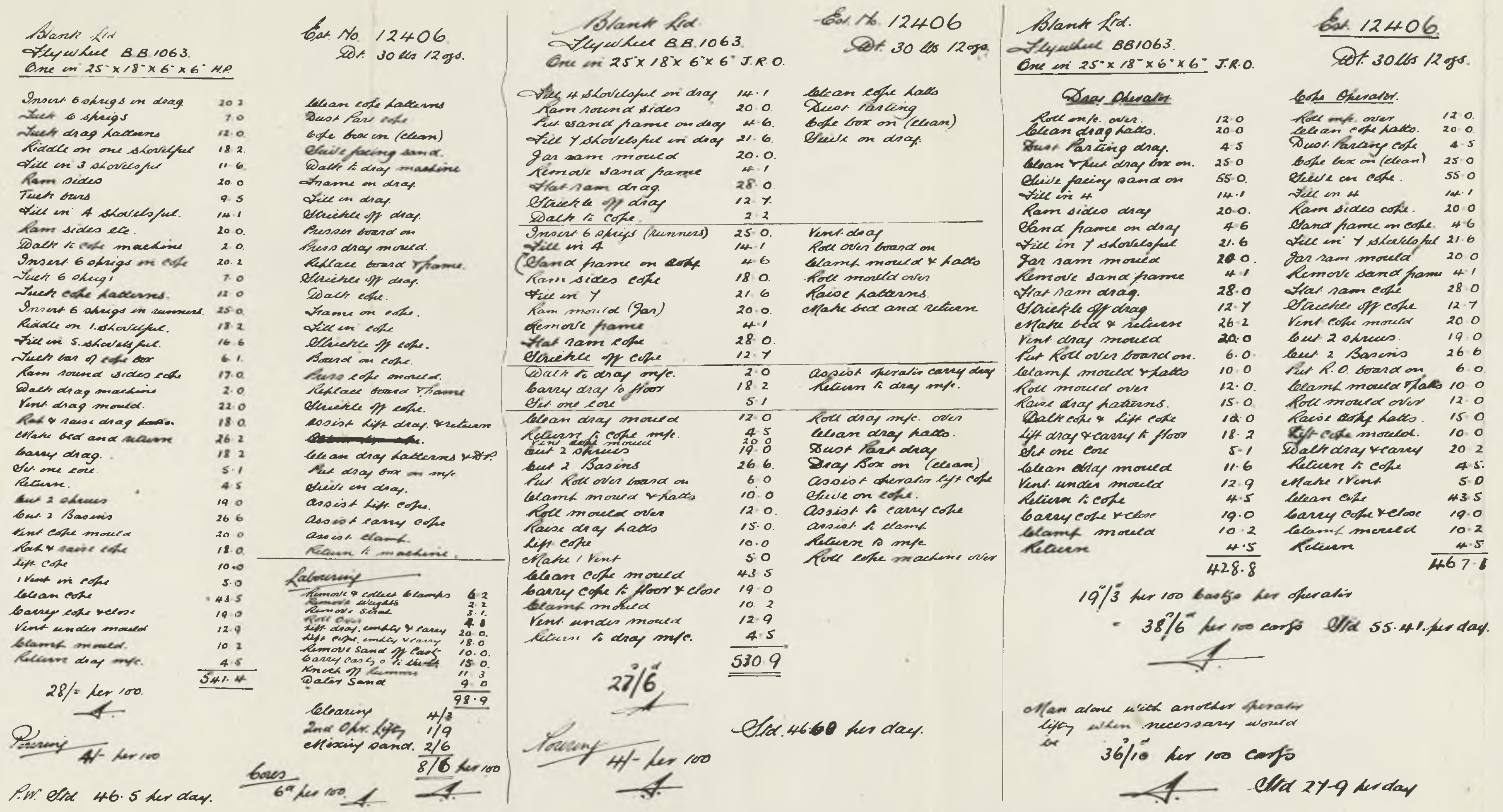
as the most economical and efficient method of producing the castings in question.

At this juncture it is germane to mention and to emphasise that the figures used in the Paper to illustrate estimating and cost of production are fictitious, and are useless for comparison with any foundry's own figures.

It often happens that, at this stage, preliminary estimates are prepared for comparison in costs of more than one suggested method of manufacture. Fig. 2 illustrates examples of the advisability of this action, when more than one obvious method presents itself. It shows three alternative methods of production of moulds from normal pattern plant. On the left the job is laid out and estimated for on two hand-press machines, the operators being one man and a boy. In this case one completed mould is made in 541.4 seconds. The piecework price is 28s. per 100 castings, and the piecework standard per day is 46.5 moulds. Included in the figure, the same job is laid out and estimated for production on two jar rollover machines, involving as operators one man and a boy. One complete mould requires 530.9 seconds, and the piecework price is 27s. 6d. per 100 castings, and the standard per day is 46.6 moulds.

There is also included the job as laid out and estimated for production on two jar rollover machines. This involves the employment of two men, one machine making copes, and the other drags. The time per complete mould is 467 seconds, the standard per day is 55.41, and the piecework price 38s. 6d. per 100 castings.

This is a splendid example of the advisability in the early stages of estimating of weighing up the cost of different methods of production, as it shows how variables can influence figures to a far greater extent than is sometimes realised. It might be reasonable to assume that a man and boy with two power machines should get more production than they could get with two hand-ram machines, but there is evidence here that this assumption would be wrong.



Blank Ltd
Flywheel B.B.1063.
One in 25" x 18" x 6" x 6" H.P.

Est. No. 12406.
Wt. 30 lbs 12 ozs.

Insert 6 sprigs in drag	20.2
Tuck 6 sprigs	7.0
Tuck drag patterns	12.0
Riddle on one shovelful	18.2
Fill in 3 shovelsful	11.6
Ram sides	20.0
Tuck bars	9.5
Fill in 4 shovelsful	14.1
Ram sides etc.	20.0
Walk to cope machine	2.0
Insert 6 sprigs in cope	20.2
Tuck 6 sprigs	7.0
Tuck cope patterns	12.0
Insert 6 sprigs in runners	25.0
Riddle on 1 shovelful	18.2
Fill in 5 shovelsful	16.6
Tuck bar of cope box	6.1
Ram round sides cope	17.0
Walk drag machine	2.0
Vent drag mould	22.0
Rap & raise drag patts.	18.0
Make bed and return	26.2
Carry drag	18.2
Set one core	5.1
Return	4.5
Cut 2 sprues	19.0
Cut 2 Basins	26.6
Vent cope mould	20.0
Rap & raise cope	18.0
Lift cope	10.0
1 Vent in cope	5.0
Clean cope	43.5
Carry cope & close	19.0
Vent under mould	12.9
Clamp mould	10.2
Return drag mfc.	4.5
	541.4

28/= per 100.

Pouring 4/- per 100

P.W. Std 46.5 per day.

Clean cope patterns
Dust Part cope
Cope box on (clean)
Sieve facing sand.
Walk to drag machine
Frame on drag.
Fill in drag.
Strickle off drag.
Presser board on
Press drag mould.
Replace board & frame.
Strickle off drag.
Walk cope.
Frame on cope.
Fill in cope
Strickle off cope.
Board on cope.
Press cope mould.
Replace board & frame
Strickle off cope.
Assist lift drag & return
~~[illegible]~~
Clean drag patterns & D.P.
Put drag box on mfc
Sieve on drag.
Assist lift cope.
Assist carry cope
Assist clamp.
Return to machine.

Labouring

Remove & collect clamps	6.2
Remove weights	2.2
Remove Sand	3.1
Roll Over	4.8
Lift drag, empty & carry	20.0
Lift cope, empty & carry	18.0
Remove Sand off Cast.	10.0
Carry casts to [illegible]	15.0
Knock off runners	11.3
Water Sand	9.0
	98.9

Cleaning	4/3
2nd Opr. lifting	1/9
Mixing sand.	2/6
	8/6 per 100

Cores 6d per 100.

Blank Ltd
Flywheel B.B.1063.
One in 25" x 18" x 6" x 6" J.R.O.

Est. No. 12406
Wt. 30 lbs 12 ozs.

Fill 4 shovelsful in drag	14.1	Clean cope patts
Ram round sides	20.0.	Dust Parting
Put sand frame on drag	4.6.	Cope box on (clean)
Fill 7 shovelsful in drag	21.6.	Sieve on drag.
Jar ram mould	20.0.	
Remove sand frame	4.1	
Flat ram drag.	28.0.	
Strickle off drag	12.7.	
Walk to cope	2.2	
Insert 6 sprigs (runners)	25.0.	Vent drag
Fill in 4	14.1	Roll over board on
(Sand frame on cope	4.6	Clamp mould & patts
Ram sides cope	18.0.	Roll mould over
Fill in 7	21.6	Raise patterns.
Ram mould (Jar)	20.0.	Make bed and return
Remove frame	4.1	
Flat ram cope	28.0.	
Strickle off cope	12.7	
Walk to drag mfc.	2.0	Assist operator carry drag
Carry drag to floor	18.2	Return to drag mfc.
Set one core	5.1	
Clean drag mould	12.0	Roll drag mfc. over
Return to cope mfc. Vent cope mould	4.5 20.0	Clean drag patts.
Cut 2 sprues	19.0	Dust Part drag
Cut 2 Basins	26.6.	Drag Box on (clean)
Put Roll over board on	6.0	Assist operator lift cope
Clamp mould & patts	10.0	Sieve on cope.
Roll mould over	12.0.	Assist to carry cope
Raise drag patts	15.0.	Assist to clamp
Lift cope	10.0	Return to mfc
Make 1 Vent	5.0	Roll cope machine over
Clean cope mould	43.5	
Carry cope to floor & close	19.0	
Clamp mould	10.2	
Vent under mould	12.9	
Return to drag mfc.	4.5	
	530.9	

27/6

Std. 46.60 per day.

Pouring 4/- per 100

Blank Ltd.
Flywheel BB1063.
One in 25" x 18" x 6" x 6" J.R.O.

Est. 12406
Wt. 30 lbs 12 ozs.

Drag Operator		Cope Operator.	
Roll mfc. over.	12.0	Roll mfc. over	12.0.
Clean drag patts.	20.0	Clean cope patts.	20.0.
Dust Parting drag.	4.5	Dust Parting cope	4.5
Clean & put drag box on.	25.0	Cope box on (clean)	25.0
Sieve facing sand on	55.0.	Sieve on cope.	55.0
Fill in 4	14.1	Fill in 4	14.1
Ram sides drag	20.0.	Ram sides cope.	20.0
Sand frame on drag	4.6	Sand frame on cope	4.6
Fill in 7 shovelsful	21.6	Fill in 7 shovelsful	21.6
Jar ram mould	20.0.	Jar ram mould	20.0
Remove sand frame	4.1	Remove sand frame	4.1
Flat ram drag.	28.0	Flat ram cope	28.0
Strickle off drag	12.7	Strickle off cope	12.7
Make bed & return	26.2	Vent cope mould	20.0
Vent drag mould	20.0	Cut 2 sprues.	19.0
Put Roll over board on.	6.0.	Cut 2 Basins	26.6
Clamp mould & patts	10.0	Put R.O. board on	6.0.
Roll mould over	12.0.	Clamp mould & patts	10.0
Raise drag patterns.	15.0	Roll mould over	12.0
Walk cope & lift cope	10.0	Raise cope patts.	15.0
Lift drag & carry to floor	18.2	Lift cope mould.	10.0
Set one Core	5.1	Walk drag & carry	20.2
Clean drag mould	11.6	Return to cope	4.5.
Vent under mould	12.9	Make 1 Vent	5.0
Return to cope	4.5	Clean cope	43.5
Carry cope & close	19.0	Carry cope & close	19.0
Clamp mould	10.2	Clamp mould	10.2
Return	4.5	Return	4.5
	428.8		467.8

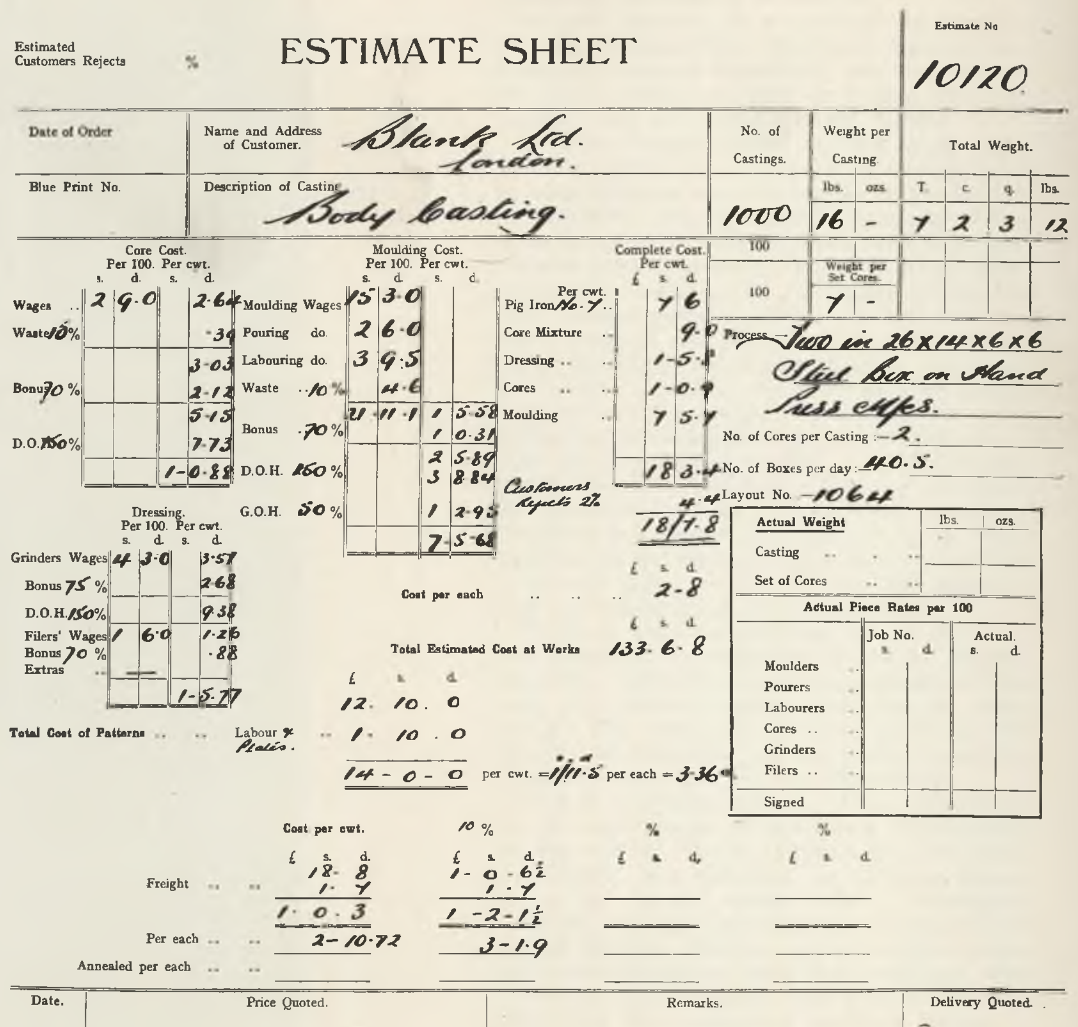
19/3 per 100 casts per operator

= 38/6 per 100 casts Std 55.41 per day.

Man alone with another operator lifting when necessary would be

36/10 per 100 casts Std 27.9 per day

Fig. 2.—Three Preliminary Estimates showing Alternative Methods of Production.



Estimated Customers Rejects %

ESTIMATE SHEET

Estimate No 10120

Date of Order	Name and Address of Customer. Blank Ltd. London.	No. of Castings.	Weight per Casting		Total Weight.			
Blue Print No.	Description of Casting Body Casting.		lbs.	ozs.	T.	c.	q.	lbs.
		1000	16	-	7	2	3	12
		100	Weight per Set Cores.					
		100	7	-				

Core Cost. Per 100. Per cwt. s. d. s. d.

	Per 100	Per cwt.
Wages	2 9.0	2.64
Waste 10%		.39
		3.03
Bonus 70%		2.12
		5.15
D.O.H. 150%		7.73
		1-0.88

Moulding Cost. Per 100. Per cwt. s. d. s. d.

	Per 100	Per cwt.
Moulding Wages	15 3.0	
Pouring do.	2 6.0	
Labouring do.	3 9.5	
Waste 10%	4.6	
	21 11.1	1 5.58
Bonus 70%		1 0.31
		2 5.89
D.O.H. 150%		3 8.84
G.O.H. 50%		1 2.93
		7 5.68

Complete Cost. Per cwt. £ s. d.

Pig Iron No. 7	7 6
Core Mixture	9.0
Dressing	1-5.8
Cores	1-0.9
Moulding	7 5.7
	18 3.4
Customers Rejects 2%	4.4
	18/7.8

Process—Two in 26 x 14 x 6 x 6 Steel Box on Hand Press M/cs.

No. of Cores per Casting:—2.

No. of Boxes per day:—40.5.

Layout No.—1064

Dressing. Per 100. Per cwt. s. d. s. d.

	Per 100	Per cwt.
Grinders Wages	4 3.0	3.57
Bonus 75%		2.68
D.O.H. 150%		9.38
Filers' Wages	1 6.0	1.26
Bonus 70%		.88
Extras	—	
		1-5.77

Cost per each £ s. d. 2-8

Total Estimated Cost at Works £ s. d. 133. 6. 8

	£	s.	d.
Total Cost of Patterns	12.	10.	0
Labour & Plates.	1.	10.	0
	14	0	0

per cwt. = 1/11.5 per each = 3.36d.

Actual Weight	lbs.	ozs.
Casting		
Set of Cores		

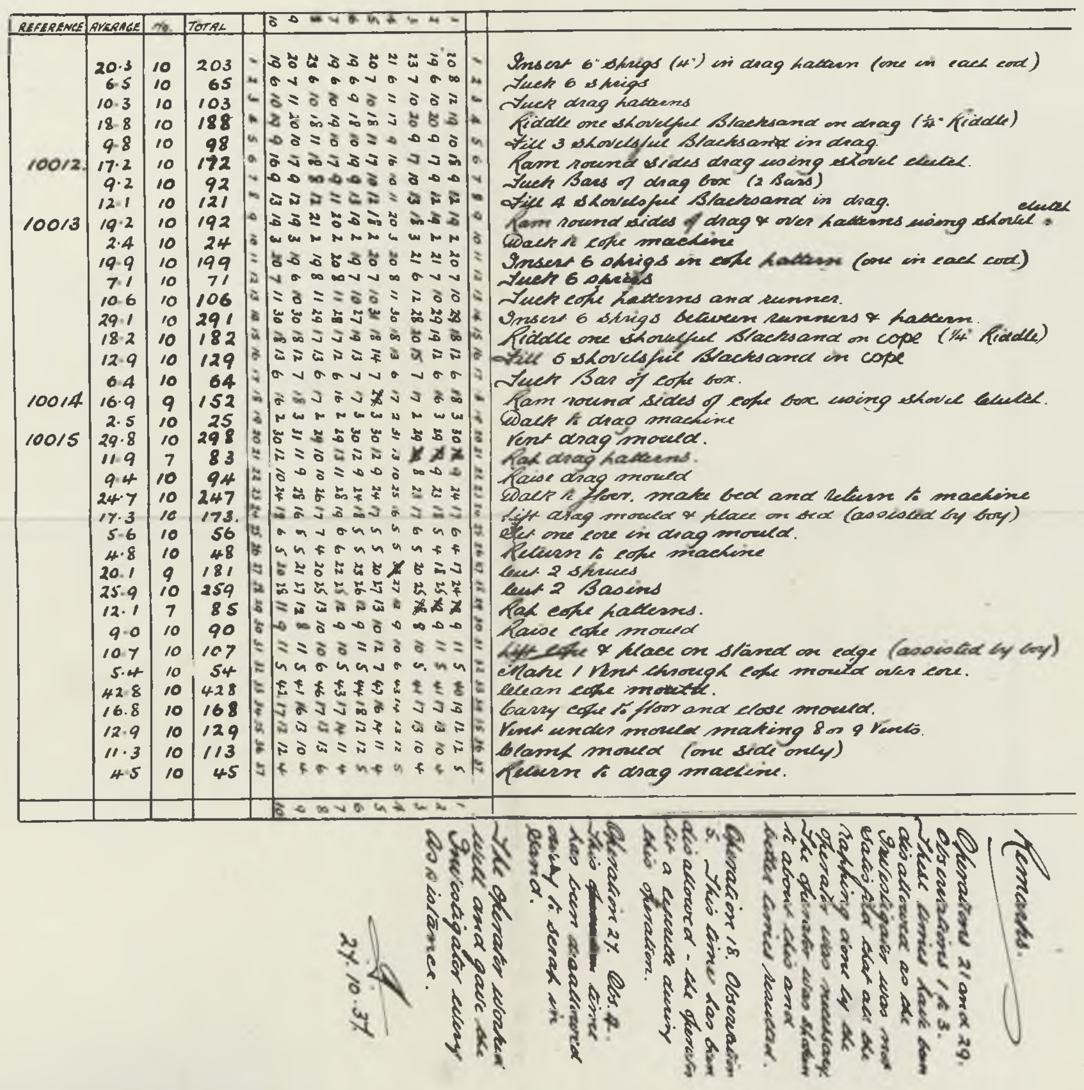
Actual Piece Rates per 100

	Job No. s. d.	Actual. s. d.
Moulders		
Pourers		
Labourers		
Cores		
Grinders		
Filers		
Signed		

	Cost per cwt. £ s. d.	10 % £ s. d.	% £ s. d.	% £ s. d.
Freight	18. 8 1. 7	1-0-6½ 1.7		
	1. 0. 3	1-2-1½		
Per each	2-10.72	3-1.9		
Annealed per each				

Date.	Price Quoted.	Remarks.	Delivery Quoted.

Fig. 3.—Specimen of Estimate Sheet.



Reference	Average	No.	Total		Operation
	20.3	10	203	1	Insert 6" sprigs (4") in drag pattern (one in each cod)
	6.5	10	65	2	Tuck 6 sprigs
	10.3	10	103	3	Tuck drag patterns
	18.8	10	188	4	Riddle one shovelful Blacksand on drag (¼" Riddle)
	9.8	10	98	5	Fill 3 shovelsful Blacksand in drag.
10012	17.2	10	172	6	Ram round sides drag using shovel clutch.
	9.2	10	92	7	Tuck Bars of drag box (2 Bars)
	12.1	10	121	8	Fill 4 shovelsful Blacksand in drag.
10013	19.2	10	192	9	Ram round sides of drag & over patterns using shovel clutch
	2.4	10	24	10	Walk to cope machine
	19.9	10	199	11	Insert 6 sprigs in cope pattern (one in each cod)
	7.1	10	71	12	Tuck 6 sprigs
	10.6	10	106	13	Tuck cope patterns and runner.
	29.1	10	291	14	Insert 6 sprigs between runners & pattern.
	18.2	10	182	15	Riddle one shovelful Blacksand on cope (¼" Riddle)
	12.9	10	129	16	Fill 6 shovelsful Blacksand in cope
	6.4	10	64	17	Tuck Bar of cope box.
10014	16.9	9	152	18	Ram round sides of cope box using shovel clutch.
	2.5	10	25	19	Walk to drag machine
10015	29.8	10	298	20	Vent drag mould.
	11.9	7	83	21	Rap drag patterns.
	9.4	10	94	22	Raise drag mould
	24.7	10	247	23	Walk to floor, make bed and return to machine
	17.3	10	173.	24	Lift drag mould & place on bed (assisted by boy)
	5.6	10	56	25	Set one core in drag mould.
	4.8	10	48	26	Return to cope machine
	20.1	9	181	27	Cut 2 sprues
	25.9	10	259	28	Cut 2 Basins
	12.1	7	85	29	Rap cope patterns.
	9.0	10	90	30	Raise cope mould
	10.7	10	107	31	Lift cope & place on stand on edge (assisted by boy)
	5.4	10	54	32	Make 1 Vent through cope mould over core.
	42.8	10	428	33	Clean cope mould.
	16.8	10	168	34	Carry cope to floor and close mould.
	12.9	10	129	35	Vent under mould making 8 or 9 Vents.
	11.3	10	113	36	Clamp mould (one side only)
	4.5	10	45	37	Return to drag machine.

Remarks.

Operations 21 and 29. Observations 1 to 3. These times have been disallowed as the Investigator was not satisfied that all the rapping done by the operator was necessary. The operator was spoken to about this and better times resulted.

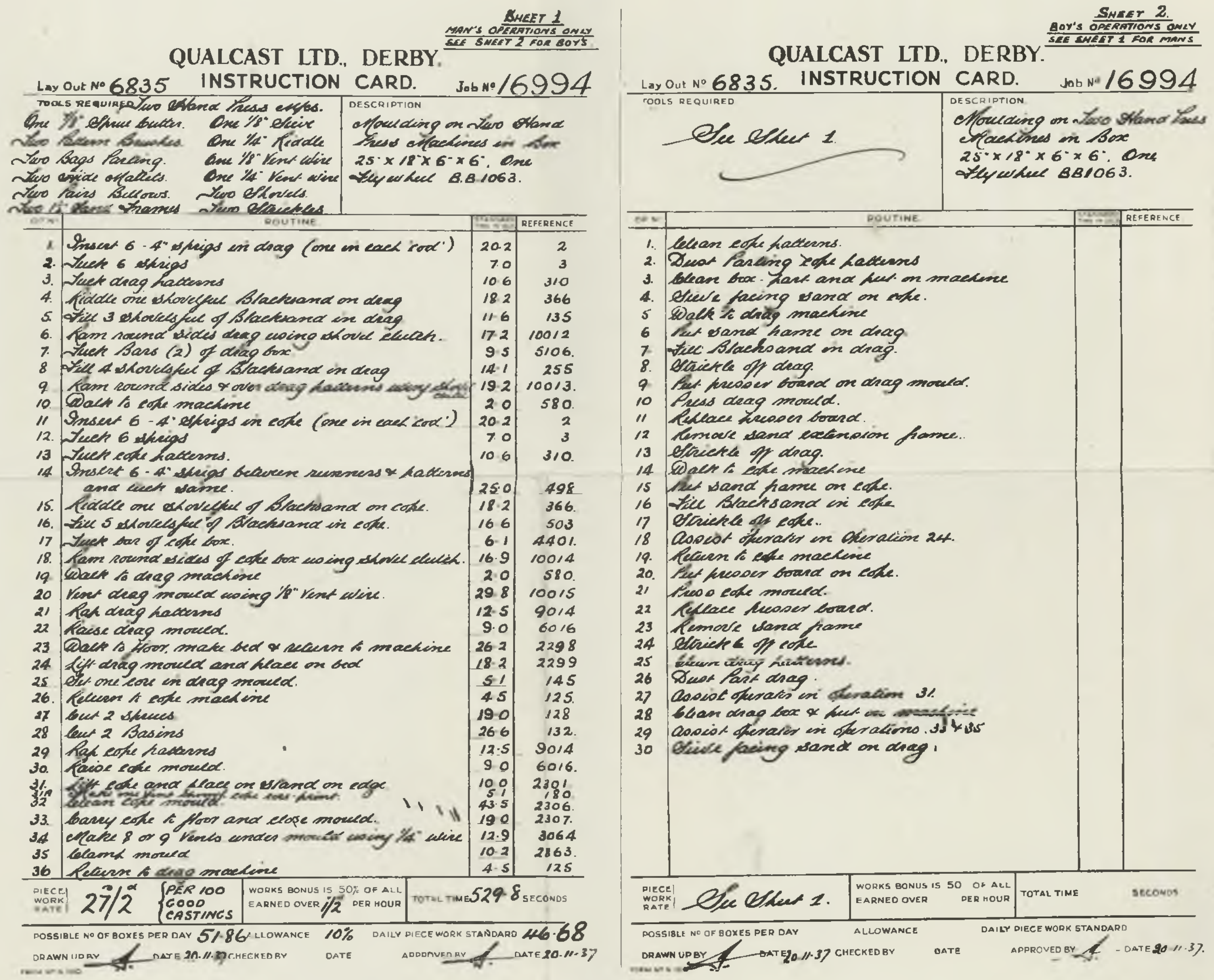
Operation 18. Observation 5. This time has been disallowed - the operator lit a cigarette during this operation.

Operation 27. Obs. 8. This time has been disallowed owing to scrap in sand.

The operator worked well and gave the Investigator every assistance.

27.10.37

Fig. 5.—Specimen Analysis Sheet, showing Method of Tabulating Time Study.



Sheet 1
Man's operations only
See sheet 2 for boys

QUALCAST LTD., DERBY.
INSTRUCTION CARD.

Lay Out No 6835 Job No 16994

Tools Required Two Hand Press M/cs.
One ⅞" Sprue Cutter. One ⅛" Sieve
Two Pattern Brushes One ¼" Riddle
Two Bags Parting. One ⅛" Vent wire
Two Side Mallets. One ¼" Vent wire
Two Pairs Bellows. Two Shovels.
Two [illegible] Frames Two Strickles

Description Moulding on Two Hand Press Machines in Box 25" x 18" x 6" x 6". One Flywheel B.B.1063.

Op. No.	Routine	Standard	Reference
1.	Insert 6 - 4" sprigs in drag (one in each 'cod')	20.2	2
2.	Tuck 6 sprigs	7.0	3
3.	Tuck drag patterns	10.6	310
4.	Riddle one shovelful Blacksand on drag	18.2	366
5.	Fill 3 shovelsful of Blacksand in drag	11.6	135
6.	Ram round sides drag using shovel clutch.	17.2	10012
7.	Tuck Bars (2) of drag box	9.5	5106.
8	Fill 4 shovelsful of Blacksand in drag	14.1	255
9.	Ram round sides & over drag patterns using shovel clutch	19.2	10013.
10.	Walk to cope machine	2.0	580.
11	Insert 6 - 4" sprigs in cope (one in each 'cod')	20.2	2
12.	Tuck 6 sprigs	7.0	3
13	Tuck cope patterns.	10.6	310.
14	Insert 6 - 4" sprigs between runners & patterns and tuck same.	25.0	498
15.	Riddle one shovelful of Blacksand on cope.	18.2	366.
16.	Fill 5 shovelsful of Blacksand in cope.	16.6	503
17	Tuck bar of cope box.	6.1	4401.
18.	Ram round sides of cope box using shovel clutch.	16.9	10014
19	Walk to drag machine	2.0	580.
20	Vent drag mould using ⅛" Vent wire.	29.8	10015
21	Rap drag patterns	12.5	9014
22	Raise drag mould.	9.0	6016
23	Walk to floor, make bed & return to machine	26.2	2298
24	Lift drag mould and place on bed	18.2	2299
25	Set one core in drag mould.	5.1	145
26.	Return to cope machine	4.5	125.
27	Cut 2 sprues	19.0	128
28	Cut 2 Basins	26.6	132.
29	Rap cope patterns	12.5	9014
30.	Raise cope mould.	9.0	6016.
31.	Lift cope and place on stand on edge	10.0	2301
31A	Make one vent through cope over print.	5.1	180
32	Clean cope mould	43.5	2306.
33.	Carry cope to floor and close mould.	19.0	2307.
34	Make 8 or 9 Vents under mould using ¼" wire	12.9	3064
35	Clamp mould	10.2	2863.
36	Return to drag machine	4.5	125

Piece Work Rate 27/2	Per 100 Good Castings	Works bonus is 50% of all earned over 1/2 per hour	Total time 529.8 seconds

Possible No of boxes per day 51.86 Allowance 10% Daily piece work standard 46.68

Drawn up by — Date 20.11.37 Checked by Date Approved by — Date 20.11.37

Sheet 2.
Boy's operations only
See sheet 1 for mans

QUALCAST LTD., DERBY.
INSTRUCTION CARD.

Lay Out No 6835. Job No 16994

Tools Required See Sheet 1.

Description Moulding on Two Hand Press Machines in Box 25" x 18" x 6" x 6". One Flywheel BB1063.

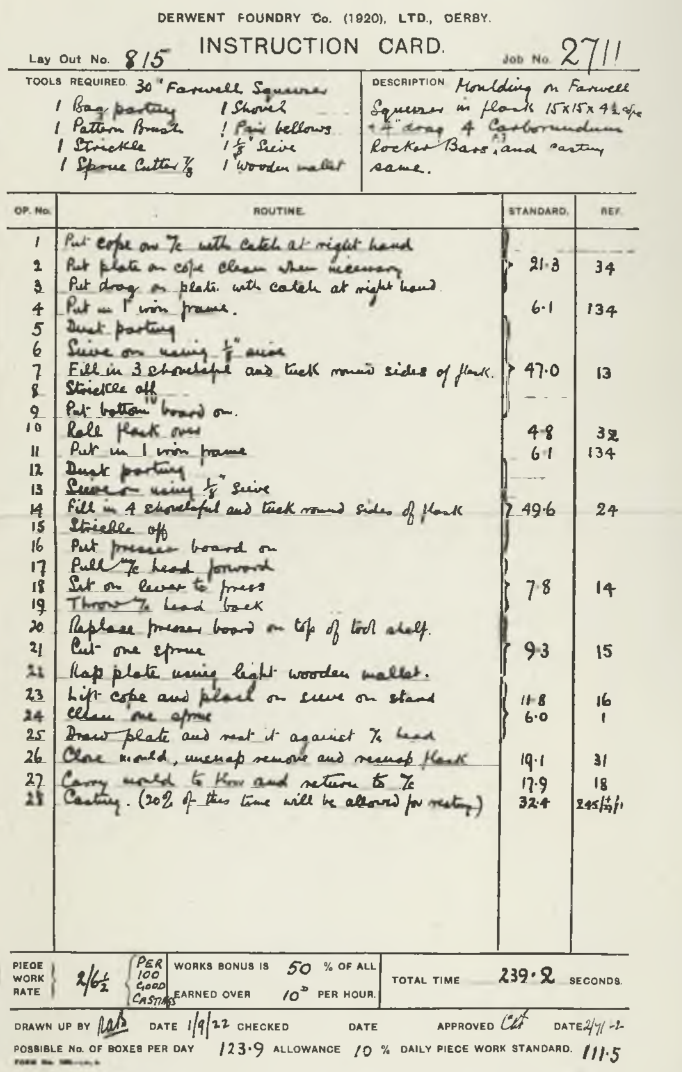
Op. No.	Routine	Standard	Reference
1.	Clean cope patterns.		
2.	Dust Parting cope patterns		
3.	Clean box - Part and put on machine		
4.	Sieve facing sand on cope.		
5	Walk to drag machine		
6	Put sand frame on drag		
7	Fill Blacksand in drag.		
8.	Strickle off drag.		
9	Put presser board on drag mould.		
10	Press drag mould.		
11	Replace presser board.		
12	Remove sand extension frame.		
13	Strickle off drag.		
14	Walk to cope machine		
15	Put sand frame on cope.		
16	Fill Blacksand in cope.		
17	Strickle off cope.		
18	Assist operator in Operation 24.		
19.	Return to cope machine		
20.	Put presser board on cope.		
21	Press cope mould.		
22	Replace presser board.		
23	Remove sand frame		
24	Strickle off cope		
25	Clean drag patterns.		
26	Dust Part drag.		
27	Assist operator in Operation 31.		
28	Clean drag box & put on machine		
29	Assist operator in operations 33 & 35		
30	Sieve facing sand on drag.		

Piece Work Rate See Sheet 1.		Works bonus is 50 of all earned over per hour	Total time seconds

Possible No of boxes per day Allowance Daily piece work standard

Drawn up by — Date 20.11.37 Checked by Date Approved by — Date 20.11.37.

Fig. 6.—Dual Instruction Card covering One Man and a Boy.



DERWENT FOUNDRY Co. (1920), LTD., DERBY.
INSTRUCTION CARD.

Lay Out No. 815 Job No. 2711

Tools Required. 30" Farwell Squeezer
1 Bag parting 1 Shovel
1 Pattern Brush 1 Pair bellows
1 Strickle 1 ⅛" Sieve
1 Sprue Cutter ⅞ 1 wooden mallet

Description Moulding on Farwell Squeezer in flask 15 x 15 x 4½ cope + 4" drag 4 Carborundum Rocker Bars, and casting same.

Op. No.	Routine	Standard.	Ref.
1	Put cope on M/c with catch at right hand		
2	Put plate on cope clean when necessary	21.3	34
3	Put drag on plate with catch at right hand		
4	Put on 1" iron frame.	6.1	134
5	Dust parting		
6	Sieve on using ⅛" sieve		
7	Fill in 3 shovelsful and tuck round sides of flask.	47.0	13
8	Strickle off		
9	Put bottom board on.		
10	Roll flask over	4.8	32
11	Put on 1 iron frame	6.1	134
12	Dust parting		
13	Sieve on using ⅛" sieve		
14	Fill in 4 shovelsful and tuck round sides of flask	49.6	24
15	Strickle off		
16	Put presser board on		
17	Pull M/c head forward		
18	Sit on lever to press	7.8	14
19	Throw M/c head back		
20	Replace presser board on top of tool shelf.		
21	Cut one sprue	9.3	15
22	Rap plate using light wooden mallet.		
23	Lift cope and place on sieve on stand	11.8	16
24	Clean one sprue	6.0	1
25	Draw plate and rest it against M/c head		
26	Close mould, unsnap remove and resnap flask	19.1	31
27	Carry mould to floor and return to M/c	17.9	18
28	Casting. (20% of this time will be allowed for resting)	32.4	245/[illegible]

Piece Work Rate 2/6½	Per 100 Good Castings	Works bonus is 50 % of all earned over 10d per hour.	Total time 239.2 seconds.

Drawn up by [illegible] Date 1/9/22 Checked Date Approved [illegible] Date 2/7/[illegible]

Possible No. of boxes per day 123.9 Allowance 10 % Daily piece work standard. 111.5

Fig. 7.—Instruction Card Prepared in September, 1922, and recently used for a Repeat Order.

(Facing page 681).

Again, one might assume that two men with two power machines would give vastly improved production over either of the other two methods. One can certainly get nine more moulds per day, but at what a cost? The piecework price is high, on account of being based on high day-work rates, the machine rates per hour would also be high, and the ultimate price of the castings would probably be out of proportion to their value, at any rate too high to give a chance of getting an order for them.

Having obtained the foundry manager's signature for acceptance of the layout of the job, the inquiry, drawing, estimate sheet and layout sheet go to the time and motion study department, where the labour costs for all operations except patternmaking are calculated and put on the estimate sheet.

In this department a survey of the job is made and the operations considered necessary for doing the work are tabulated. Doubt sometimes arises, of course, as to whether some specific operation is necessary, and in such a case queries are sent or stated to the foundry manager, who decides whether or not he wishes to include the particular operation in question. For instance, the man who is estimating may be uncertain as to whether a mould should be vented or not, or whether a sprue should be cut or rammed up; these are only minor points probably, but if not cleared up and settled, they leave doubts as to procedure if the order comes along at a later date. Having decided on the necessary operations, times are allocated to each one from the time and motion study records. Standard times may not be available for every operation, but usually, even on non-standard operations, some comparable records for similar work can be turned up. The job is then investigated to see what labour is most economical, *i.e.*, a man only, a man and boy, or a man and two boys, and so on, the decision being influenced to a large extent by the number of, and rates for, skilled and unskilled operations on the job. When this has been done the actual time per mould is obtained, and the costs per casting or per 100 castings are calculated and recorded on the estimate sheet.

The chief chemist gives information regarding the metal to be used.

The patternshop at this stage do their estimating, and it will be realised that as the method of production is definitely laid down on the layout sheet, the patternshop know exactly how the pattern plant is to be prepared. Thus variables in this direction are eliminated.

Passing from the patternshop to the costs department, where the overheads, freights, etc., are given, the inquiry finally is returned to the sales department with the complete estimate. All this sounds as though the estimating will take an alarming length of time, and the chance of getting an order is lost before the quotation is ready, but such is not the case, for with very few exceptions the quotations are posted within scheduled time.

Fig. 3 shows an estimate sheet specimen, which is almost self-explanatory. Spaces are provided for actual production figures to be inserted immediately the piecework rates are fixed, thus giving the sales office comparative figures whilst the job is in production.

This is a hurried survey of the process of estimating, and it will probably be agreed that variables are almost eliminated because the majority of the labour figures placed on the estimate sheet represent standard time allowances for the operations. The fact that the labour costs are analysed to such fine limits as quoting the number of shovels full of sand required per mould and how many seconds it will take to handle that sand, other operations being covered in the same manner, assures that variables cannot easily find a way in at the estimating stage.

The only serious variable that exists is the choice of the method of making the job, but even in this, as already stated, when doubts and differences of opinion do arise, trial estimates are taken out to satisfy all concerned that the most economical and efficient method of manufacture is adopted from the various suggestions under consideration.

Dealing with Orders

Passing from estimating to the receipt of an order, the sales department issue to the works the necessary order-sheets, each pattern being given a separate works order number, which is used throughout the works and offices for booking and costing purposes. The layout sheet which was filed when the estimate was completed is now issued to the patternshop, and must be regarded as a direct and definite indication as to procedure in the pattern-plant preparation and moulding methods. The patternshop in due course issue the pattern plant to the foundry.

When a new job is going into production, the information is passed on to the foundry manager and the time and motion study department from the planning or progress department, who schedule the work in the foundry some days in advance. It is the duty of the time and motion study department to advise the foundry manager (or one of his assistants) what labour is required for the particular job, and whether the layout calls for one man only, one man and one boy, two men, and so on. Thus the foundry foremen, in conjunction with the progress department, can allocate their labour for any job, before the actual day on which it goes into production. As soon as the job is in work, an investigator from the time and motion study department goes into the shops to make a survey to ensure that all tools, etc., which are known to be necessary, are available, and easily accessible to the operators, in order to eliminate any waste of time or energy on their part whilst they are at work.

The investigator then discusses the various operations with the manager or foreman and the operators, with a view to eliminating unnecessary work, and trials are carried out to prove that, by the methods adopted, satisfactory moulds can be made from the pattern plant in use. The investigator now makes a more detailed motion study whilst the work is going on, and allocates the less skilled operations to the assistant operator (except, of course, in cases where one man is making complete moulds) in such a manner as to synchronise the movements on cope and drag parts.

This is not exactly a matter of trial and error, as the data in the files of the time and motion study department give sufficient information to control these allocations, but it is to the advantage of the operators and the investigator to prove the allocations, and adjust them where advisable on every job, because where two or more operators are working together, they must attain a balance of movement which amounts to rhythm and results in 100 per cent. efficiency

From the time the job is put into production until this stage is reached, the vital work of the investigator is carried out, and in the majority of cases it occupies far longer than the actual time study. When the operators have settled down and are working smoothly, the investigator proceeds with the time study.

Time Study in Progress

To imagine that the investigator from the time and motion study department has a policeman's sort of job is erroneous. This investigator has, by means of the motion study, made an endeavour to help the workman to make moulds off the pattern plant by a series of operations which should be carried out with rhythm and the minimum of expended energy. It is by time study and observation, during actual production, that proof can be obtained as to whether or not the results of the motion study are satisfactory. Of course, it is essential to record the time taken, in order to fix piecework prices.

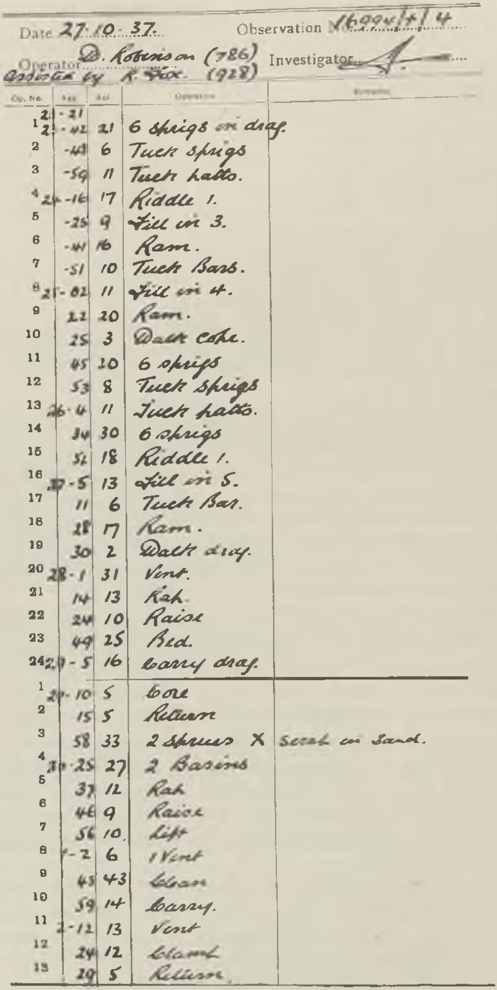
Specimen Observation Sheet

Fig. 4 shows a specimen of the observation sheets on which the investigator makes a record of the time study. In this case the study on a particular mould commenced at 23 min. 21 sec., the mould being completed at 32 min. 29 sec., and it will be seen that the investigator has accounted for every second of the time between these figures. Each operation is clearly picked out and the actual time taken to complete it is recorded. Even at this stage the operator may be doing some unnecessary work and wasting energy, and should be corrected.

For instance, the pattern plate must be rapped with a mallet on completion of the ramming and before the flask or box is lifted, in order to facilitate an easy draw or lift. Years of experience and innumerable time studies have shown that a certain type of plate requires 12 to 13 sec. total time for this operation, including picking up and putting down the mallet. If that has been proved satisfactory, why waste energy by rapping the plate for a longer period? The time study will result in guidance for the operator in this and other directions.

Further than this, the investigator will take care that there is a convenient spot on which to put the mallet without causing the operator to reach over or bend down in the operation, or find it necessary to make awkward movements which take the rhythm out of the sequence of operations. This is observation No. 4, and on operation No. 27 an abnormal time is recorded. This point should be noted, as it will be referred to in Fig. 5. The total number of operations on this mould is 37.

The actual number of observations made for each time study (*i.e.*, the total number of moulds on which time is taken) is at the discretion of the investigator, and depends to a large extent on the nature of the job and on the comparable data in existence. For instance, the whole of the operations on some moulds would be standard for the particular size of moulding boxes in use, and in consequence the investigator



Date 27·10·37.   Observation No. 16994/4/4

Operator D. Robinson (786)   Investigator

Assisted by R. Fox. (928)

Op. No.	Agg.	Act.	Operation	Remarks
1	23-21 23-42	21	6 sprigs on drag.	
2	-48	6	Tuck sprigs	
3	-59	11	Tuck hatts.	
4	24-16	17	Riddle 1.	
5	-25	9	Fill in 3.	
6	-41	16	Ram.	
7	-51	10	Tuck Bars.	
8	25-02	11	Fill in 4.	
9	22	20	Ram.	
10	25	3	Dash coke.	
11	45	20	6 sprigs	
12	53	8	Tuck sprigs	
13	26-4	11	Tuck hatts.	
14	34	30	6 sprigs	
15	52	18	Riddle 1.	
16	27-5	13	Fill in 5.	
17	11	6	Tuck Bar.	
18	28	17	Ram.	
19	30	2	Walk drag.	
20	28-1	31	Vent.	
21	14	13	Rap.	
22	24	10	Raise	
23	49	25	Bed.	
24	29-5	16	Carry drag.	
1	29-10	5	Core	
2	15	5	Return	
3	58	33	2 Sprues X	Scrap in Sand.
4	30-25	27	2 Basins	
5	37	12	Rap	
6	46	9	Raise	
7	56	10	Lift	
8	31-2	6	1 Vent	
9	45	43	Clean	
10	59	14	Carry.	
11	32-12	13	Vent	
12	24	12	Clamp	
13	29	5	Return.	

FIG. 4.—SPECIMEN TIME-STUDY OBSERVATION SHEET.

would not find it necessary to extend his time study.

On the other hand, there are new jobs on which the operations are not all standard, and the investigator must take time studies over an extended period of production, in order to arrive at a satisfactory time for the non-standard operations. It will be understood that some jobs call for more sand tucking than others, some need more facing sand, and so on. Thus, the standard time allowed for such operations will vary on different types of moulds, despite the fact that the same size of moulding boxes is used.

Whilst the time study is proceeding, the operators carry on in the usual manner of production, and the investigator notes incidental happenings, such as cigarette lighting, talking to workmates, or maybe the removal of pieces of metal scrap from the backing sand, etc., which cause varying times to be recorded against certain operations in succeeding observations.

Analysis Sheet

Fig. 5 shows a specimen analysis sheet, and indicates the method of tabulating the time study figures. On completion of the time study on a job, the figures are copied on this sheet from the observation sheets, and the actual time against each operation, on each succeeding mould, is shown in columns, with a view to working out the average times taken.

In this case ten moulds have been made on which time study was carried out and are shown as Nos. 1 to 10. As indicated in Fig. 4, there are 37 operations in making up each mould, and these are shown as Nos. 1 to 37. The investigator makes an analysis of the figures and strikes out any abnormal time, where obviously something has happened to break the sequence of production. For instance, there is the rapping of the pattern plate, as already remarked upon. It is apparent that on the first three moulds the rapping of the plate (operations Nos. 21 and 29) took 18 to 20 seconds, but after a talk on the matter, around 12 seconds were proved to be satisfactory. On mould 5, operation 18 was struck out, as the time taken was abnormal, and on mould 4, operation 27 was also struck out.

Provided all times were considered to be normal and no striking out was necessary, the average would be taken on all ten moulds, but in cases where striking out has occurred, the average is taken on those figures which are left. In this example the average time for operations 18, 21, 27 and 29 is taken on 9, 7, 9 and 7 moulds respectively, and for the remaining 33 operations the average is taken on 10 moulds.

The average times for each operation would then be compared with existing data, and standard times allowed on standard operations, irrespective of the time taken by the operators during the time study. On non-standard operations the average time shown on the analysis sheet is allowed.

In the example given in Fig. 5 there are four non-standard operations on which non-standard times would be allowed, and they are indicated by the numbers in the left-hand column. Such non-standards are logged, filed and indexed, and may eventually become one of thousands of references which make up standards for certain operations.

The essence of this investigation and time study is the determination of how many times in a working day an operator can repeat a certain process (for example, making moulds or cores, or the process of grinding castings, etc.), providing he or she has every facility offered in respect of tools, equipment and materials, and the work is so organised as to prevent unnecessary waste of energy.

When that determination has been made, it is regarded as the possible daily standard of production, but it is appreciated and acknowledged that incidental delays, which interfere with continuous work, must be allowed for in the determination of the accepted standard output. Therefore, an allowance of 10 per cent. is made off the possible standard, which gives the piecework standard, on which the piecework rates are calculated. Thus, if the possible standard is 100 per day, the actual standard on which all calculations are based for piecework prices and bonus would be 90 per day, and 90 per day or more is what is expected from the operator.

Instruction Cards

Piecework rates are now worked out, and the investigator makes out an instruction card, shown in Fig. 6. This is a typical card (or in this case a dual card) covering one man and one boy working on two hand-press moulding machines. As much detail as can be put into writing is shown on these cards.

In the first place, the tools to be supplied to the operators are enumerated, and the type of moulding machine, size of boxes, etc., are shown. Details are also given of the piecework price, the bonus to be paid, total time per box, possible standard, percentage allowances for eventualities, and the daily piecework standards. The whole of the operations which were recorded during the time study, and the standard time for each of those operations, are given, and in the right-hand column is the index number of the reference card which gives the standard for that particular operation.

The operators may at any time ask to see those reference cards; in fact, the investigators are always ready to turn up references and confirm any figures regarding time allowances, in order to satisfy the operators that the piecework prices are based on facts, as they are represented by figures in the files of the time and motion study department.

A copy of the instruction card for any process on which they are working is available for the operators, and they may have one in their possession for guidance and information whilst they are on the job to which a particular card refers.

When repeat orders are received, the sales department usually call for a re-estimate of the job in order to check the price, and later issue to the works the order sheets giving all the details required for the internal booking in the works and offices.

The planning department give consideration to delivery requirements, and in due course the job is scheduled for production. The foundry manager and time and motion study department take note of this, and the latter issue a copy of the instruction card for the job to the foundry foreman, whose duty it is to see that the required tools, etc., are ready for the operators at the time the pattern actually goes into work. This instruction card, by the way, would be the original one prepared when the job first went into work, and is made up from the original time study figures.

The foreman must also satisfy himself that the operators understand the whole of the operations as laid down on the instruction card. As with a new job, so with a repeat order—the operators may at any time retain a copy of the instruction card for the work on which they may be engaged. Thus, the operators make a positive start on any job which comes in as a repeat order, whether they had actually worked on it or not when it had been in work previously.

The variables which usually creep in at the start of work on repeat orders are practically eliminated, as the instruction card and layout sheets give in minute detail all that was done previously and leave no doubt as to what labour, tools and materials are required, and with few exceptions production re-commences where it was left off on the previous order.

1922 Instruction Card

An example of actual experience is shown in Fig. 7, which is a reproduction of an original instruction card dated September, 1922, which was issued to the foundry a few weeks ago upon receipt of a repeat order. The author had seen neither the pattern plant, instruction card, nor drawing, prior to the job being scheduled for work, but with a copy of this instruction card as a guide, no difficulty in starting up the job was found, and the operator was able to exceed standard production on his first day's work, thus earning a fairly high efficiency bonus.

Fixing of Piecework Rates

Turning now to the fixing of piecework prices and payment of wages, it must be borne in mind that the management's energies should be expended on producing first-class castings at competitive prices. Whatever the system of control, that object will not be achieved unless the operators are satisfied, and the most appealing factor in this direction is to offer every opportunity for them to earn good wages.

Some workers are satisfied with earnings somewhat in keeping with the standard day rate, and show no ambition to earn more, and although their low production may not reach such a point that the overhead charges on the unit being produced are not covered, the minor absorption of the overheads by virtue of low output will have an adverse effect on the profit and loss account. On the other hand, there are workers who will get the maximum production and consequently absorb or over-absorb the estimated overheads. Thus the ideal system of payment is one which makes it necessary for the average workers to maintain a certain output or suffer a corresponding reduction in earnings, and at the same time increases the opportunities of the faster workers to reap a full reward for their efforts.

A differential system of payment was adopted many years ago, and put into operation for this purpose. In this system of payment the operators are given piecework rates of so much per article or so much per 100 articles, plus a percentage bonus of all earned over a certain sum per hour.

For example, if an operator's basic rate is 1s. per hour, the basic piecework rate is based on that figure plus 33⅓ per cent.; thus the basic piecework rate would be equal to 1s. 4d. per hour, and in such a case an efficiency bonus of, say, 50 per cent. of all earnings over approximately 1s. per hour would be paid. In the fixing of the basic piecework rate, every encouragement is given to the operators by the liberal interpretation of the usual trade agreements which are to the effect "that piecework prices should be fixed to allow operators of average ability to earn day rate plus 25 per cent."

In addition to the liberal interpretation of this by giving a high piecework rate, there is the added incentive of the efficiency bonus, which is paid on earnings exceeding a sum approximately equal to day work.

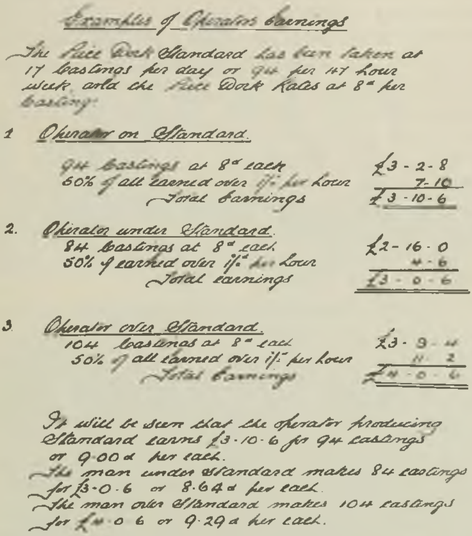
Piecework Earnings

Fig. 8 illustrates what is meant by differential payment of wages, and shows by comparison the advantage derived when an operator maintains or exceeds standard output. In these examples 94 castings represent standard output in a week of 47 hours, *i.e.*, one casting per half-hour. The piecework price is based on day rate of 1s. per hour; therefore the piecework price per casting is 8d., equal to 1s. 4d. per hour. From the figures given it is seen that an operator working exactly to standard earns a bonus of 7s. 10d. in 47 hours, and the total wages earned are equivalent to 9d. each for the 94 castings.

The second set of figures shows the results of an operator working under standard to the extent of 10 castings per week. He earns a bonus of 4s. 6d. and the price per casting is down to 8.64d. for the 84 castings produced.

The third example shows an operator's earnings on 104 castings, or 10 over standard in the week. In this case the bonus earned is 11s. 2d., and the price per casting is lifted up to 9.29d.

each for 104 produced. Therefore, there is every incentive for the operators to maintain or exceed standard, because with each succeeding casting made there is the knowledge that the price is increased on those already made during the current working week.



Examples of Operators Earnings

The Piece Work Standard has been taken at 17 castings per day or 94 per 47 hour week and the Piece Work Rates at 8d per casting.

1 Operator on Standard.

94 castings at 8d each	£3-2-8
50% of all earned over 1/- per hour	7-10
Total Earnings	£3-10-6

2. Operator under Standard.

84 castings at 8d each	£2-16-0
50% of earned over 1/- per hour	4-6
Total earnings	£3-0-6

3. Operator over Standard.

104 castings at 8d each	£3-9-4
50% of all earned over 1/- per hour	11-2
Total Earnings	£4-0-6

It will be seen that the operator producing Standard earns £3-10-6 for 94 castings or 9·00d per each.
The man under Standard makes 84 castings for £3-0-6 or 8·64d per each.
The man over Standard makes 104 castings for £4-0-6 or 9·29d per each.

Fig. 8.—Example of Differential Payment of Wages.

Underlying Principles

There are no printed rules and regulations posted about the works concerning the working of the scheme; the necessity for this course to be adopted has never occurred, as both sides work to the spirit of the arrangement with apparent satisfaction.

There is one unwritten law, however, which is strictly adhered to and observed to the letter. It is that, once a piecework price is fixed, it must remain unaltered, unless the pattern plant is modified, or an alternative method of production is adopted.

Naturally, there are times when changes in the method of running or feeding, or other alterations, are considered advisable after a pattern has gone into production, and in such cases the foundry manager discusses the matter with the time and motion study department, who prepare a new estimate covering the suggested alteration to procedure. Providing the modification does not increase the cost of production, all is well, and the people concerned are notified of the change; if the modification increases production cost, however, the foundry manager must decide whether the contemplated improvement of the castings, or saving in rejects, is sufficient to justify the suggested modification to procedure.

If he considers it policy to make the alteration despite the added cost, the necessary retiming of the job is carried out by the investigators from the time and motion study department, the piecework prices are adjusted, and all record cards are amended to the new figures.

The stage has now been reached where a job is in production, satisfactory prices have been fixed, and the investigators have checked every operation, second for second against estimate, to prove that actual labour cost does not exceed the estimated cost on each separate operation. If it should happen that there is a discrepancy in any one operation, the costs department, with all the facts laid before them by the time and motion study department, prepare a cost per unit, and the foundry manager is advised as to what extent the production cost is affected. At the same time it is the duty of the investigator, and in the interests of the foundry manager, to investigate the circumstances and reorganise the labour and the use of materials if at all practicable, to bring the cost within estimate figures. The positive nature of the figures presented by the investigator leaves no doubt as to whether production costs are on the right side or not, and also leaves no doubt that the overheads on any particular unit will be absorbed, provided the standard output is maintained.

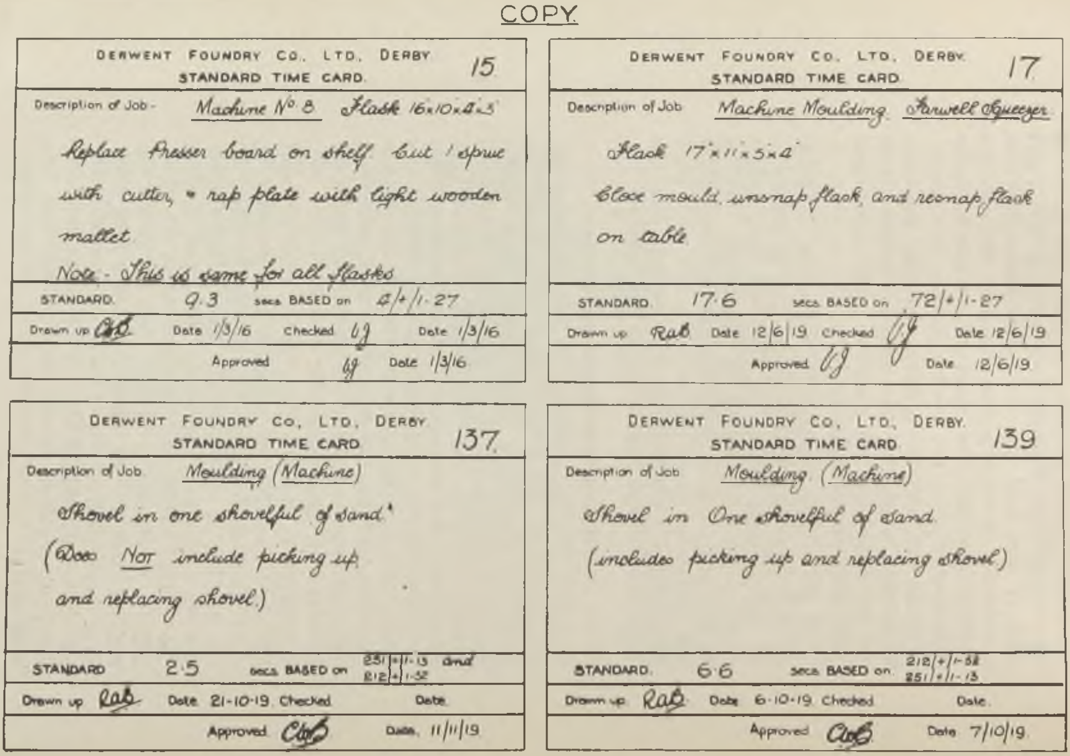
These are, in the author's opinion, the most important phases of the system, because it is at this stage that one wants to know how actual costs and estimates compare.

To make any attempt in the space available to show reproductions of each type of reference or index cards in use by the time and motion study department would be impossible. But it is desirable to give sufficient evidence to justify the statement that the investigators give positive figures when estimating or setting standard times for various operations in the foundry.

1916 and 1919 Reference Cards

Fig. 9 is a reproduction of four standard reference cards which have been in constant use since the respective dates shown upon them; they are representative of thousands of such reference cards in the files, which comprise that centralised and permanently-recorded knowledge to which reference was made earlier. Taking the oldest card reproduced on Fig. 9, it is shown that this standard was established in 1916, and it is referred to to-day as the recognised and accepted standard for that particular operation.

Looking at the two lower cards, Nos. 137 and 139, is it possible to estimate the quantity of sand that has been handled in this foundry, or the number of operators who have lifted shovels for the purpose of shovelling that sand, during the period which has elapsed since October, 1919? Obviously it is not, but it should be realised that all the wages for doing that work have been paid at the rate of 6.6 seconds for one shovelful, and 2.5 seconds for each remaining shovelful required to fill each mould that has been made.



COPY.

DERWENT FOUNDRY CO. LTD. DERBY. 15
STANDARD TIME CARD.

Description of Job - Machine No. 8 Flask 16×10×4×3
Replace Presser board on shelf Cut 1 sprue with cutter, + rap plate with light wooden mallet
Note - This is same for all flasks

STANDARD. 9·3 secs BASED on 4/+/1·27
Drawn up Cab Date 1/3/16 Checked CJ Date 1/3/16
Approved CJ Date 1/3/16

DERWENT FOUNDRY CO. LTD. DERBY. 17
STANDARD TIME CARD

Description of Job Machine Moulding Farwell Squeezer
Flask 17"×11×5×4"
Close mould, unsnap flask, and resnap flask on table

STANDARD. 17·6 secs BASED on 72/+/1-27
Drawn up Rab Date 12/6/19 Checked CJ Date 12/6/19
Approved CJ Date 12/6/19

DERWENT FOUNDRY CO, LTD, DERBY. 137
STANDARD TIME CARD

Description of Job Moulding (Machine)
Shovel in one shovelful of sand
(Does Not include picking up and replacing shovel)

STANDARD 2·5 secs BASED on 251/+/1·13 and 212/+/1·32
Drawn up Rab Date 21-10-19 Checked Date
Approved Cab Date 11/11/19

DERWENT FOUNDRY CO, LTD, DERBY. 139
STANDARD TIME CARD

Description of Job Moulding (Machine)
Shovel in One shovelful of sand
(includes picking up and replacing shovel)

STANDARD. 6·6 secs BASED on 212/+/1-32 251/+/1-13
Drawn up Rab Date 6·10·19 Checked Date.
Approved Cab Date 7/10/19

FIG. 9.—STANDARD TIME CARDS PREPARED IN 1916 AND 1919.

Sand Shovelling Times

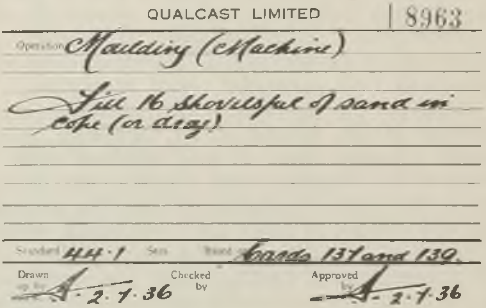
It can also be taken for granted that a number of operators have doubted these standards, and have been re-timed at their own request, but the standards set up in 1919 still stand as satisfactory to all concerned. For instance, in Fig. 10 is a reproduction of a card taken from the files at random, showing the standard for filling a moulding box with 16 shovelfuls of sand, on a job which was timed in 1936. It shows a total time of 44.1 seconds. This standard was made up from the cards 137 and 139 shown in Fig. 9; thus one shovelful at 6.6 seconds and 15 at 2.5 seconds each give a total of 44.1 seconds for the 16 shovelfuls. This example is typical of thousands of others which are governing the estimating and production costs every day.

Attention has principally been directed to the working of the scheme in the moulding shops, simply because there is not sufficient time to cover all the sections of the foundry, and moulding is the most important process. The estimating and control of costs for coremaking, knocking-out the castings, grinding and fettling, and the preparation of backing sand, are carried out by investigators on exactly the same principles, and remarks regarding procedure in time and motion study of moulding operations would apply to the other processes. Figs. 11 to 13 will serve to illustrate this point without going into too much detail.

Job Cards

Fig. 11 shows specimen job cards for the easy reference to piecework prices and standards for any particular process on any particular pattern. The job number as such on these cards is actually the reference number of the instruction cards which would be made out and issued to the works when the job was in work. Taking these cards in rotation, No. 12909 is the reference card to the moulding of the job, and 12910 the pouring of the moulds, which in this case would be done from hand ladles and not direct from the crane ladle. Nos. 12911 and 12912 cover the knocking-out of the moulds, taking the castings and scrap from the casting floor, and mixing the backing sand ready for use the next day.

Where more than one type of core is required per casting, corresponding reference cards (Fig. 12) are made out and filed. In this case four different types are used and the information regarding their production is fairly well covered by these cards. They show that seven cores in all are required for each casting off



QUALCAST LIMITED 8963

Operation Moulding (Machine)

Fill 16 shovelsful of sand in cope (or drag)

Standard 44·1 Boards 131 and 130.

Drawn up by A. 2·7·36 Checked by Approved by A. 2·7·36

Fig. 10.—Standard Time Card for Operation of Filling Moulding Box.

Pattern No. 5396B, what sand mixture is to be used, how many driers are required, the piecework prices, standards, etc.

An incidental benefit the planning department may derive from the information on these cards is indicated by reference to Card No. 12909 (Fig. 11) which showed that 35.4 castings was the daily standard output, and on the coremaking cards it is shown that the standard production of the body cores for this job is 218.6 per day, so that one day's work on these cores will give sufficient body cores for 6 days' moulding output, but one day on centre cores will not be quite sufficient for 2 days' moulding, and so on.

These and other index reference cards obviously simplify the planning of the work.

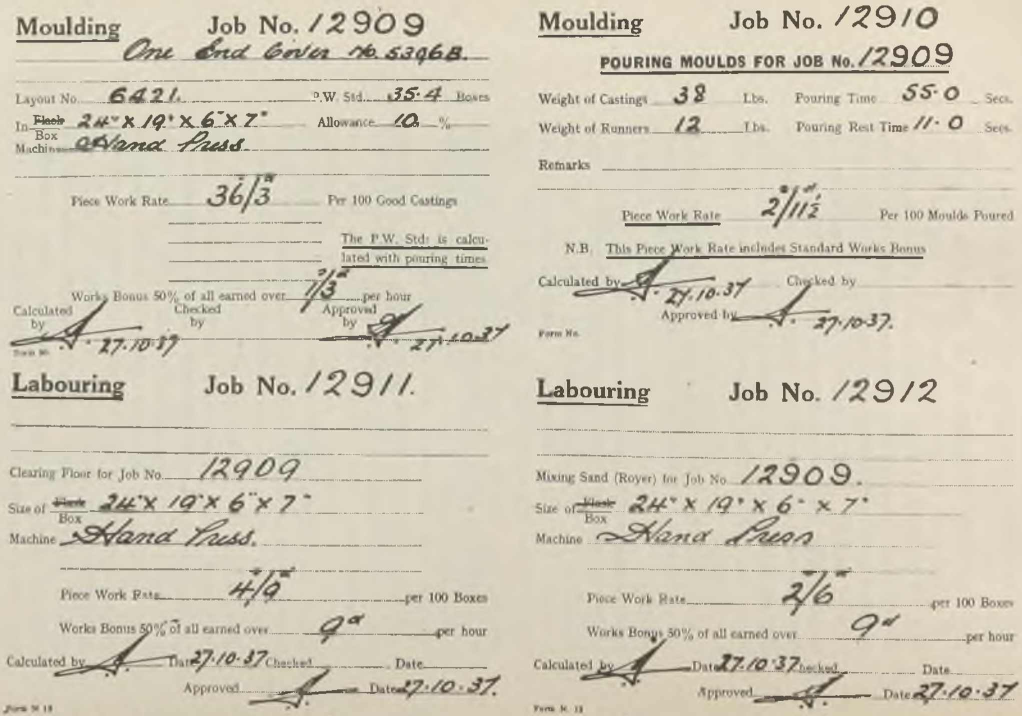
Specimen Cards for Dressing

Typical job cards are shown in Fig. 13. It will be noticed that on these, as well as on those illustrating the coremaking and moulding, is the pattern number 5396B, whilst Fig. 14 shows the master index card. Should it be necessary to re-estimate for, or seek reference to, the manufacture of castings from Pattern No. 5396B, a glance at this card shows the avenue to the cards on which the necessary information will be found.

One of the incidentals to the scheme which is worthy of mention, on account of its importance in its effect on production, is the experimental work carried out on all new jobs prior to the pattern plant being issued to the foundry. This experimental section is controlled by the foreman patternmaker, who supervises the making of trial moulds and cores, the closing of such moulds, etc., in order to eliminate such variables as core filing, bad lifts, mismatch, etc. The moulders in this section, by the way, are skilled men.

When the trial casts are made, the resultant castings are taken to marking-off tables in the patternshop, and when the samples are not correct to drawing, or are flashed, or otherwise unsatisfactory, the pattern plant is rectified or touched up where necessary. Such trials and re-trials are carried out at the discretion of the foreman patternmaker, and he does not issue the plant to the foundry until he knows it is satisfactory in all respects.

It will be appreciated that this procedure is a necessity, because the object of machine moulding, apart from speed and cheapness, is to get perfect moulds on the floor, if such are at all practicable. Much money is spent on pattern plant in order to make this possible, and any necessity for tooling on the moulds, or core filing, or rubbing, is considered bad



Moulding Job No. 12909

One End Cover No. 5396B.

Layout No. 6421. P.W. Std. 35.4 Boxes

In ~~Flask~~ Box 24" x 19" x 6" x 7" Allowance 10 %

Machine Hand Press.

Piece Work Rate 36/3 Per 100 Good Castings

The P.W. Std. is calculated with pouring times

Works Bonus 50% of all earned over 1/3 per hour

Calculated by 27.10.37 Checked by Approved by 27.10.37

Form No.

Moulding Job No. 12910

POURING MOULDS FOR JOB No. 12909

Weight of Castings 38 Lbs. Pouring Time 55.0 Secs.

Weight of Runners 12 Lbs. Pouring Rest Time 11.0 Secs.

Remarks

Piece Work Rate 2/11½ Per 100 Moulds Poured

N.B. This Piece Work Rate includes Standard Works Bonus

Calculated by 27.10.37 Checked by

Approved by 27.10.37.

Form No.

Labouring Job No. 12911.

Clearing Floor for Job No. 12909

Size of ~~Flask~~ Box 24" x 19" x 6" x 7"

Machine Hand Press.

Piece Work Rate 4/9 per 100 Boxes

Works Bonus 50% of all earned over 9d per hour

Calculated by Date 27.10.37 Checked Date

Approved Date 27.10.37.

Form N 13

Labouring Job No. 12912

Mixing Sand (Royer) for Job No. 12909.

Size of ~~Flask~~ Box 24" x 19" x 6" x 7"

Machine Hand Press

Piece Work Rate 2/6 per 100 Boxes

Works Bonus 50% of all earned over 9d per hour

Calculated by Date 27.10.37 Checked Date

Approved Date 27.10.37

Form N. 13

FIG. 11.—FOUR SPECIMEN JOB CARDS COVERING THE MOULDING, POURING, KNOCKING-OUT AND SAND MIXING FOR PATTERN NO. 5396 B.

Core-Making Job No. 25601.
Casting Blank's End boiler 5396B.
Description of Core Body core.
Plant Iron core-box. (One core per casting)
Sand Mixture No. 1.
Standard Time 125·60 Secs.
Daily Piece Work Standard 218·6 Cores
Piece Work Rate $2/3^d$ Per 100 Good Cores
Works Bonus 50% of all earned over 5^d per hour
Calculated by 26·10·37 Checked by
Approved by 26·10·37

Core-Making Job No. 25602.
Casting Blank's End boiler 5396B.
Description of Core Chamber core.
Plant Iron core-box & 20 driers
Sand Mixture No. 2A. (2 cores per casting)
Standard Time 94·05 Secs.
Daily Piece Work Standard 292·6 Cores
Piece Work Rate $1/8^d$ Per 100 Good Cores
Works Bonus 50% of all earned over 5^d per hour
Calculated by 26·10·37 Checked by
Approved by 26·10·37

Core-Making Job No. 25603.
Casting Blank's End boiler 5396B
Description of Core Centre core.
Plant Iron core-box (one core per casting)
Sand Mixture No. 2.
Standard Time 41·0 Secs.
Daily Piece Work Standard 67·2 Cores
Piece Work Rate 9^d Per 100 Good Cores
Works Bonus 50% of all earned over 5^d per hour
Calculated by 26·10·37 Checked by
Approved by 26·10·37.

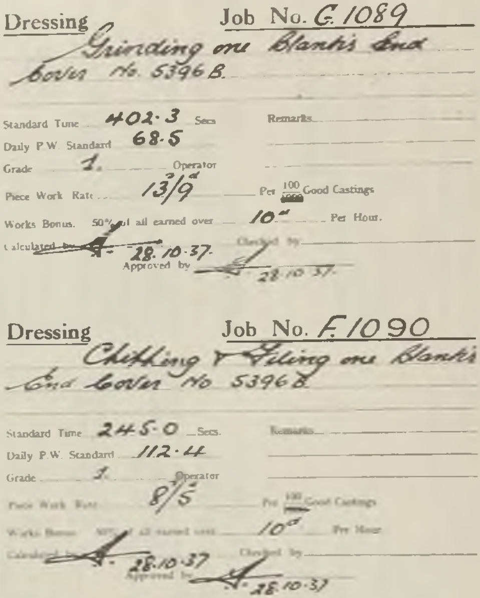
Core-Making Job No. 25604
Casting Blank's End boiler 5396B.
Description of Core Ram-up.
Plant Iron core-box to make 3 cores
Sand Mixture No. 2. (3 cores per casting)
Standard Time 50·00 Secs. per 3 cores
Daily Piece Work Standard 1653. Cores
Piece Work Rate 4^d Per 100 Good Cores
Works Bonus 50% of all earned over 5^d per hour
Calculated by 26·10·37. Checked by
Approved by 26·10·37

FIG. 12.—FOUR REFERENCE CARDS RELATING TO THE CORES REQUIRED FOR THE CASTING FROM PATTERN No. 5396 B.

practice. In fact, the time study investigators have no authority for allowing time on such operations.

Conclusion

An endeavour has been made to explain the system of control in as brief a manner as possible, without introducing too many figures. The author has tried to convey the correct atmosphere created in the foundry and to afford readers the opportunity of forming some idea, if only vaguely, of what it means to work-people and staff where such a system is employed. There are many ramifications either directly or indirectly connected with the



Dressing Job No. G. 1089

Grinding one Blank's End Cover No. 5396 B.

Standard Time 402·3 Secs
Daily P.W. Standard 68·5
Grade 1. Operator
Piece Work Rate 13/9d Per 100 Good Castings
Works Bonus. 50% of all earned over 10d Per Hour.
Calculated by 28.10.37.
Checked by
Approved by 28.10.37.
Remarks

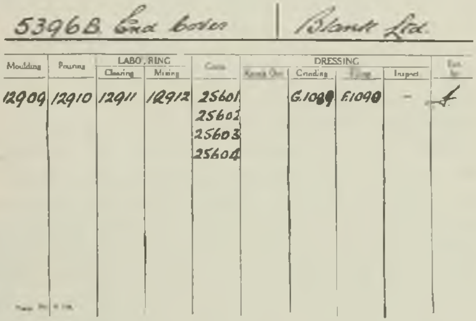
Dressing Job No. F. 1090

Chipping & Filing one Blank's End Cover No 5396 B.

Standard Time 245·0 Secs.
Daily P.W. Standard 112·4
Grade 1. Operator
Piece Work Rate 8/5d Per 100 Good Castings
Works Bonus. 50% of all earned over 10d Per Hour
Calculated by 28.10.37
Checked by
Approved by 28.10.37
Remarks

FIG. 13.—CARDS FOR DRESSING OPERATIONS ON CASTINGS FROM PATTERN No. 5396 B.

system, many of which would form the basis of long discussion, and it would be far too big a task to attempt to cover all the important features surrounding the application of the scheme. Therefore, quite a number of incidentals to the system have not been mentioned, but by this omission it must not be deduced that they are unimportant. To do justice to the costing system, for instance, one would resort to innumerable figures, to such an extent that no time would be left for attention to other phases. An explanation of the internal working of the index systems and interchange routine between the time and motion study and costs departments has been left out for the same reason.



5396B [illegible] | Blank Ltd.

Moulding	Pouring	LABOURING		Cores	DRESSING				[illegible]
		Clearing	Mixing		Knock Out	Grinding	[illegible]	Inspect	
12909	12910	12911	12912	25601 25602 25603 25604		G.1089	F.1090	–	✓

Fig. 14.—The Master Index Card for Pattern No. 5396 B.

To a certain extent it was not intended that such features should come within the scope of this Paper, for as was indicated initially, the object was to give some idea of how the production of castings was affected by the application of time and motion study methods of control.

One hears at times that such schemes as the one under consideration remove the encouragement of, and the necessity for, scientific training, initiative and personality in the foundry. Such views are untenable. The production of castings in any metal from moulds made on machines, or by other repetition methods, calls for much common sense and organising ability on the part of the executive staff in the foundry, but the basis of that production must be sound and scientific knowledge of the subject, as a result of technical training and practical experience.

The evolution in the foundry trade which has led, through keen competition from abroad and in other directions, to the necessity for so much machine-moulded production, has resulted in limited opportunities for training the majority of the boys who enter the foundries to become skilled craftsmen.

The only personal observation called for is that if one analysed the opportunities for training boys in two foundries where the whole of the production was from moulding machines, one foundry being controlled by time and motion study and the other not so controlled, one would not find the latter offering better facilities for training the boys than the former. This is a very controversial subject and does not come within the scope of the Paper, and it is hoped that no one will try to draw the author into a discussion on this matter, nor on the merits of machine moulding by unskilled or semi-skilled operators and boys as against the work being done by skilled labour. Machine moulding and mechanisation of foundries have come to stay, regardless of the system of control the foundries may adopt.

In conclusion, the author wishes to express his sincere thanks to Mr. V. Jobson, managing director, and Mr. C. W. Bigg, assistant managing director, of Qualcast, Limited, for permission to read this Paper, and to express his appreciation to those of his colleagues who assisted in the preparation of the Paper and the necessary slides.

DISCUSSION

The Branch-President (Mr. J. B. Allan), opening the discussion, said that the system of which Mr. Pollard had given a detailed description appeared very complicated, but it was probable, when one knew more about it, that it would prove much simpler. He was particularly interested to learn that the system, or a large part of it, had been in operation for such a long time. He thought that was rather unusual; it had started from the very basis, with the time it took to lift a shovel and put it back again, as long ago as 1916. Probably that fact had much to do with the success of the Qualcast concern. He asked what type of people the investigators were —whether skilled moulders or clerks. Obviously, as the figures they produced were the very basis, they must be very trustworthy and reliable.

The Case of the Jobbing Foundry

Mr. J. Roxburgh said the author's outline of the system he had for tackling sales from the estimates to the orders was very much on the lines that others practised in the industry. Mr. Pollard's ideas with regard to the settling of prices and the creation of confidence between management and men were very praiseworthy, as was the realisation that they were in business to produce first-class castings at an economic price. The figures and other information disclosed apparently dealt in the main with repetition work in a mechanised plant; naturally, under those conditions both scientific control and the obtaining of statistics were very much easier than in other types of foundries. Actually, they represented the ideal conditions under which one could obtain those statistics. Probably the members had all had experience of repetition work, and from that standpoint investigations such as the one described were both necessary and useful. In a jobbing foundry craftsmanship was of the highest importance, and in dealing with the human element a tremendous difference was found in the speed of working of the various operators; he knew from experience that it took one set of men on a particular job a real effort to make time and a quarter, whilst another set of men would make double time. In such cases times had to be based on the "average moulder," and that was difficult to do at times, because the men all asserted they were average moulders.

Yet even in a jobbing foundry the management went into each detail as far as was practicable at the estimating stage, and again at the stage of setting the price. They estimated so many hours for ramming, jointing, ramming the top, finishing and closing, and they based the piecework price accordingly. The rate fixer, for his own and for the firm's benefit, naturally took as many records as possible for reference, so that when an entirely new job came along, he was able, from his experience, records and references, to make a fairly accurate estimate of how long the job would take.

Estimates

When an inquiry was received, naturally it first went through the channels in the office and then was sent to the foundry manager. Particularly in a jobbing foundry, where it was possible to make a job four or five different ways, it was the duty of the foundry manager and his staff to devise the best and cheapest way of doing that job, and then to co-operate with the patternshop in the making of the tackle and deciding on the method which was to be employed, so that when the order came along, it was processed in the same manner and a definite method was devised for doing the job. In addition, when the job had been made, records were kept of the method employed and any particulars which would be of use for the future. The nature, sizes and position of the runners and risers, the mixture of the metal, and various operations on the job were obviously recorded. From that standpoint, a jobbing foundry to a certain extent kept particulars of the various operations. Where mechanised plant was used in a jobbing foundry, naturally they were able to get nearer to their figures where they used a moulding machine of some sort, and in that way as many records were kept as possible because, in addition to experience, they had got those facts and figures before them to guide them on any particular job which might come in.

Mr. C. D. Pollard said it was probably surprising to people who had not come into contact with the works to know the system had been working so long. It was started by six people more than 17 years ago, and to-day the system was operated by the right-hand man of the creator (Major Briggs) of the scheme, together with an assistant, a youth, and a typist. Since the production of Qualcast was of the order of 65 tons of cupola metal daily, and the largest casting would go in a box which two men could lift, it would be seen the system was not overloaded by staff. Those operating the system were not skilled moulders, and they might not know whether a certain runner would give a good casting, but they knew from their experience and references and knowledge that so many patterns in a box with certain types of runners would do the job. It was the foundry manager's job to decide, but they gave the lead in the direction of thinking out the cheapest way of doing the job.

Mr. Roxburgh had said it might be easier to work the scheme in conjunction with repetition work. He (the author) would say that repetition work lent itself to the system, but the possibilities of such control extended into the realms of a far wider field, and it was for the executive of a foundry either to re-organise or redesign the foundry, knowing what it meant to apply time and motion study methods. He had seen in his short contact with the scheme the possibilities of jobbing foundries controlling the smaller and some of the medium-sized castings produced from their moulding machines far more economically. It was obvious that foundrymen in estimating got as much detail as they could, but the more positive figures they secured from such a scheme where the analysis of the operations brought them down to operations which took two or three seconds was very much more satisfactory from a price-controlling point of view, and coupling up production costs against estimate when they embraced so much detail. It did give the foundry manager a confident feeling whilst he was in production.

Overhead Adjustment Figures

Mr. T. R. Walker said he noticed that the charts of operations were most carefully timed to fractions of seconds, but on the estimates there were some figures of bonus of 50 per cent. of something. Were those comparable in accuracy with the fractions of seconds, and where did they come from? Was it the foundry manager's business to fix these, or were they from the investigator or from the costs office? He presumed some of them referred to overheads. Were they subject to alterations?

Mr. Pollard said he had explained that all the figures were fictitious, and naturally when they were putting representative figures down for bonus and overheads they put down round figures. The system allowed the accountant to take out his costs weekly. The overheads, if the accountant thought fit, did fluctuate weekly. The foundry manager took the figures from the operation sheet as given during the day's work, so they knew from every job whether the standard was 100 per cent. or 110 per cent. From the records of daily production the accountant got out his figures of production, and the necessary knowledge was ready for him as to whether his overheads were being absorbed, over-absorbed, or under-absorbed, thus giving him an opportunity of adjusting his overhead figures weekly. He did not say they were done weekly, but they were certainly done monthly.

Mr. Walker thought that if the overheads were to vary week by week it must be difficult to get out an exact estimate.

Mr. Pollard pointed out that he did not say they varied weekly, but " if they did."

No Direct Interference

Mr. Harrison asked if the investigator dealt directly with the man, in case of discrepancy, or through the foreman.

Mr. Pollard replied that there was always a trio. The foundry manager, the investigator, and the operator were always in the discussion. There was no such thing as an investigator going to a machine and interfering with an operator without the foundry manager or one of his assistants being on the job. An operator could complain about any operation in standard time or anything in connection with piecework prices through his foreman, and through the foreman the piecework investigator went on to the job.

Unlimited Production

Mr. F. Smith said that one card showed that the cost of moulding was highest in the case of the man who worked the quickest. The extra cost might be only a penny, but a penny on hundreds of castings mounted up. Was not there a limit to the procedure whereby it paid the firm to let a man make his work dearer because he made more?

Mr. Pollard replied that no limits were put on anything. It would be realised that, with the very careful analysis that was taken during time study, the net time for all the operations in the aggregate did give a fairly accurate time that it would take to make the mould. It could fluctuate slightly, but the system was such that a man could work continuously and earn proportionately, and everybody was satisfied. There was no limit at all; the more the men did, the more the firm were satisfied. The price per article went up, but that did not influence their cost, because they had to balance the piecework price and the quantity made and the overheads, and they balanced one another.

Manual Dexterity Eliminated

Mr. F. Williams said the object of using piecework, as he saw it, was to take advantage of the difference in the manual dexterity of the operators. If the time study system was properly and logically applied it seemed to him that manual dexterity went by the board and there should be no need for a piecework system. If they ever had need for a piecework system how far did they apply standard costs as opposed to the detailed job? With regard to bonus earnings, the cost of 104 castings produced by the man who made most was 9.29d., whilst the cost of 94 was 9d. each. How were the overheads applied in that case?

Mr. Pollard reiterated that it had not been his intention to approach the subject purely as a costing system, and it would be folly for him to attempt to detail how the overheads were distributed and allocated day by day, but the knowledge of the accountancy side of the system was equal to the knowledge of the application of it in the shops, and they had sufficient confidence in the accountant to adjust those figures in order to satisfy whoever was in control of the works. Regarding the men's dexterity, if they timed all the good men and then put second-rate men on, and the production fell, they would meet the serious problem of the overheads not being absorbed. They had specialist jobs on which they had to put fairly skilled men. Once the jobs were timed with men of that class they were not given to second-rate men; they had to make good castings.

Group System

Mr. Roxburgh said his firm had piecework for moulders and coremakers. In their system, if the job was made by one man so much quicker than by another man, they got the benefit of that and their overheads were based on the actual working hours. If one set of men made a job in 50 hours and another set of men made it in 75 hours, the overheads were based on the actual hours taken, and the bonus earned was added on. Therefore, it paid the firm for a man to make time and a half on a job rather than time and a quarter. If they produced more, the firm were producing cheaper.

"Paper Costs"

Dr. C. J. Dadswell said that if the piecework price appeared high, the paper cost of the job would be more, because it was based on the overhead charge which had been established for a week, month, or six months. The actual costs of jobs were not paper costs; the paper costs were only to get some idea. The actual cost depended on the number of the castings which were produced in an hour, or in a week, as against the indirect charges of capital cost of machines, the indirect charges of the man's sand handling, and so forth, which one did not change into an overhead figure varying from week to week. They in Sheffield were not mass producers of castings. They had probably attempted in a very primitive manner some sort of time studies, but they had not been familiar with the systems or processes by which they had been applied in real quantity-production foundries such as the one with which Mr. Pollard was connected. He thought they had all learnt something in that respect, and that was the manner in which it could be simply applied with a small staff. If it was applied at places where there was a bigger variety of work, it would be necessary to have a much larger staff. In jobbing foundries where they had little bits of production going on to some extent, he did not see why a system like the one described could not be applied. It might not be worth the cost of putting it in quite the detail that was shown, but even if one timed the larger groups of operation, one would obtain some sort of economy and greater efficiency. He noticed one or two smiles at the mention of shovelling. He thought that the timing of shovelling was one of the very first things that was applied, which really was the fore-runner.

Mr. Tabor in America was the first man to study the time of shovelling, and also the size of the shovel which gave the most efficient shovelling. The Derby foundry had apparently started from the basis and worked upwards, because shovelling in the foundry was, perhaps, one of the most common manual operations.

Mr. Pollard said he was pleased to hear those remarks, because when one began to prepare a Paper such as he had done, one could only hope it would lead somebody into a new line of thought or help him to develop some ideas he might have. As most of them knew, he had spent much time in Sheffield and probably with many people saw the difficulties of applying such a scheme, but it was astounding when one was in contact with it how easy one could find help whilst he was doing his job in the shop. With regard to shovelling, he had picked out something which was easy to speak about. There might be 200,000 reference cards, and about 17 years ago there were 70,000, he thought. They were so easily indexed and filed and logged that they could have all the information they wanted almost instantaneously. That might sound a little exaggerated, but it was a fact, and it was because people had started at the bottom and developed the scheme step by step.

Patternshop Organisation

Mr. G. Offiler asked if the card index system was in vogue in the patternshop to any extent. Was there an investigator in the patternshop and, if so, what type of man was he?

Mr. Pollard replied that the patternshop was never time-studied at all. The instructions were so definite on the lay-out sheet. The patternmaker knew exactly what to do, and the question of timing him was never entered into at all.

Perfect Patterns

Mr. Wharton asked if the system could be related to the firm that worked only to the finest patterns it was possible to make. Mr.

Pollard had said it could be extended to jobbing foundries. Did he see the possibility of working with any sort of pattern or patterns which were not quite as good as he worked with himself?

Mr. Pollard said the object of machine moulding, apart from speed and cheapness, was to get perfect moulds. If an operator had a pattern plant which caused him difficulty he could refuse to make another mould. It would be realised, therefore, that they did put good pattern plant in. If they set a standard of so many a day, it was set on the assumption that the man could get on with the job. If the operator had any cause to complain about his pattern plant he definitely was entitled to refuse to work, and the manager decided whether it was justified.

A Member asked if there was any allowance on the estimated time for bad castings. At the conclusion of the day's work, who had to decide who was at fault for bad castings? Was the man paid for bad castings, and had he to replace them at the original rate?

Mr. Pollard said there was always an estimate for customers' rejects; it was always definitely put on the estimate sheets. The shop waste was also estimated by everybody concerned. Naturally, the foundry manager was the man who had the responsibility and authority for putting those figures, but those two items, their own scrap and customers' rejects, were always taken care of in estimating. As the castings were knocked out they went through to the fettling shop, and the doubtful castings were picked out for inspection by the foundry manager. It was definitely his duty to say which castings were to be paid for and which were not.

Accuracy of Estimates

Mr. F. Whitehouse said he was interested in scientific production. He had not quite got the point of the motion study, whether it meant that the production was scientific or whether it was a scientific means of getting more out of a man.

Were they increasing the skill of a man by cutting out unnecessary operations, or were they hurrying him along in the operations he did? Could Mr. Pollard indicate to what degree of accuracy the estimating was done? Could the estimating department give a very close figure to actual costs, even in the estimating stage, or were they rather like foundry managers who said, "We rather think there will be 80 boxes produced to-day, but we will reckon on 70"? To how fine a degree of accuracy could the estimating department work?

Mr. Pollard recalled that he had said, "It must be the duty of the time and motion study men to feed the foundry manager and his assistants with all the available information regarding the cheapest method of doing any job or operation, but at the commencement, *i.e.*, at the estimating stage, this factor must not be allowed to jeopardise the production of good castings." The time and motion study man, because of the information he had tabulated and recorded, could say that so many patterns would go in a certain sized box, with a certain sized runner, etc. If the foundry manager objected to the figures, then the time and motion study man said, "The next cheapest is so and so." None of the factors of time study must interfere with or jeopardise the production of good castings.

Mr. Whitehouse asked in what way was the firm training better men by the time and motion study method than were being trained elsewhere.

Mr. Pollard replied that scientific production was always taken care of by the foundry manager. It was his responsibility to make castings, whatever hints he might get from the time and motion study people. He had always to keep in mind that he had to produce good castings. Scientific production hand in hand with the scientific investigator made it easy for the man to do the job for which he was employed. The investigator was not there to hurry the men; if a man was making a mould, he carried on in a normal way. The investigator's work was to stand on the job and investigate those things which he thought were preventing quick production, but not to interfere with a man's speed of work. He was there to offer facilities by the removal of unnecessary work and offer facilities for easy movement.

Mr. Pollard, continuing, said he could not illustrate the question of accuracy of estimating better than by referring to the fine analysis to which estimating was taken. In beginning an estimate, the investigators made a survey and put down the sequence of operations which they knew from their records should be necessary for making up that type of mould. The foundry manager went through the operations, and if he thought there were any missing or any redundant, he added or took away, which meant that the estimating, by virtue of such fine analysis, was as fine as it could be. That analysis of the estimating was put down on the observation sheet and was transferred to the instruction card, which went in when the job went into work, and the man's and the investigator's work gave on the instruction card operation for operation as it was laid down in estimating. Thus they got a parallel between production and estimating.

Mr. B. Gray said he thought the last question could be answered by the case of the rapid production of machine tools. From a study of the quick worker and the slow worker it was found that the loss of time by the slow worker was almost entirely due to inefficient and wasteful actions. It could be truly said that the scientific method could improve an indifferent worker. They could see him make all sorts of actions which dissipated his strength and slowed him up. Mr. Gray observed how refreshing it was to hear a detailed description of a foundry which was being run on those lines. It was quite evident that Qualcast had something to teach all of them on the subject. He could not help asking the question whether Major Briggs studied policy very ingeniously when he used a 14-in. shovel instead of a 12-in. shovel, which was bound to increase output by 20 per cent.

Mr. Pollard said he was afraid he was one of the neophytes at Qualcast, but no doubt the commencement of the scheme was based on such study. The shovels at Qualcast were of standard size, except when they came to cupolas, when they could have what size they liked.

Mr. Whitehouse asked whether Qualcast tried to govern where a man should move his shovel, the place where it stood, and the exact height of the box he was filling.

Mr. Pollard replied that that was part of the organisation; it definitely was the basis of the scheme. If they did not standardise and pay very careful attention to such details it was useless keeping an investigator.

Sand Standardisation

Mr. T. R. Walker said that, if everything was standardised in a standardised foundry, he presumed the sand was standardised. Did the author have regular examinations of the sand to ensure it was the same always? He would have to standardise the core compound and the core sand to give the same degree of workability, and everything correspondingly.

Mr. Pollard replied that sand control was carefully handled, but not to the same extent as in some foundries. The facing sand was very carefully handled and mixed, and so was the core compound. Regarding the backing sand, the night men who did the knocking out of the castings were paid approximately so much per cubic foot of sand. They had so many moulds of a certain size from a machine and they knew within very fine limits that the same quantity of sand would come off that machine every day. The moistening was not done in a scientific way, but it was controlled by the quantity of water added to so much sand per night.

Replacement Problems

Mr. J. C. Jones asked if the system tended to segregate workmen into first-class skilled operators. When the supply of first-class skilled men ran out, would the second class of operators enter, or would they have to adjust their standards to the second-class scale?

Mr. Pollard said it would be realised that when they had upwards of 200 machines working every day they had quite a number of first-class machine moulders. They were skilled in their own particular sphere. There was no difficulty in replacing one or half a dozen men with such a number of machines. If they had only 30 machines, then the problem might present itself.

Advantages Summarised

Mr. J. B. Allan said it was perfectly certain that even in a purely jobbing foundry the regular and scientific collection of data and the proper analysis of that data must, in the end, assist very much in the efficient running of a foundry. Generally, he was rather afraid, there was a tendency for those in the jobbing shop to take the view that the collection of data was unnecessary, and that they could not make use of it if they had it. He did not think that was true at all, because over a period of months or years they were certain to come across jobs which had many points of similarity, and the points of one they could apply to some extent to another. Probably Mr. Pollard's Paper had made them think of the possibility of applying something even in a very small way to running a particular job, and he was pretty sure it could be applied to almost any. One very happy result of the arrangement, certainly to Mr. Pollard, must be the availability of costs in a day. If they could get the costs of work of the previous day on the following morning they could make very good use of them. Mr. Whitehouse had asked some very interesting questions, he thought. Surely if they wanted to get the best out of the men they wanted to make it as easy as possible for them to do their work, and the shovel business was the best way to do it. For any skilled man, whether he was skilled in the term that was generally used or a skilled man such as applied to Mr. Pollard's establishment, the less shovelling he had to do, and the less stooping and turning round he had to do, obviously were going to improve output and production. Certainly, careful thought and motion study, because that was what it was, must help enormously.

Vote of Thanks

Mr. Roxburgh said it gave him great pleasure to propose a hearty vote of thanks to Mr. Pollard for giving them such an interesting lecture and one which had given rise to one of the most interesting discussions they had had at that Branch. He thought, too, that the attendance was splendid, and it was a tribute to Mr. Pollard, and he was sure none of them had been disappointed. He had had experience of repetition and semi-repetition work, and in the jobbing foundry they made a point of collecting data and keeping as many records as possible. But, as Mr. Pollard had admitted, their estimates were very accurate indeed and they accorded with the time taken. When they came to a jobbing foundry, competing on the open market, he was a good man who could get within a few hours of his estimating. When they manufactured jobs taking 2,000 hrs. he was a very good man, despite all the records he had, if he could get to a degree of accuracy commensurate with what Mr. Pollard had shown them. But with experience and the collection of data they were gradually improving in the jobbing foundry.

Mr. Wharton seconded the vote of thanks, which was carried.

Mr. Pollard, in acknowledgment, said that if his address had given them pleasure and created any thoughts of giving attention to some of their costs, he was very well recompensed.

South African Branch

USE OF PLYWOOD FOR PATTERNMAKING

Paper No. 652

By Lieut.-Col. W. J. GROSE (Member)

It would be difficult to find a material more useful for patternmaking purposes than plywood, yet how seldom it is used in the patternshop. Unfortunately, there are still many sound practical patternmakers and moulders who are prejudiced against the use of plywood.

The objections raised are usually:—(*a*) Patterns are not strong enough for heavy ramming; (*b*) invariably the patterns draw badly, and (*c*) moisture affects the skin or surface of the pattern. These difficulties may be overcome in most cases by the patternmaker with practical experience and a will to improve the general construction of his patterns.

With this end in view, it is intended in this Paper to explain a few of the principal methods which can be applied to patternmaking, using plywood. The Paper does not cover the whole field of operations, but is a guide to those who have not made a study of it. Plywood is not suggested for use on all patterns, but only where an improvement in time and labour can be accomplished. Only trial and practical experience can show the great advantages of plywood compared to other materials, which is why a more sympathetic use of plywood is suggested for the future.

The chief factors to be considered when designing and constructing plywood patterns are the following:—(1) The pattern must be entirely satisfactory from the foundry point of view; (2) the saving of time on previous similar patterns made, and (3) saving in cost of material used compared to other materials.

Types of Patterns

The following types of patterns which have been made from plywood will give some idea of the extent to which it can be used:—

Jigs for setting multiple, irregular-shaped patterns on boards, for moulding machine; templates, small bend pipes, tees, etc., made with ¼-in. plywood plate to prevent warping, the bodies shaped with solid wood; centre plates or arms for spur wheels and pulleys up to 3 or 4 ft. in diameter; a tapered column 18 to 24 in. in diameter, 24 ft. long; bushes, all sizes from 6 in. to 5 ft. in diameter; straight or tapered bushes, collapsible, with corebox to suit; conical liner segments; cones; cylinder bodies, with circular waterjacket corebox made in sections; curved caps for gear boxes, large and small, with coreboxes to suit, and valves and coreboxes.

A Tapered Bush Pattern

The following is the method of construction of a tapered bush pattern having a large diameter of 48 in., a small diameter of 36 in. by 24 in. long, the method being similar for either large or small straight or tapered bushes. First, the rectangular tapered body is constructed, since it is easily made rigid, thus guaranteeing that the top and bottom rings are concentric. This box or body may be built up of ⅞-in. shelving, which is cheap, and with suitable 1¼-in. batons placed inside at the corners and centres. The size of the body across the corners is made to the inside of the ply shell, allowing flats wide enough to take two rows of nails for the butt jointing of the plywood later on.

The length of the body is less than the thickness of the two rings which are screwed to the top and bottom of the body. These rings may be built of two thicknesses of ⅞-in. segments, 4 or 5 in. wide, screwed and glued. As the distance between these rings is too great, it is necessary to place bridges 4 or 5 in. apart to reinforce the plywood shell. The plywood can then be cut to suit two or four sections of the cone. To mark the sheets of plywood, all that is necessary is to roll the skeleton pattern over the sheet and mark it with a pencil, allowing ⅛ in. top and bottom for finishing off after nailing.

It is very important to nail radially, beginning at the left edge and from the centre working equally to the top and bottom. This overcomes any tendency to warp the plywood. If extra layers are required, repeat with overlapping joints. Wetting the faces of the plywood with hot water before glueing is essential, the glue being applied just ahead of the nailing to prevent chilling. Assuming a grinder has been used, the approximate time taken to make this pattern is about 16 hrs., while the material cost is about £2 6s.* An old-style lagged pattern would have taken about 48 hrs., the material costing about £5. Thus there is a saving of 32 hrs. and £2 14s. in material.

One Half of a Cone Pulley

This is a somewhat different type from the previous pattern. It is 23½ in. diameter to 4 in. diameter, 4⅝ in. deep, ⅝ in. metal with 1½ in. metal at the top.

Body Form.—The plate can be made of ⅞ in. shelving. On this are screwed radially twelve ribs, forming the inside skeleton cone.

Marking.—The plywood is cut in one circular piece, less the gap, to form the cone.

Glueing and Nailing.—Place the 3 mm. plywood on to the form, taking particular care that the butt-joint is radial, then nailing to the ribs and baseplate in a similar manner as was described for the tapered bush. The layers of plywood are nailed and glued overlapping the joints, continuing until the required thickness is obtained. When dry, trim the large diameter to size with the band saw, and finish off the edge with the grinder. To remove the inside form, unscrew the baseplate from the ribs, then pull

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* South African costs are not necessarily the same as those obtaining in the U.K.—EDITOR.

each rib separately off the nails. The nails are removed from the cone by cutting them off flush with the face, with the hacksaw, finishing by filing.

Varnishing and Waxing.—To prevent the edge of the cone from opening out through moisture in the sand, lead rivets made from $\frac{3}{16}$ in. round lead wire are used. These rivets are spaced with a pitch of 3 in., $\frac{1}{2}$ in. from the edge. The small end is now filled in with a piece of clear pine, nailed or screwed, filling in the corners with leather fillets. Wax is well rubbed into the edge with a heated tool and then the whole well varnished or "ducoed." Every precaution should be taken to prevent moisture opening the layers of plywood, for once this happens, very little can be done to repair the damage.

This yields a pattern that is accurate, serviceable, easily made and inexpensive, and should stand up to several hundreds of moulds being made from it. The time it required was $9\frac{3}{4}$ hrs., and the cost of the timber 10s. 6d. Allowing for part of the timber of the form to be used again for other purposes, the cost of the pattern would be 7s.

Making a Cone Flange with 3 mm. Plywood

A start is made by drawing a section of the steel plate cone and showing the position of the flange on the side.

Sizes.—The diameter of the flange is 24 in. by $1\frac{1}{2}$ in. thick. From this, project the plan and show the plywood at least 2 in. wider than the flange on each of the four joints. This extra width is the allowance for nailing the ply to the form, also to give sufficient room to cut out the flange, missing the nails. Now draw the end elevation showing the three curves, the radius of each being taken from the section. Marking off the width, the depth of the form, allowing sufficient wood for the nails at each side, can then be decided. It is now necessary to mark in the baseplate with the required number of bridges, which are spaced about 5 in. apart. The depth of this form reduces the amount of timber to a minimum as compared to the form if made from the centre-line.

Form.—One first makes a baseplate of ⅞ in. shelving about 28 in. square. Across this will be screwed the bridges, forming a complete section of the cone. Along the ends of the bridges are fastened two strips; these are for the purpose of nailing the two edges of the ply.

Flange.—The method of glueing is lightly to wet both faces of the ply with hot water before applying the glue. The glueing and nailing must be done as rapidly as possible, as the glue sets very quickly. Continue until the required thickness of 1½ in. is reached. The time taken for the glue to set is regulated by atmospheric conditions, so allow sufficient time to set before cutting.

Finishing.—After this it is only necessary to mark off the flange with a ply template, cutting out the flange with the band saw and finishing the edge with the grinder. Then remove the form, rivet, and varnish.

It has been found that a ply pattern is far superior to the clear pine pattern in that it does not shrink or warp, and remains true to form, being easier to construct and taking less time to make. The following is the approximate difference in time and timber:—Plywood pattern: Time, 8 hrs.; timber, 16s. Clear pine pattern: Time, 24 hrs.; timber, 30s. Thus there is a saving of 16 hrs. and 14s. timber.

Kiln Feeder Bucket

Sizes.—The bucket is 9 in. long, 7 in. wide and 7 in. deep. Here again plywood forms an ideal foundation. The ends are ½ in. thick, the sides ⅜ in. thick, the bottom round, having a 2 in. radius. The top is cut away at an angle.

Body.—The pattern is required to leave its own core. If this pattern were made of clear pine, most likely it would not stand up to heavy usage. By making it of plywood, the pattern is strong, rigid and serviceable, standing up to several hundreds of moulds.

Form.—As with the previous examples, the form, made to the inside dimensions, but with the extra length and depth for nailing, will be started with the baseplate, screwing three bridges—one in the centre $\frac{7}{8}$ in. thick, one each end $1\frac{1}{4}$ in. thick. This allows sufficient space to saw-cut between the nails, and leaves a thickness of $\frac{1}{2}$ in. on the ends of the pattern. The ends can then be ground by the grinder, allowing the necessary taper. The taper for the inside was allowed for before the end bridges were secured to the baseplate.

Cutting.—For cutting the top at an angle, place the pattern on its flat side, cut with the band saw and finish with the grinder.

Glueing and Nailing.—The fastening of the 3 mm. plywood to the form should be carried out as follows: Start by nailing along the baseplate, then up evenly at both edges on the one side, gradually bending and nailing, finishing on the other side at the baseplate. The first layer of plywood should be glued to the ends, but not to the centre bridge. All that is now necessary is to nail or screw the three layers of plywood to the $\frac{1}{2}$ in. thick ends before cutting, and to allow sufficient time to elapse for the glue to set.

Finish.—Rivet, wax and varnish.

For the construction of this pattern the time was $7\frac{1}{4}$ hrs., and the material cost 3s. 3d.

Plywood Jig for Setting Patterns on Moulding-Machine Boards

Frame Sizes.—The boards for setting the patterns are made to suit rectangular-shaped aluminium frames. For this particular frame the outside dimensions are 16 in. by $19\frac{1}{2}$ in., accurately machined all over. They are used in most cases in pairs, for cope and drag boxes. At each end are placed pins to suit the moulding boxes, one $\frac{5}{8}$ in. diameter and the other $\frac{3}{4}$ in. diameter.

Jig Marking and Cutting.—For the jig the most convenient thickness is 3 or 4 mm. plywood. This is cut accurately to the outside dimensions of the frame. Place the eight half-grenade patterns in two rows of four, with sufficient length of print between for supporting the double core, mark carefully and cut out the shape of the pattern with the jig saw machine. Four edges are cut for setting the prints. The jig is now nailed temporarily to the board, setting the edges carefully to the outside edges of the frame.

Pattern Setting.—The patterns are now set in the jig and fastened to the board. Remove the jig, turn over and fasten to the second board and set pattern. This method of setting has been found very accurate and the jig is simple to make. As the shape of the grenade pattern is irregular, to set it by measurement is very difficult and inaccurate. The principle of this jig can be applied to numerous other patterns, such as bend pipes placed diagonally on the boards, etc.

Cylinder Liner

Fig. 1 shows a gas engine cylinder liner pattern, 7 ft. long, barrel 24 in. diameter, and a valve chamber of 36 in. diameter. The job was cast vertically.

Body.—It is an excellent example in which plywood can be used to advantage. In the centre is seen one outside half of the pattern covered entirely with 4 mm. plywood. On the right is shown the other half of the pattern at the joint, with the plate and built-up bridges which support the plywood. On the left hand is the corebox. This is of simple construction, having boxed-up sides and ends, with crossed ribs covered with plywood. In nailing on the plywood of this pattern, extreme care must be taken, for otherwise a twist of $\frac{3}{8}$ in. to $\frac{5}{8}$ in. may occur.

Frame Inside Ends.—By having a solid pattern and corebox, it can readily be appreciated that a considerable saving of time in the foundry results. Not only in time does one score, but a better quality casting is assured by having a first-class mould and core. The finish of the mould and core from a first-class pattern and corebox, and its effect on the quality of the casting, and also its stresses, are not always appreciated as they should be. The extra cost of the work on the pattern is more than compensated by the saving in time by the foundry.

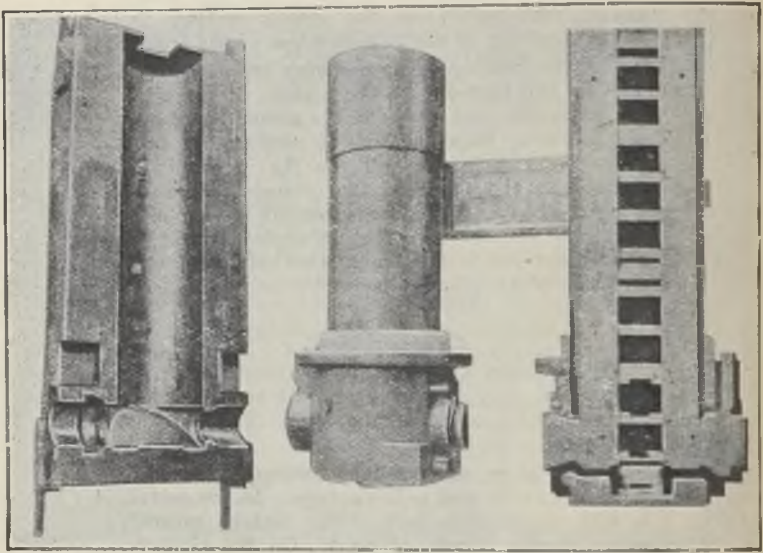


FIG. 1.—GAS-ENGINE CYLINDER LINER PATTERN.

Cylinder Water-Jacket Corebox

Sizes (*Outer*).—In Fig. 2 is shown a cylinder water-jacket corebox. The sizes are roughly 26 in. diameter, $1\frac{3}{4}$ in. thick, and 24 in. long. On the right will be seen one half of the box, with the collapsible bush to form the inside of the core. This bush is made up of four segments, each fitting against a flat of the square box or body. The segments are made with a $\frac{7}{8}$ in.

plate with bridges, the outer side covered with 3 mm. plywood. This method overcomes warping and shrinking, is quickly made, and cheaper in material compared to solid timber. The left of Fig. 2 shows the other half of the box outside. It will be seen to be constructed of four layers, 6 in. deep, the whole set, when together, having a diametrical joint. Each piece is of skeleton construction covered on the inside with plywood. The whole is a straightforward band saw and grinder job.

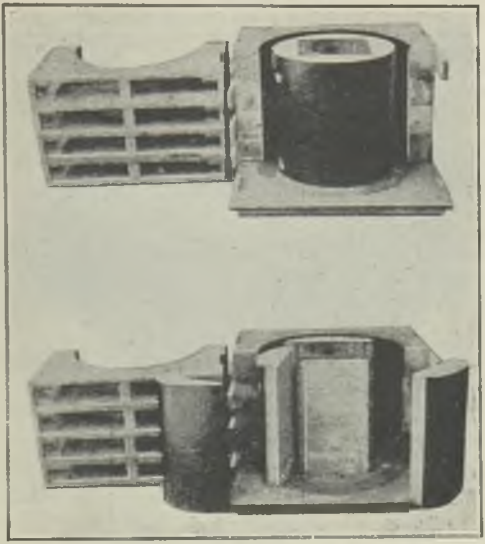


FIG. 2.—CYLINDER WATER-JACKET COREBOX.

Gearbox

A typical example of the employment of plywood in a gearbox pattern is illustrated in Fig. 3. This represents the general construction of the pattern, which is 25¾ in. long, 22 in. high, with 6 in. from face of flange to back of body. The flange and footstep, back and walls are made entirely of plywood. The body was first started by making a form of ⅞ in. shelving to the inside dimensions, allowing for the necessary taper, the depth being ½ in. from the face of the flange to the outside of the back, a total of 5½ in. This is done so as to utilise the piece cut from the inside of the flange to be used as the back, which is ½ in. thick.

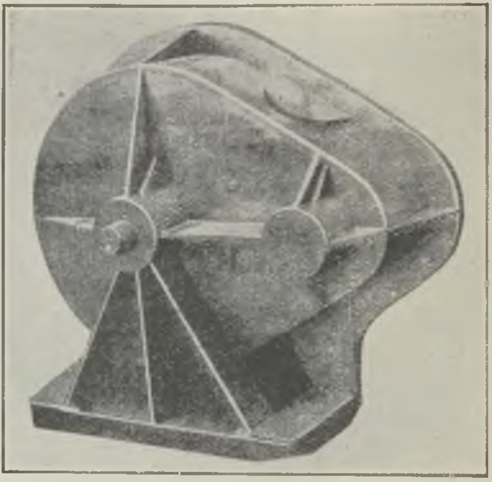


FIG. 3.—PATTERN FOR A GEARBOX.

Extra segments 1¼ in. thick are then screwed, but not glued, round the edges on both faces. These segments are for nailing the plywood to the form. After glueing the plywood and nailing to the form, the segments are removed by pulling each separately from the nails. The edges with nails through are cut off with the saw and the wall ground to the depth of the form.

The flange, which is built up to ½ in. thick, is now marked off to the outside and inside dimensions, the inside is cut out with a jig saw and ground to size. It is now nailed to the walls of the pattern, then built up round the body to the thickness of 1 in., including the front of the footstep in one piece. The inside piece of the flange is now used for the back, glued and nailed into place. The fact that plywood is constructed of a number of thin layers of wood calls for very great care, when nailing into the edges, that the nails do not act as a wedge and force the layers apart. This difficulty is overcome by drilling with a small hand drill to the size of the nails.

A pattern is essentially a moulding tool. As a tool, its serviceability must always take precedence over its rank as a "work of art." In this pattern of a gearbox, one must agree that as a " work of art " it has great serviceability, obviating the necessity of building a corebox. It leaves its own core and results in greater accuracy in the bosses as compared with the setting of a loose core. This has been proved by experience. No mention of the cover is necessary, as this is contructed on a joint plate.

West Riding of Yorkshire Branch

Paper No. 653

FEEDING OF CASTINGS WITH SPECIAL REFERENCE TO THE STEAM-PRESSURE METHOD

By BEN HIRD (Member)

What is the purpose of feeding certain castings? Feeding is an endeavour to overcome the defects caused by liquid shrinkage. All foundrymen and metallurgists have to face these defects, and strive to overcome them by various methods. They have always been one of the worst troubles experienced in foundry practice. It is probable that more thought, study and ingenuity have been concentrated on this subject than on any other connected with cast iron. Right back through the files of The Foundry Trade Journal, and from the first published Proceedings of the Institute of British Foundrymen the subject has been studied and discussed. Although it has been so thoroughly ventilated, and much light thrown upon it, it still remains a problem, especially with castings of certain design.

In 1912 R. Carrick gave a Paper on “ The Use of Chills to Overcome Liquid Contraction.” Later E. Longden dealt at length with this subject, also with the effects of gases causing these defects. Buchanan put forward his “ box theory ” in about 1910 or 1911, when he pointed out that liquid contraction in one part of a casting was due to expansion in another part, and in 1923 he gave a Paper, “ Some Notes on Liquid Contraction,” when he further developed this theory. In the same year the Ronceray “ pencil runner ” theory was described and discussed, and Smalley compiled a splendid Paper on “ Volume Changes of Cast Iron on Solidification,” in which he stated that “ Cupola melted grey cast iron, of normal chemical composition, does not shrink on solidification, *if* poured with a sufficient degree of superheat and *if* cooled faster than a certain critical rate." The following year J. Longden gave an excellent practical Paper on "Some Considerations of Liquid Shrinkage in Cast Iron," and stated in one of his conclusions that "Grey iron shrinks about 4.5 per cent. of its liquid volume on crystallising."

Many other excellent Papers and discussions have been published on this subject. Those mentioned have been taken at random to show part of the range explored. Although many theories have been expounded, and useful remedies suggested, the defects still persist, and it is not claimed that the method of pressure feeding to be put forward in this Paper is a positive cure for all liquid shrinkage defects.

Rod Feeding

Before introducing steam-pressure feeding, it is proposed, at the risk of being elementary, to deal briefly with rod feeding, probably the oldest method of feeding, and one which is common practice in many foundries.

In spite of its utility, the feeding rod has many failings, and some moulders appear to have a very hazy idea of its functions, whilst others shirk doing the job thoroughly because of the heat, with the result that the casting would have been better if the rod had not been used. Sometimes there is difficulty in placing the riser correctly over the thick part requiring feeding, and consequently the mould or cores are in danger of being struck with the rod, dispersing a quantity of sand and creating an unsightly lump on the casting. Some men move the rod up and down in the riser pump fashion, and think that they are feeding the casting in spite of the fact that they are pulling metal out of the mould as it sets around the rod; this they usually knock off with a short piece of iron bar. Actually they are creating a cavity instead of preventing one. Feeding with a rod is useless unless it is done efficiently, and correct rod feeding requires concentration of effort to prevent the metal in the riser setting sooner than the metal in the mould,

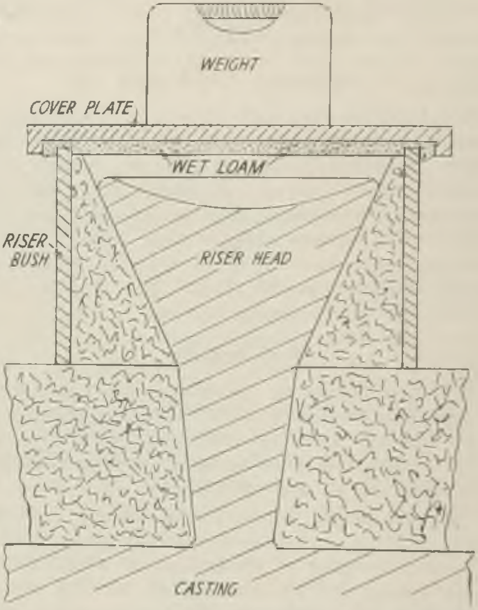


Fig. 1.—Section of Assembly for Steam-Pressure Feeding of a Casting.

and thus to allow the casting to feed itself from the liquid metal in the riser.

Practical Hints

The following procedure is recommended. The diameter of the feeding-rod should be suitable to the size of job and the riser, and will vary from a ¼ in. rod for an 1 in. to 1½ in. dia. riser, to ½ in. or ¾ in. for 2 in. to 3 in. risers. The rod should be well warmed before inserting it into the molten metal in the riser, then lowered gently until it touches the bottom of the mould, or any obstruction, then raised at least one inch, and the position noted carefully. The rod is then moved round the circumference of the riser with a gentle up and down movement, taking care not to go below the point noted. The rod should be revolved by the fingers as the feeding proceeds; this action keeps the rod clean by the rubbing action on the circumference of the riser, preventing the metal setting on the rod. The feel of the rod will indicate the solidification taking place in the mould, and coinciding with the setting of the metal the rod must be gradually lifted, and be taken from the mould before the final solidification takes place. If the metal in the riser shows signs of setting first, fresh hot metal must be poured into the riser-bush to enable the feeding to proceed until the mould has solidified.

This method of feeding occupies a considerable amount of time and labour, and is not a pleasant task. If a number of moulds have to be fed at the same time, it is often difficult to spare sufficient men from the shop to do the job, or spend the time doing it thoroughly.

Pressure Feeding

Pressure feeding is a method that can be recommended for most jobs. It eliminates the use of the rod, provides metal for the loss due to expansion of the mould, as mentioned in Buchanan's "box theory," and also for the shrinkage due to crystallisation dealt with by J. Longden. It retards the formation of cavities and porous places caused by gases, and assists the mould and core gases to escape into the open air through their proper channels, the vents. Most foundrymen will agree that iron is usually more dense and homogeneous in the lower parts of the mould due to the pressure exerted thereat.

The usual method of applying pressure feeding is by building up the runner and riser bushes (or in some cases the runner bush only) to more than the usual height above the moulding box top, in some cases heights of 12 to 24 in. being necessary to produce a sound casting, dependent on the amount of feeding the job requires. The objection to this method of feeding is the time taken to make up the runner and riser bushes, and the cost of melting and handling the extra metal required to fill them to get the head pressure.

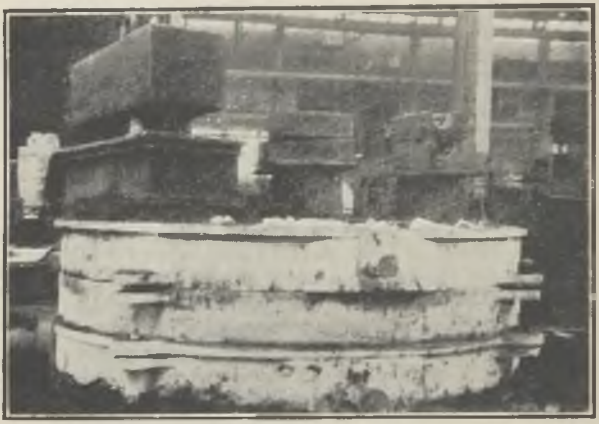


Fig. 2.—Flywheel Mould Arranged for Steam-Pressure Feeding.

Steam-Pressure Feeding

The steam-pressure method was introduced to obtain the benefits of pressure feeding without the expense in labour and material involved in making up high runner and riser heads. Over a long period of application the method has given satisfactory results on various types of castings. The method of application is very simple. Special cast-iron plates in the form of a shallow dish are made to suit the various sizes of bushes used. These plates should be sufficiently strong to be rigid without being too heavy to handle easily; from $\frac{3}{8}$ to $\frac{1}{2}$ in. section is suitable for most cases, and the dish is formed by a beading about $\frac{1}{2}$ in. high around the edges of the plate. It is important that the inside sizes of the dish should be at least an inch to two inches larger than the outside sizes of the bush.

The dish is filled level with wet sand, or, better still, loam. It is most important that the sand be really wet. Runner and riser bushes are made up in the usual way, but care must be taken to ensure that the top edges of the metal bushes are flat and true, and if a surface grinder is available it is well worth grinding one edge of the bush. The wet loam plates must be prepared and placed conveniently near the moulds before the metal for casting arrives, together with a suitable number of box weights, 56-lb. weights being very convenient.

FIG. 3.—RISER HEADS FOR HEAVY FLYWHEELS, SHOWING EFFECT OF STEAM-PRESSURE FEEDING.

Immediately the mould is poured, the plates, loam side down, are placed on the runner and riser bushes, and the weights quickly dropped on to the plates, simultaneously if possible, or the metal may be pushed up into the unweighted bush and disturb the plate.

As soon as the weight is dropped on to the plate, the wet loam makes a seal between the plate and the bush edges, and steam is generated at once from the wet loam by the heat of the metal, and a pressure approximating that of the weight placed on the plate is produced. Feeding risers should be of a well-tapered funnel shape, having the neck connecting the riser to the casting as short as possible, thus ensuring a maximum time before the metal sets in the neck.

A point that must not be overlooked when pressure feeding is that, when extra pressure is applied to the liquid metal, the mould must be strong enough to withstand it; therefore, it must be weighted, or clamped very securely. Also precautions must be taken against bursting through, if portions of the casting extend up into the top part with only a small section of sand above them.

Fig. 1 shows diagrammatically a section of a steam-pressure-fed riser, and the other illustrations indicate some of the many applications of steam-pressure feeding. The method has proved very successful on heavy flywheels which are machined all over; they have turned out very free from porosity, and are much improved in balance. Cylinder heads which are subjected to water pressure have definitely benefited by steam-pressure feeding.

DISCUSSION

The discussion which followed the Paper began with a number of questions on points of detail concerning various jobs the lecturer had described, and gradually developed into a friendly argument between Mr. Hird and some of the Branch members as to the extent to which gases may, or may not, be found escaping from metals.

In answer to a query by **Mr. E. Illingworth**, **Mr. Hird** said it was obviously desirable not to fill a riser to the level at which the seal plate would be fitted on. It was quite simple to stop $\frac{3}{4}$ in. or so from the top; otherwise, the man handling the plate might be burned by a splash of metal.

Mr. H. Bradbury questioned whether the use of a crane weight or other weights on top of a runner—as in one of the author's photographs—might be liable to cause uneven pressure, with consequent ill results.

Mr. Hird replied that the pressure was exerted on the whole area.

Mr. A. S. Worcester asked was there any substantial difference between the metal that left the bushes from the nearest to the runner and that which was farthest away from it?

Mr. Hird pointed out there was not a great deal of room there, neither was there any quantity of water for generating steam. In any case one found a quantity of moisture behind the plate. The pressure persisted for quite a period. It was, he thought, the initial pressure for the first half-minute or so on a light job or for two to three minutes on a heavier job, that exercised the influence, rather than that over a period. He agreed that possibly in some risers the later metal might have cooled off somewhat. The loss of temperature between the time of pouring the metal into the runner and the time it came out of the riser was certainly a point that was not always given the consideration it deserved.

Application to Small Moulds

Mr. D. W. Hammond inquired whether Mr. Hird had found the method similarly beneficial in small castings, operating on the lower pressures, as compared with the larger castings. Might one assume that in small jobs a 56-lb. weight would produce a similar action in the mould? Mr. Hammond asked also what type of metal was used, and whether it had a long or short solidification range.

Mr. Hird replied that he had used the steam-pressure method on some quite small jobs, and instanced the case of some cylinder heads which had given successful results. In some cases it was unsuitable, and he did not advocate it as a panacea. It was desirable in some cases to give it a trial, but if the metal actually rose into the bush it would be obvious as to whether the method was worth while.

The metals used in the jobs described (continued Mr. Hird) were all of a low phosphorus content, most of them with about 0.4 per cent. P and about 1.5 to 1.8 per cent. Si. The first job he tried on this work was a small engine casing, and the experiment was very successful. They did not get 1 per cent. scrap now, whereas they had been getting up to 75 per cent. before pressure feeding; and they had no chills or the like.

Temperature Measurement

Mr. H. A. MacColl raised a question on a temperature drop mentioned by the lecturer, and inquired what type of pyrometer had been used. Being informed that it was an optical pyrometer, Mr. MacColl said there was liable to be a big divergence of results between different types of optical pyrometers, and he did not consider results with that instrument could be taken as reliable except as a matter of comparison if the use of the same pyrometer was continued. To his mind, the disappearing filament pyrometer was more strictly accurate.

Mr. S. W. Hanson considered the optical pyrometer a good instrument as a guide for comparative purposes. He expressed surprise that Mr. Hird should need steam-pressure feeding for flywheels. He (Mr. Hanson) had had similar experience in this matter, and found a satisfactory method was to eliminate the riser and take, say, $\frac{1}{8}$ in. or so increased depth of pattern-plate, and cast at a temperature, measured by optical pyrometer, of about 1,300 deg C.

Mr. Hird said he believed that with the pressure on the mould indicated it was definitely ameliorative. If for no other reason, it was worth while in the matter of separation of gases that entered the metal and the removal of gas cavities. The more pressure one exerted on a mould, the less were the losses due to these escaping gases. Again, if one could exert a pressure on a mould one must be assisting the operation of the core vents, and it would help to drive the gases through the vents provided. He agreed that with many types of castings adequate self-feeding was possible.

Mr. Hanson said he felt that Mr. Hird's explanation in regard to the gases fully justified his case for steam-pressure feeding. All founders had to deal with this trouble due to gases, and anything that would help was well worth consideration.

Gas in Steel

Mr. MacColl recalled that in the case of steel casting the more gas there was in the steel the less was the resultant shrinkage. That was just the opposite to the experience in cast iron.

Mr. Hird said that that was one cause of some foundry troubles. There was gas in steel, and when ironfounders used moulders' sprigs made of steel, the iron received the gases from the sprigs! It would cause trouble in machining, and they should, whenever possible, be avoided.

Mr. A. W. Walker doubted the possibility of gas being evolved from steel, and suggested that it was more a matter of the oxide.

Mr. Hird insisted that gas could come out of the steel, and he had tested and proved it to be correct. At one time he did much research work in calculating gases coming from steel and iron and tinned chaplets, and as a result he would state definitely that with many tinned chaplets one was likely to find that more than 25 per cent. had blowholes.

Mr. Walker objected that that was not the case if pure tin were used as a coating.

West Riding of Yorkshire Branch

Paper No. 654

COPPER IN CAST IRON AND MALLEABLE IRON

By W. B. SALLITT (Member)

I.—COPPER IN CAST IRON

During the last decade, ironfoundry technique has developed very rapidly, both in respect of moulding and melting practice, and much experience has been gained regarding the effect of alloy additions upon the properties of cast iron. As a result, cast irons of greatly improved strength and uniformity have been developed. In the past engineers have regarded cast iron with a certain amount of suspicion, but in the face of these improvements their attitude has been modified considerably and the field of application of cast iron has, in consequence, been greatly extended. The use of alloy cast irons for such highly stressed parts as automobile crankshafts, camshafts and valve push-rods may be quoted as typical examples. It is significant of the changing attitude of the engineer towards cast iron that the Institution of Mechanical Engineers is now sponsoring a comprehensive research into the properties of a wide range of alloy cast irons.

Copper has played no small part in this "renaissance" in the foundry: for example, the first cast crankshafts to be put into production contained 2 per cent. copper, and the first camshafts 3 per cent. As the work of research has proceeded, new properties of copper as an alloying element have been revealed, which are now being put to practical use in the foundry.

Although the use of copper additions in cast iron is of comparatively recent development, it is interesting to find that about 100 years ago, in the Birmingham district, it was the practice to add a couple of "Boulton pennies" to a handshank of malleable iron when specially good metal was required. These "Boulton pennies" weighed about 2 ozs. and contained over 99 per cent. copper.

Copper Additions

Copper is very easily alloyed with cast iron. As it is less prone to oxidation loss than any of the common alloying elements except nickel, full credit may be given for the copper content of back scrap and no allowance for oxidation need be made in calculating additions. Although its melting point is relatively high (1,083 deg. C.), copper goes into solution very readily, particularly as its density is greater than that of molten iron. Additions of up to 3 per cent. may be added

T.C (per cent.)	3.23	3.13	3.13	3.09
Si (per cent.)	1.25	—	—	1.17
Mn (per cent.)	0.54	—	—	0.46
P (per cent.)	0.33	—	—	0.32
Cu (per cent.)	0.00	0·82	1·78	2·43

FIG. 1.—CHILL BARS SHOWING PROGRESSIVE REDUCTION OF CHILL WITH INCREASING COPPER ADDITION. SCALE APPROXIMATELY $\frac{1}{5}$ FULL SIZE (B.C.I.R.A.).

to the ladle, but copper may be also introduced as part of the charge in cupola or other furnace practice, although in the latter instance it is usual to make additions just before tapping. Scrap copper in any size or shape is suitable for furnace additions, provided that it is reasonably free from impurities; for ladle additions, copper shot, *i.e.*, granulated copper, copper wire, turnings or small pieces of scrap such as fire-box stay bolts, cut into lengths of about 3 in., are suitable. The ladle should be well stirred before pouring.

Cost

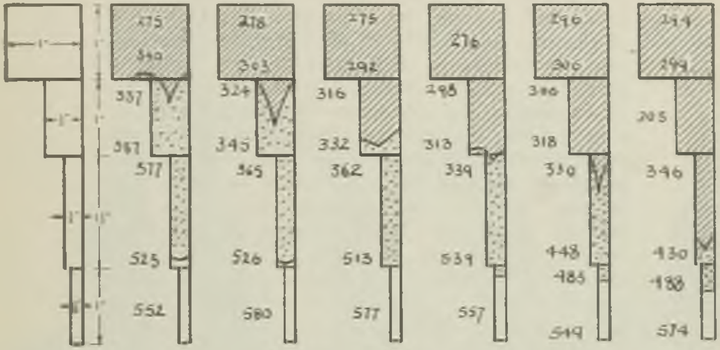
Cost is an important factor where alloy irons are concerned. Table I shows the cost (per ton of metal melted) of a 1 per cent. addition of the more common alloying elements. It will be seen that the cost of copper is of the same order as that of the cheaper metals such as chromium and manganese.

TABLE I.—*Cost of* 1 *per cent. Addition of Alloying Elements*

Alloying elements.	Method of addition.	Cost of 1 per cent. addition per ton of metal melted.	
		s.	d.
Manganese ..	Ferro-manganese ..	5	0
Chromium ..	Ferro-chrome ..	7	0
Copper	Light scrap copper ..	5	8
Nickel	Nickel " F " shot ..	33	0
Molybdenum ..	Ferro-molybdenum	112	0

Influence of Copper on Structure of Cast Iron

The useful limit of copper additions in ordinary cast iron is about 3½ per cent. Up to this percentage the influence of copper on the structure of cast iron resembles that of nickel: it acts as a graphitiser, and refines graphite, and secondly it hardens and strengthens the matrix. The graphitising action of copper is illustrated in Fig. 1, which shows four chill bars poured from the same heat and having the same composition except for copper content. Chill is progressively reduced as copper is added, indicating that in so far as chill is concerned, copper behaves in a similar manner to silicon. There are, however, two very important differences between copper and silicon; the first is that silicon coarsens graphite, *i.e.*, causes open grain, whereas copper refines graphite, and thus closes up the grain. This difference has a very material bearing on mechanical properties, because cast iron invariably fractures along the graphite flakes and therefore its strength is largely dependent on the graphite size and shape.



COPPER %	0·07	0·56	0·61	0·80	1·21	1·52
Combined Carbon % (1″ section)	1·08	1·08	1·00	0·90	0·88	0·90

Analysis: Total Carbon % 2·87
Silicon % 1·54
Manganese % 0·46

▨ Grey
▦ Mottled
☐ White

Hardness figures:
1″ and ½″ section Brinell hardness
¼″ and ⅛″ section Vickers d.p. hardness

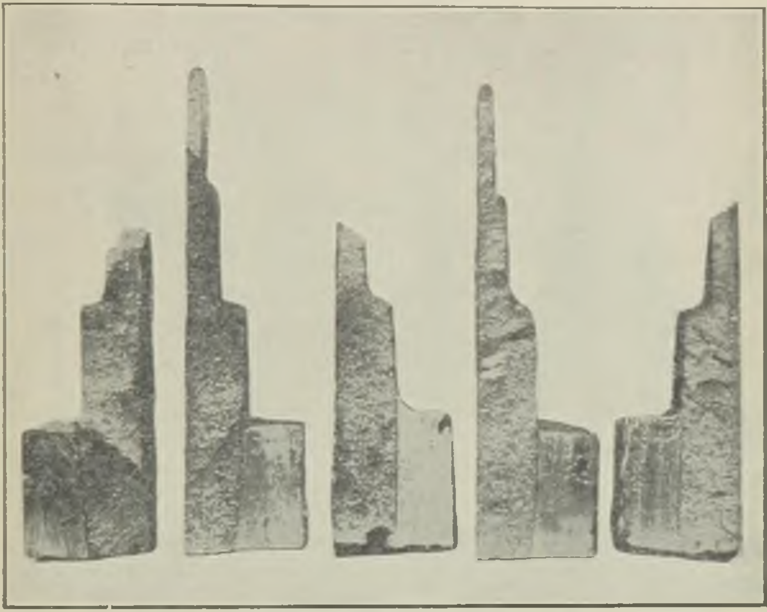
FIG. 2.—STEP-BAR CASTINGS WITH INCREASING PERCENTAGES OF COPPER (BY COURTESY OF SIR W. G. ARMSTRONG-WHITWORTH & COMPANY LIMITED.)

The second difference is that if, to a casting with varying sectional thickness, silicon is added to reduce chill in thin sections, the structure of thicker sections also becomes softer and coarser, because the combined carbon content in these sections is also reduced and free ferrite is formed. Copper, on the other hand, does not cause pearlitic carbide to break down to ferrite, and so, far from softening the matrix in thicker sections, it actually hardens, toughens and strengthens it, at the same time as it is removing chill from thin sections.

The matrix of cast iron is very similar to that of pearlitic cast steel, and the effect of 2.5 per cent. copper on such a steel is to increase the tensile strength by as much as 16 tons per sq. in. The effect on the cast-iron matrix is similar, though the improvement in strength of the iron as a whole is, of course, less marked, since it is largely dependent on the condition of the graphite. These essential differences between copper and silicon are illustrated in Figs. 2 to 5. Fig. 2 shows the effect of increasing the copper content in step-bar castings: chill is progressively reduced in the thinner sections, but in the thicker 1-in. sections, once the free carbides have been broken down, the hardness increases as copper is added. Figs. 3 and 4 show that additions of silicon to an iron of approximately "cylinder" composition causes open grain and even shrinkage defects at changes of section, whilst copper additions tend to close up the grain. The hardness figures on the step-bars shown in Figs. 3 and 4 are plotted in Fig. 5. It will be noticed that copper tends to render the hardness more uniform in the thick and thin sections, whilst there is considerable "scatter" in the bars containing silicon additions.

Figs. 2 to 5 illustrate very clearly the value of copper for castings having thin and thick sections, such as cylinder blocks, heads and liners. For castings of this type, composition must be maintained within accurate limits if hard spots on the one hand, or sponginess on the other, are to be avoided. Clearly, if trouble be experienced with hard spots in thin sections, copper may safely be added without risk of increasing the tendency towards sponginess in thick sections; and further, by making still larger additions of copper and simultaneous reductions in the silicon content, an iron may be obtained the structure of which will be much less sensitive to small changes in composition.

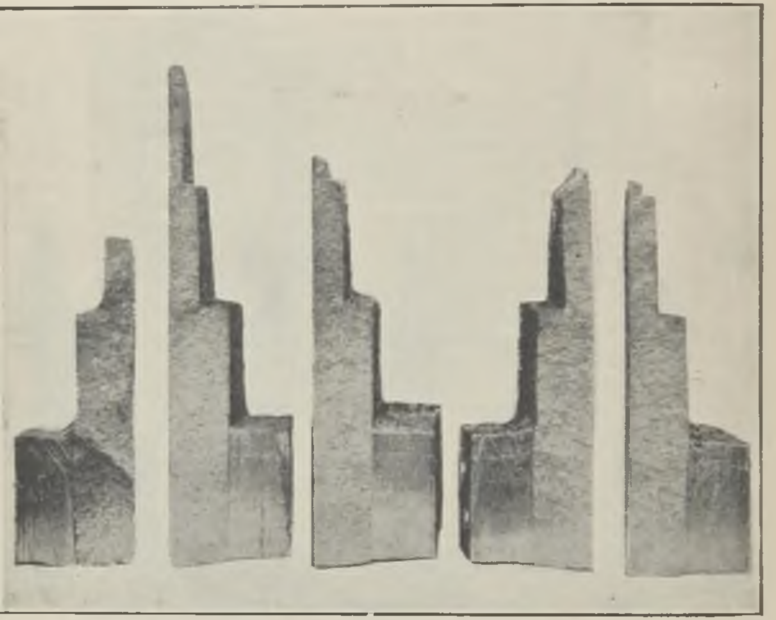
It is also found that when copper is added in substitution for silicon, the variation of chill during a day's run from the cupola can be controlled within much narrower limits. The Ford Motor Company use no less than 3 per cent. copper in their cast camshafts, in which the silicon content is reduced to 0.5 per cent. For these castings, no artificial chills are used, but the composition is controlled so accurately that



	No. 1	No. 2	No. 3	No. 4	No. 5
T.C ..	3.20	3.18	3.24	3.18	3.24
Si ..	2.02	2.13	2.21	2.32	2.44
Cu ..	0.04	0.04	0.04	0.04	0.04

Fig. 3.—Effect of Silicon Additions to Cylinder Iron. In each case the Mn is 0.55 per cent. and P and S low.

the cam-tips chill white by virtue of their comparatively thin section, whilst the bearings are grey and machinable. The high copper content is found to maintain the depth of chill within very narrow limits during the day's run.



	No. 1	No. 6	No. 7	No. 8	No. 9
T.C ..	3.20	3.22	3.20	3.18	3.18
Si ..	2.02	2.09	2.06	2.03	2.06
Cu ..	0.04	0.55	1.03	1.58	1.69

FIG. 4.—EFFECT OF COPPER ADDITIONS TO CYLINDER IRON. IN EACH CASE THE MN IS 0.55 PER CENT. AND P AND S LOW.

The fracture of the Ford camshaft is shown in Fig. 6, whilst the microstructure of the cam-tip and core is shown in Figs. 7 and 8 respectively.

If the copper content in cast iron exceeds about 5 per cent., globules of copper appear in the structure, which (as will be noticed in Fig. 9) nearly always contain particles of slag. Norbury has suggested that slag particles, which are solid at the temperature at which the eutectic freezes, form the nuclei upon which primary graphite separates, and that if such particles have been removed, as for example by superheating, or have been coated with a low melting-point film which is liquid at the eutectic temperature, no primary graphite is formed and the iron supercools, the graphite which separates at lower tem-

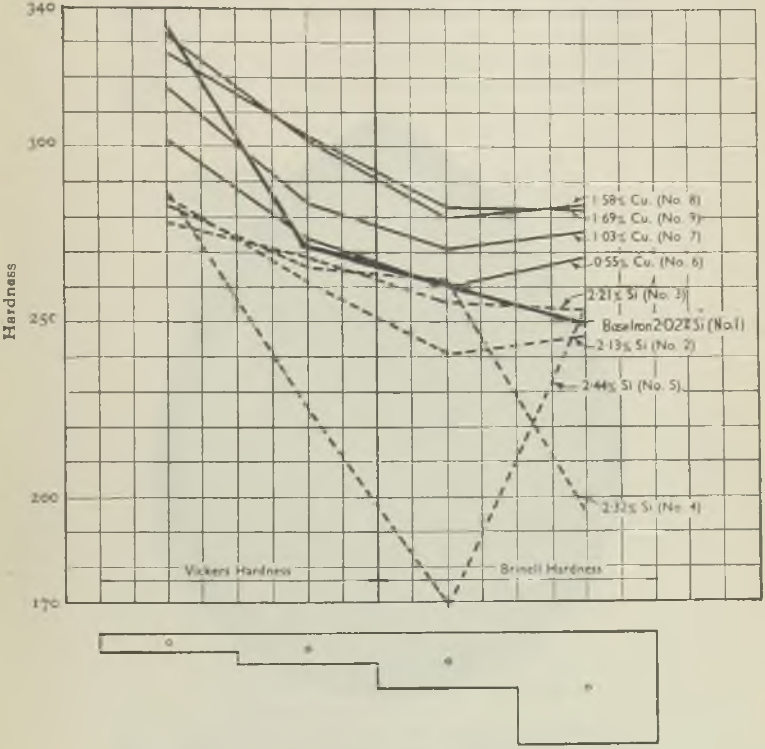


FIG. 5.—HARDNESS FIGURES ON STEP-BAR CASTINGS SHOWN IN FIGS. 3 AND 4. NOTE UNIFORMITY OF HARDNESS OF COPPER BARS AND INCREASE IN HARDNESS IN THICK SECTIONS DUE TO COPPER.

peratures being completely refined. In irons containing copper in excess of the liquid solubility limit, the free copper is found to precipitate round any solid inclusions in the melt, and since the melting point of the copper-rich constituent (1,094 deg. C.) is lower than that at which the cast-iron eutectic freezes, the solid inclusions become in effect liquid, and do not

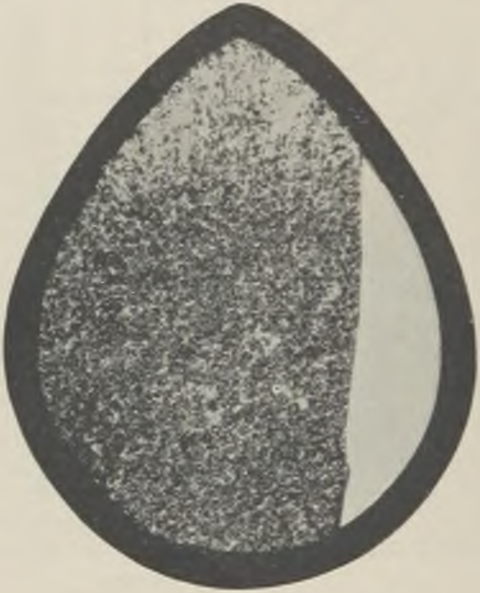


Fig. 6.—Fracture of Ford V-8 Cast Camshaft. (By Courtesy of Ford Motor Company.)

therefore appear to provide nuclei for the separation of coarse primary graphite; consequently, the graphite, which separates at lower temperatures, is in a very fine state of division, as is shown in Fig. 9. For purposes of comparison, normal graphite, such as would have been formed in the absence of primary copper, is shown in

Fig. 10. If the suppression of primary graphite is to be complete, the copper content must be somewhat in excess of the molten solubility limit, *i.e.*, 6 to 8 per cent., in order that all the slag inclusions in the melt may become coated with copper.

Pearce has suggested that for castings such as ingot moulds, which must offer resistance to thermal shock and growth, cast irons should preferably have a high carbon content with a very fine graphite structure, since the high carbon content will confer resistance to thermal shock, whilst the fine graphite will prevent the entry of oxidising gases and thus delay growth. Such a combination has in the past been difficult, if not impossible to achieve, because the effect of raising the carbon content is to coarsen the graphite. Refinement by means of primary copper may, however, provide a solution of this difficulty.

Fig. 7.—Microstructure of Cam-Tip of V-8 Cast Camshaft. Etched 5 per cent. Nital. × 100. (By Courtesy of Ford Motor Company.)

Balanced Alloy Additions in Cast Iron

Since copper is a graphitiser, it may be usefully added in conjunction with hardeners such

TABLE II.—*Graphitising Value of Elements.*

Element.	Graphitising value.
Silicon	+ 1.0
Copper—	
Carbon over 3.0 per cent.	+ 0.30
Carbon below 3.0 per cent	+ 0.20
Nickel	+ 0.35
Manganese	− 0.25
Molybdenum	− 0.35*
Chromium	− 1.20

* This value should be accepted with caution, as under certain conditions molybdenum appears to exert little or no influence on chill.

FIG. 8.—MICROSTRUCTURE OF CORE OF V-8 CAST CAMSHAFT. ETCHED 5 PER CENT. NITAL. × 100. (BY COURTESY OF FORD MOTOR COMPANY.)

as manganese, chromium and molybdenum. These three elements can produce very material improvements in the strength of cast iron, but from the point of view of chill they act in an opposite manner to silicon, *i.e.*, they increase chill. Therefore, if one of these elements be added to cast iron, a balanced percentage of a graphitiser must also be added, or the iron will become brittle and unmachinable. The disadvantage of silicon has already been stressed; it coarsens the grain and therefore prejudices the improvement in properties resulting from the hardening alloy. Copper, on the other hand, contributes to this improvement. Table II shows the graphitising value of the more common elements. It will be seen that, for a balanced addition, copper and manganese or copper and molybdenum should be added in approximately equal proportions, whilst the copper-chromium ratio should be about 4 : 1.

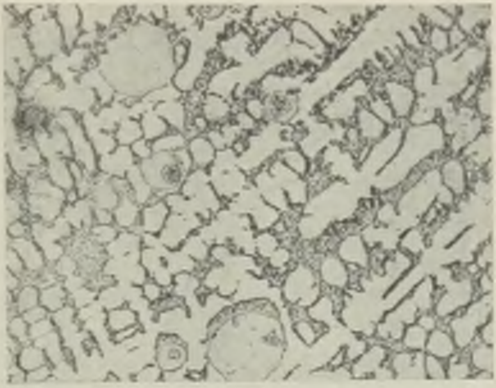


FIG. 9.—MICROSTRUCTURE OF CAST IRON SHOWING GRAPHITE REFINEMENT PRODUCED BY PRIMARY COPPER. UNETCHED. × 50. (B.C.I.R.A.)

Influence of Copper on Mechanical Properties of Grey Iron

Simple Copper Additions. — As is shown in Fig. 11, no very striking improvement in the properties of cast iron results from a simple addition of copper. It will be seen that compressive strength, tensile strength and Brinell hardness increase progressively as copper is added. This increase in Brinell hardness is not accompanied by any appreciable reduction in machinability, such as would result from a similar increase in hardness produced by raising the combined carbon content.

A curious feature of either copper or nickel additions to cast iron is that the transverse strength is increased progressively in irons having a Brinell hardness of under 200, but in harder irons there is usually an improvement only with the first addition, and thereafter a slight falling-off. In view of the simultaneous increase in both tensile and compressive strength, this falling-off in transverse strength may perhaps be regarded as a peculiarity rather of the test than of the properties of the iron.

Fig. 10.—Microstructure of Cast Iron showing Normal Graphite. Unetched. × 50. (B.C.I.R.A.)

It has been shown experimentally that additions of copper alone, or nickel alone, or copper plus nickel up to a total alloy content of 3 per cent., have a very similar effect on mechanical strength.

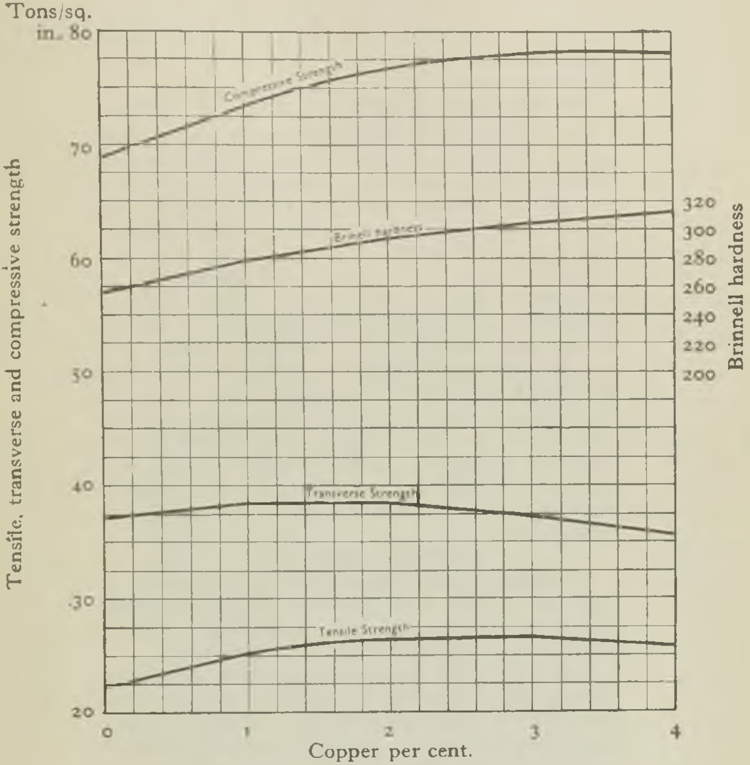


FIG. 11.—EFFECT OF COPPER ADDITIONS ON MECHANICAL PROPERTIES OF GREY CAST IRON (EASTWOOD, BOUSU, AND EDDY).

The toughness of cast iron, as judged by the repeated impact test, is considerably improved by additions of up to 1½ per cent. copper, as is shown by the following data obtained on inoculated cast iron containing 3.0 per cent. carbon, 1.50 per cent. silicon, 0.80 per cent. manganese, 0.106 per cent. phosphorus and 0.102 per cent. sulphur.

	1	2	3
Copper, per cent. . .	—	1.02	1.60
Repeated impact blows to fracture	1,277	2 851	3,372

The improvement in toughness resulting from copper additions is also noticeable in white-iron castings which are being increasingly used even for highly stressed and moving parts, an example of which is the Ford die-cast valve push-rod shown in Fig. 12.

These valve push-rods are chill-cast in permanent moulds with a sand core, and are heat-treated to remove casting strains and to soften the matrix, but are not heated hot enough nor long enough to make the iron grey, as white iron is essential to give wear resistance. This iron is very low in silicon and contains 0.75 to 1.0 per cent. copper; the action of the copper is to confer on the pearlitic matrix the necessary toughness to counteract the inherent brittleness of the undecomposed cementite in the chilled iron.

Balanced Additions

A striking improvement in the properties of grey iron arises from the replacement of silicon by copper or from balanced additions of copper with manganese, chromium or molybdenum.

Table III gives typical examples of such additions. The properties of the first pair of irons illustrate the improvement obtainable by replacing silicon by copper, while the second and third pairs show the effect of balanced additions of copper and manganese, and copper and chromium respectively. In the last group, the first two irons show the improvement in properties obtainable in an iron containing ½ per cent. molybdenum by the addition of about 1½ per cent. copper, whilst a comparison between the first and third irons in this group again emphasises in a striking way the effect of replacing silicon by copper.

TABLE III.—*Effect of Balanced Alloy Additions to Cast Iron.*

Composition, per cent.						Tensile strength. Tons per sq. in.	Modulus of rupture. Tons per sq. in.	Brinell hardness.
C	Si	Mn	Cu	Cr	Mo			
2.95	2.26	0.70	0.30	—	—	18.8	30.6	248
2.85	1.61	0.53	1.90	—	—	27.8	44.3	299
3.10	1.63	0.48	0.16	—	—	—	31.0	225
3.08	1.52	1.10	2.20	—	—	—	38.2	233
3.21	2.39	0.61	—	—	—	—	27.0	188
3.21	2.35	0.71	1.92	0.45	—	—	32.0	240
2.99	2.25	0.61	—	—	0.51	17.0	31.8	207
2.99	2.25	0.61	1.66	—	0.51	21.0	34.2	255
2.92	1.61	0.64	1.23	—	0.47	26.1	46.7	259

High-nickel austenitic cast irons such as "Ni-Resist" usually contain about 7 per cent. copper. Such irons offer a marked resistance to almost all types of corrosive media and are practically immune from growth at elevated temperatures. Owing to their surface work-hardening properties, they are also widely used for plant handling liquids containing abrasive solids, *e.g.*, sand in suspension.

FIG. 12.—DIE-CAST VALVE PUSH-ROD, HAVING ANALYSIS: T.C, 3.65-3.90; SI, 0.30-0.65; MN, 0.15-0.50; CU, 0.75-1.0; P, 0.05 (MAX.), AND S, 0.08 (MAX.) PER CENT.

II.—COPPER IN MALLEABLE IRON

Copper has proved itself a valuable addition to blackheart malleable iron, since it both accelerates annealing and also improves mechanical properties.

Effect on Annealing

Copper additions to blackheart malleable have a marked effect on the rate of formation of temper carbon, which increases progressively with the copper content up to the limit of solubility of copper at the annealing temperature, *i.e.*, about 3.5 per cent. The explanation appears to lie in the fact that copper in solution favours the formation of a larger number of carbon nuclei in the initial stages of breakdown. Figs. 13 and 14 show the structure of a 1 per cent. copper and a

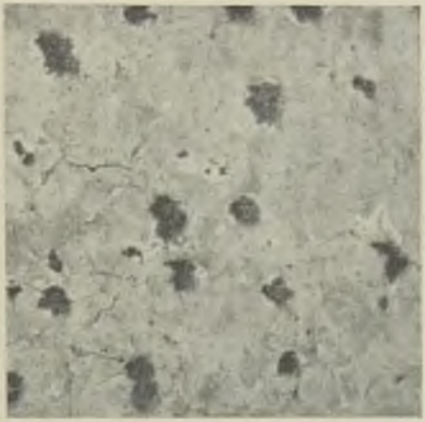


Fig. 13.—White Cast Iron containing 1.2 per cent. Si and 1 per cent. Cu, annealed 2 hrs. at 925 deg. C., air cooled. Etched Sodium Picrate. × 200. Note Fine Nodules of Temper Carbon. (Smith & Palmer.)

copper-free iron respectively, after two hours soak at 925 deg. C., etched in boiling sodium picrate, which stains cementite brown (photographs black). It will be noticed that, although the breakdown has been more complete in the copper iron, the carbon nodules are appreciably smaller. This refinement of temper carbon is reflected in the improved mechanical properties of copper-bearing malleable iron discussed later.

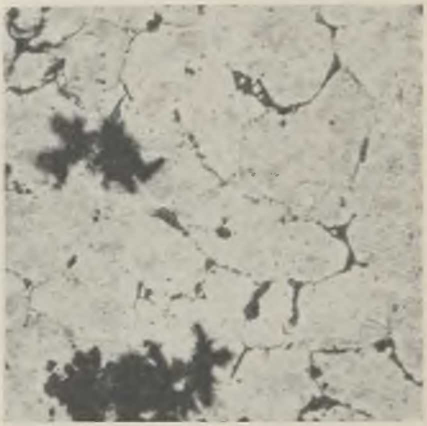


FIG. 14.—WHITE CAST IRON CONTAINING 1.2 PER CENT. SI AND NO COPPER, SAME TREATMENT AS IN FIG. 13. ETCHED SODIUM PICRATE. × 200. (SMITH & PALMER.)

Table IV shows the time required under laboratory conditions for the two stages of graphitisation—the breakdown of free carbide and of pearlitic carbide respectively—in an iron containing 2.4 per cent. carbon, 1.01 per cent. silicon, 0.31 per cent. manganese, 0.144 per cent. phosphorus and 0.075 per cent. sulphur. Experiments with higher carbon irons and varying soaking temperatures have given similar results. The shortness of these annealing times may come as something of a shock to those accustomed to cycles of several days in batch type, and even tunnel

TABLE IV.—*Influence of Copper on Graphitising Malleable Iron.*

Copper, per cent.	Time, at 925 deg. C. for first-stage graphitisation. Hrs.	Time, at 725 deg. C. for second-stage graphitisation. Hrs.
—	8.0	13.2
1.33	5.2	6.0
1.73	4.0	5.5
2.94	2.4	4.5

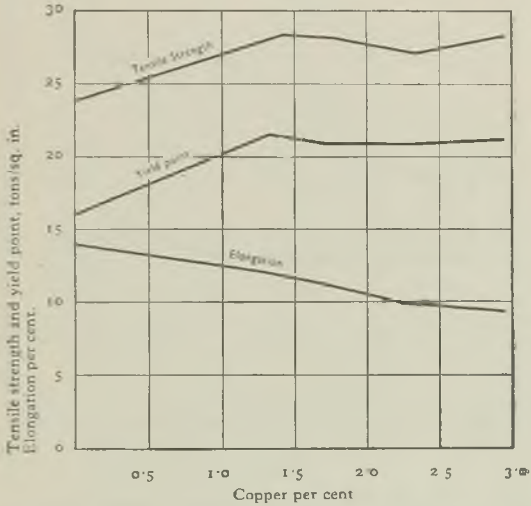


FIG. 15.—EFFECT OF COPPER ADDITIONS ON MECHANICAL PROPERTIES OF BLACKHEART MALLEABLE IRON CONTAINING C 2.4, SI 1.01, MN 0.31, P 0.144 AND S 0.075 PER CENT. (LORIG & SMITH.)

furnaces, but low-carbon copper malleable is to-day being fully annealed in atmosphere-controlled continuous annealing furnaces in as little as 13 hrs.

Mechanical Properties of Copper Malleable Iron

Fig. 15 shows the effect of increasing copper additions on a malleable iron which was annealed in a commercial furnace to give an all ferrite matrix. An addition of 1.4 per cent. copper produces an increase in tensile strength of 3½ tons per sq. in., and in yield point of 5½ tons per

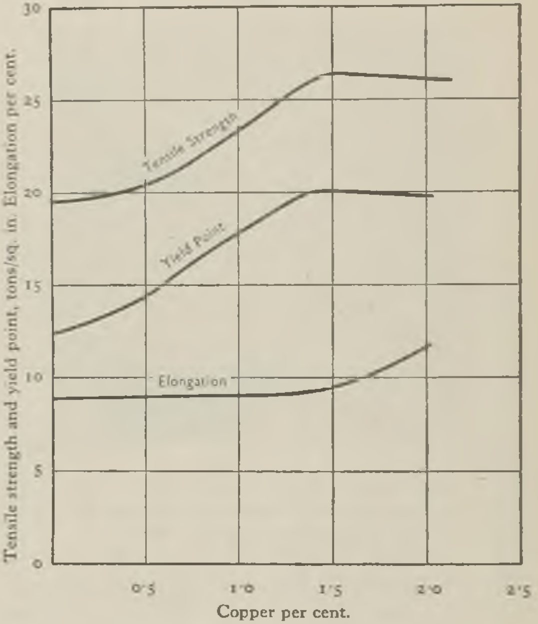


Fig. 16.—Effect of Copper Additions on Mechanical Properties of Blackheart Malleable Iron containing C 2.8, Si 0.95, Mn 0.27 and P 0.12 per cent. (Lorig & Smith.)

sq. in., whilst the elongation is reduced from 14 to 12 per cent.

It will be observed that the base iron is a low-carbon malleable of fairly high strength. It may be seen from Fig. 16, however, that if copper additions are made to weaker high-carbon irons, the tensile strength and yield point can be raised to almost the same figures, *i.e.*, about 27 tons per sq. in. and 20 tons per sq. in. respectively. Since the weakness of high-carbon irons is mainly due to the fact that the temper-carbon nodules are relatively large, the equality of strength in high- and low-carbon irons containing copper is an indication of the refinement in temper carbon arising from the copper addition.

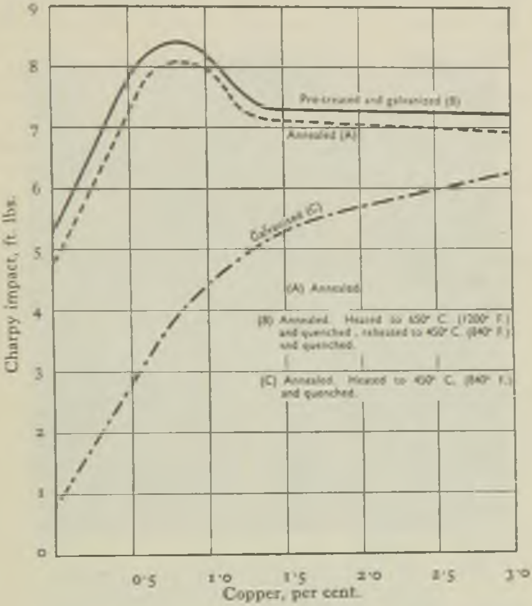


FIG. 17.—EFFECT OF COPPER ON IMPACT RESISTANCE OF MALLEABLE IRON. (LORIG & SMITH.)

Malleable iron is susceptible to intergranular embrittlement when held at temperatures of about 500 deg. C., as, for example, in the galvanising process. It is therefore often necessary to precede galvanising with a corrective treatment which consists of quenching from about 650 deg. C. The presence of copper, however, greatly reduces this tendency to embrittlement and obviates the necessity for such preliminary treatment. As shown in Fig. 17, copper-free irons are very brittle after galvanising as compared with annealed irons, unless they have previously received a corrective treatment; but in irons containing upwards of 1 per cent. copper, the impact resistance after galvanising is about the same as in annealed copper-free irons. The

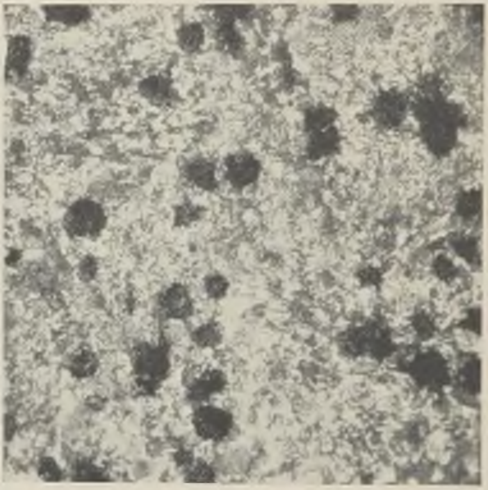


FIG. 18.—MICROSTRUCTURE OF WHITE-HEART MALLEABLE IRON (CORE) CONTAINING 1.65 PER CENT. COPPER. ETCHED PICRIC ACID. × 100. (B.C.I.R.A.)

curves in Fig. 17 incidentally show the general improvement in toughness arising from copper additions.

Whiteheart Malleable Iron

There does not appear to be any record of copper additions to whiteheart malleable iron. However, in view of their beneficial influence on blackheart malleable iron, the Copper Development Association is now investigating the effect of copper on the mechanical and annealing properties of whiteheart. The investigation has not, as yet, proceeded very far, but in Figs. 18 and 19 are shown the microstructure at the core of two whiteheart bars poured from the same ladle and containing 1.65 per cent. copper and no copper respectively. Both bars were given a quick anneal in the same pot, the whiteheart process being employed. The analysis of the two bars after annealing was as follows:—

	No. 1. Per cent.	No. 2. Per cent.
T.C	2.46	2.58
C.C	0.75	0.93
Gr.	1.71	1.65
Si	0.78	0.79
Mn	0.40	0.39
S	0.231	0.240
P	0.052	0.051
Cu	1.65	—

The refinement of temper carbon in the copper-bearing iron is very marked, and cannot fail to have a favourable influence on mechanical properties, although this has yet to be confirmed by means of tensile tests. Moreover, a comparison between the combined and total carbon contents of the two bars as annealed, indicates that the addition of copper has not only promoted the breakdown of combined carbon to temper carbon, but has also accelerated the diffusion and reduction of iron carbide—the essence of the whiteheart process.

The author wishes to express his gratitude to the British Cast Iron Research Association for permission to use information contained in Research Reports Nos. 124 and 125, to the Ealing Park Foundry, Limited, for permission to include data on copper additions to Meehanite cast iron, and to Sir W. G. Armstrong Whitworth & Company (Ironfounders), Limited, for their co-operation in connection with the step-bar castings illustrated in Figs 2 to 4.

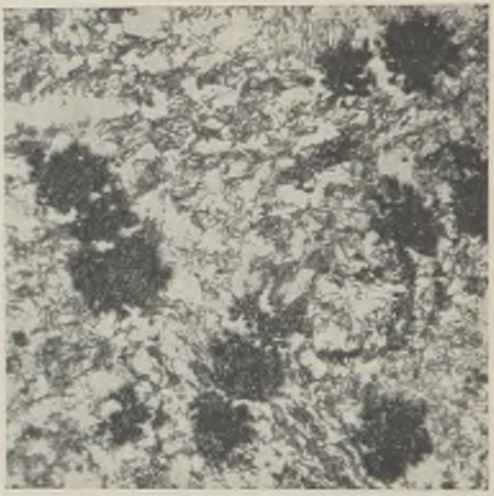


FIG. 19.—MICROSTRUCTURE OF COPPER-FREE WHITEHEART MALLEABLE IRON (CORE). ETCHED PICRIC ACID. × 100. (B.C.I.R.A.)

DISCUSSION

MR. F. K. NEATH said it had, of course, been obvious for some years that copper was a useful element to add to cast iron as well as to steel; it was, moreover, considerably cheaper in use than some of the more familiar alloys. Mr. Sallitt had made considerable reference to the use of copper in the Ford motor works. That concern had done much research, and it was certain that the question of cost had entered into the matter as well as other factors. Members would appreciate from Mr. Sallitt's lecture, however, that cost was by no means the only point to be submitted in favour of copper additions. Mr. Neath said he was sure members would look forward to the opportunity of reading Mr. Sallitt's book on the subject when published.

Additions of copper were very easy to make, and did produce a more uniform and wear-resistant structure. Mr. Sallitt had dealt with the subject chiefly in relation to motor-car parts; in the West Riding, foundrymen were concerned largely with textile plant and machine tools, and they would be glad to learn whether the lecturer had had any experience of copper additions to castings for such purposes, and if so what his conclusions were in regard to improved wear resistance and closening of grain.

Mr. Sallitt replied that the use of copper had been so far chiefly confined to industries making light castings such as the motor industries, and he had not had experience of copper being used for really heavy castings. It was, however, apparent that the refinement and hardening of the matrix by copper were little affected by cooling rate, in view of the fact that copper produced a considerable increase in hardness and strength in fully-annealed steel castings.

Mr. S. Carter, referring to the claims for copper addition in the direction of Brinell hardness, inquired whether it might perhaps create difficulties in machinability. He also asked whether the lecturer would explain the reason for the inverse action of copper on the hardness of thin or thick sections.

Mr. Sallitt said, in reply to the first question, that copper was present in cast iron either in solution or as fine particles of what was virtually pure copper. In neither form could it lead to any machining trouble, despite the increase in Brinell hardness. As to the second question, copper by its graphitising action removed chill from, and hence softened, thin sections, but by its alloying and refining action strengthened and hardened thicker sections.

Impurities Added with Copper

Mr. H. A. MacColl, B.Sc. (Bradford Technical College), inquired which of the alloy irons mentioned required heat-treatment. Was there any beneficial thermal effect or improvement in heat-conductivity, and were these copper irons being used in the manufacture of rolls? Mr. MacColl noted also that Mr. Sallitt had mentioned the use of old fire-box scrap, which might contain substantial quantities of arsenic. What would Mr. Sallitt consider the limit of impurities permissible?

Mr. Sallitt replied that only the low-carbon white irons such as were used for crankshafts were heat-treated; copper did not increase the heat-conductivity of cast iron. As regards rolls, experimental work was proceeding in that direction, and in answer to the fourth question he had not found any harmful effect resulting from such impurities as might be present in copper fire-box scrap, etc.

Mr. A. S. Worcester asked whether, in a copper alloy, there might be a danger of the copper "sweating" out in beads on the face of the metal. Mr. Worcester noted also that the lecturer had referred only to low-carbon irons, and he wondered whether there was any reason against copper addition to ordinary high-carbon irons of, say, 3 per cent.?

Mr. Sallitt said that all copper was in solution above the critical temperature, so that there was no danger of sweating. In regard to carbon content, most of the experimental data, used to illustrate the lecture, referred to irons with a fairly low-carbon content. Low-carbon irons were, of course, considerably stronger than higher carbon irons, and many people took the view that the first step in securing a high-duty iron was to lower the carbon content. However, copper had proved itself to be effective in high-carbon irons; for example, the carbon in the two camshafts ran as high as 3.65 per cent. and in the push rods 3.90 per cent.

Influence of Phosphorus

In answer to a member who asked whether phosphorus content had any substantial effect in the addition of copper, Mr. Sallitt said he did not think the phosphorus content mattered at all in so far as the graphitising action of copper was concerned, but naturally the beneficial effect of copper on strength would be obscured if the phosphorus content were very high.

Mr. Neath said he was inclined to think this might be a point worthy of further inquiry. When alloy additions to cast iron were first introduced into this country, foundrymen started putting all manner of things into the metal, and they experienced shrinkage cavities, porosity, open grain, etc. He felt there was scope for every member individually to make some research on this ground. In Mr. Sallitt's own work, he would like the lecturer to visualise the average jobbing foundry in which there was usually only one mixture. If he could give any lead, or any member could assist with his own experience, it would lead to valuable information.

Mr. Worcester asked if Mr. Sallitt could say that, in an ordinary 3 to 3½ per cent. carbon iron with, say, 1 per cent. phosphorus, copper would have a beneficial effect.

Mr. Sallitt said that by preventing open grain, it would be beneficial.

How Sulphur Reacts

In answer to Mr. Carter, the lecturer said there was no danger of copper combining with the sulphur in cast iron, since the affinity of manganese for sulphur was higher than that of copper.

Vote of Thanks

Mr. Neath, moving a vote of thanks to Mr. Sallitt, suggested it would be worth while for all members to do a few experiments with copper additions. Personally, he intended carrying out a series. He felt satisfied that, treated properly, copper was a useful addition, and certainly had an advantage in the matter of cost.

Mr. Slingsby, seconding, said Mr. Sallitt had given a most illuminating outline of the value of the process. He had, however, shown that the addition of copper tended to break down the carbon, whereas they had always been given to understand that the carbide should be retained in a malleable casting. Perhaps the lecturer might offer a little more enlightenment on that point?

Mr. Sallitt, replying to the vote of thanks, and to Mr. Slingsby's comment, reminded the meeting that copper was a more powerful graphitiser during the annealing than in the casting, which was one reason for its usefulness as an addition to blackheart malleable iron.

Written Contribution

Mr. E. M. Currie, who wrote to congratulate the author upon his concise and informative Paper, referred to the section dealing with the influence of copper on the mechanical properties of grey iron. He added that since it was known that the solution power for copper of high steel mixes of lower total carbon content, with a graphitic deposition of less than 2.2 per cent., was greater than that of ordinary cast iron, then the series of results obtained from such a mix would be likely to vary from the results as given in Fig. 11 of the Paper.

To confirm his opinion, Mr. Currie referred to the following table, which was based upon the work done by the Meehanite Metal Institute on the effect of copper on Meehanite metal.

It is to be noted that as the copper increases, so do both the tensile and the transverse properties. It is admitted that the results given are applicable only to 3.0 per cent. copper. It is not at all clear that additions above this amount will go into complete solution in ordinary grey iron. Iron itself will take up about 9.0 per cent. in solid solution but, in the presence of carbon, solution is rapidly diminished so that in a 2.8 per cent. carbon iron particles of copper will begin to show up soon after 3.0 per cent. copper is reached, except where intensifying elements, such as nickel, molybdenum, manganese or chromium are present.

Copper. Per cent.	Brinell hardness.	Tensile strength. Tons per sq. in.	Transverse, 1.2 in. dia. bar, 18-in. centres. Breaking load. Lb.	Deflection.
None	229	23.3	3,171	0.260
0.6	234	24.9	3,202	0.280
1.4	269	27.9	3,362	0.255
2.0	285	27.5	3,541	0.270
3.0	302	27.7	3,400	0.255

In conclusion, Mr. Currie drew attention to the fact that the additions of copper to graphitised irons had been patented under British Patent No. 463,145 granted to the Meehanite Metal Corporation of America.

Author's Reply

In reply, the AUTHOR wrote that he was in full agreement with Mr. Currie that copper additions have a more beneficial effect on the mechanical properties of low carbon irons of the Meehanite type than on those of high carbon irons.

With regard to the solubility of copper in iron and steel, although steel can hold as much as 8 per cent. of copper in solid solution at a temperature of about 1,100 deg. C., it is doubtful if more than 3 to 3.5 per cent. can be retained in solution at the critical temperature unless the steel be quenched from high temperatures. He thought, therefore, that the effect of copper on the strength of the cast iron matrix was probably very similar in all irons, but that in high carbon irons it was obscured by the presence of relatively coarse plates of graphite. In low carbon irons, however, and more particularly in the "graphite conditioned" irons of the Meehanite type, the strength of the iron as a whole more nearly approximates to that of the matrix and, therefore, copper additions may be expected to be the more effective.

Sheffield Branch

CARBON AND ALLOY STEEL CASTINGS* Paper No. 655

By J. E. MERCER and D. K. BARCLAY

Cypritic Steel

The authors have been requested to make some reference to the new copper-chromium stainless steel developed by W. P. Digby and E. Digby. The information may not be as complete as may seem desirable from a steel-castings point of view, owing to the fact that the reports expected on castings on trial for various uses are not yet to hand. The firm with which the authors are connected is only interested in castings and forgings made from this steel, but they will, as a matter of interest, include information on other aspects in connection with it. The knowledge that it contains a large copper content naturally suggests the question: "What does this steel look like?"

At first sight, as a bar is taken from the pickling solution, it looks not unlike any of the now familiar austenitic stainless steels. When polished and compared, the new steel appears to be more silver-like and less blue than the austenitic steels. For certain uses the chromium is under 15 per cent. and the copper content is from 6 to 10 per cent. Usually the composition is 18 per cent. chromium and 8 per cent. copper; the carbon is kept as low as possible. Silicon and manganese are about 0.30 and 0.50 per cent. respectively.

Compositions with copper as high as 15 per cent. have been found homogeneous and forge-

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* The original Paper consisted of a comprehensive discussion on general steelfoundry practice and on most of the carbon and alloy steel compositions. Owing to space limitations it has only been possible to include in this volume that part of the Paper dealing with a more recent development in alloy steels.

able. The melting practice in no way differs from that associated with the making of other stainless steels. The copper can be added at any stage of the melting without fear of loss by oxidation.

FIG. 1.—PHOTOMACROGRAPH OF SAND-CAST COPPER-CHROMIUM STEEL, SHOWING COARSE GRAIN. × 5.

A notable feature of these steels is their high fluidity; it can be tapped out when the metal just leaves the spoon clean. It flows freely in the moulds, and castings with sections as thin as $\frac{5}{16}$ in. thick present no difficuty.

Grain Refinement

It was found at the beginning that, especially on the heavier sections of castings, the grain size was inclined to be coarse, but attention to pouring temperatures and cooling rates has reduced the grain size to reasonable dimensions. The series of macro etchings (Figs. 1 to 3) will show the result of efforts made in that direction. The black patches on some of the photomacro-

Fig. 2.—Photomacrograph of Sand-Cast Copper-Chromium Steel, showing Medium Grain. × 5.

graphs shown are from shadow owing to the specimens not fracturing cleanly. Fig. 1 shows the coarse grain from 3 in. by 4 in. sand-cast

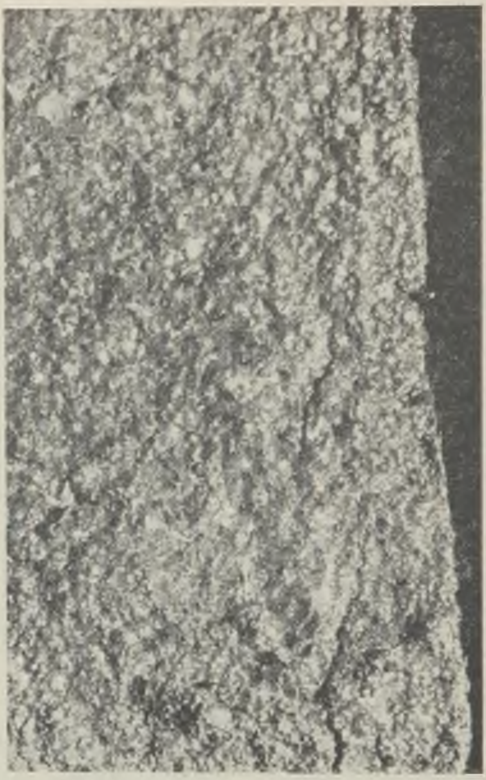


FIG. 3.—PHOTOMACROGRAPH OF SAND-CAST COPPER-CHROMIUM STEEL, SHOWING FINE GRAIN. × 5.

test-bars; Fig. 2 a medium grain; and Fig. 3 fine grain, all similarly cast. On fracturing sand-cast ingots, and ingots from ingot moulds,

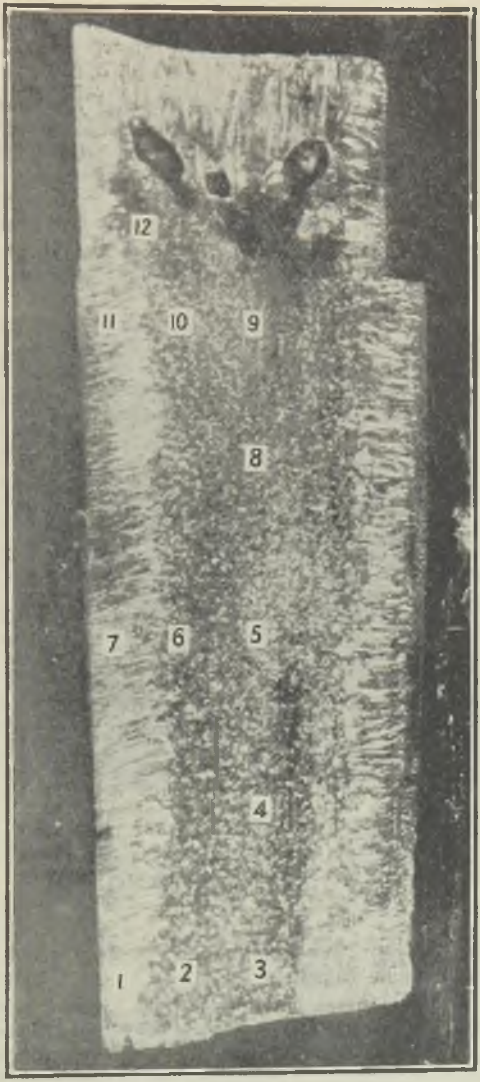


FIG. 4.—SPLIT INGOT OF COPPER-CHROMIUM STEEL, SHOWING DISTRIBUTION OF COPPER. (BATTELLE INSTITUTE, OHIO.)

Location No. 1, 8.02 per cent. Cu; No. 2, 7.83; No. 3, 7.93; No. 4, 7.75; No. 5, 7.74; No. 6, 7.91; No. 7, 7.81; No. 8, 6.97; No. 9, 7.11; No. 10, 7.97; No. 11, 7.35 and No. 12, 7.93.

a noticeable difference is at once apparent. Both are abnormal; in the former there are equi-axial crystals which apparently suggest a product of dubious utility, and in the latter the characteristic is that of a periphery or border of dendritic crystals and a core of equi-axial crystals. An excellent example of the above is given in Fig. 4, relating to a 7-in. by 7-in. by 16-in. split ingot prepared and photographed by the Battelle Institute, Ohio.

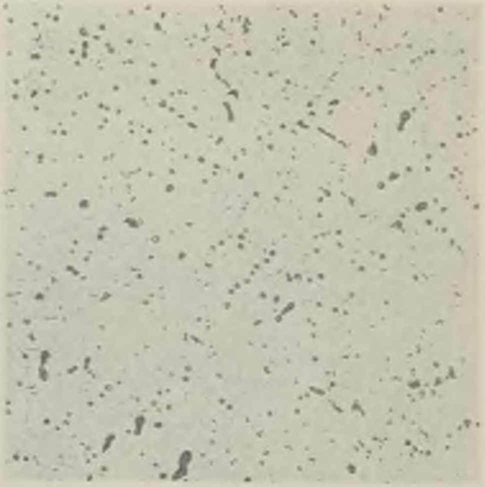


Fig. 5.—Microstructure at Location No. 11 in Fig. 4. Specimen Heat Tinted. Dark Particles constitute Copper-rich Phase. × 100.

If this illustration is examined at the various locations it will be observed that besides there being no rich copper core, there is comparatively little difference in distribution throughout the ingot. Attention is directed to locations 10, 11, 9; 7, 6, 5; and 1. 2, 3.

The microstructure at location No. 11 is shown in Figs. 5 and 6, both of which are at 100 magnifications.

Homogeneity Satisfactory

The Battelle Institute's reading of the structure is:—Rich copper constituent in an iron chromium matrix, the darker phase having distinct martensitic markings under high magnifications. Inclusions are few and well distributed.

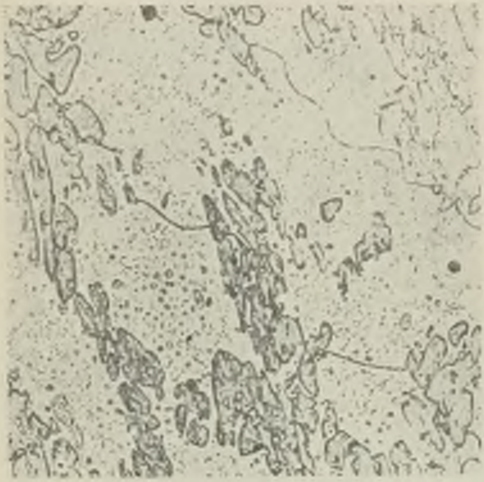


FIG. 6.—AS FIG. 5, AFTER THE SPECIMEN WAS REPOLISHED AND ETCHED WITH FERRIC CHLORIDE. × 100.

The chromium-copper steels are magnetic and show no definite change-point. It can be said, however, that quite different mechanical characteristics are obtainable by heat-treatment at temperatures in the vicinity of 930 deg. C. and 500 deg. C. An interesting feature is the wide range of hardness possible by heat-treatment.

On castings containing 10 per cent. of copper, Brinell figures of from 170 to 440 have been obtained.

It is worthy of mention that, unlike other stainless steels, a marked increase in hardness takes place, due to precipitation hardening, when tempered at 500 deg. C. Tempering at 750 deg. C. produces the softest material, and the best impact values are obtained about that temperature. Izod values of as high as 27 ft.-lbs. have been obtained on copper-chromium steel castings, but on the whole an average of 15 ft.-lbs. is about the normal result. Possibly with the improvement in grain-size attributable to pouring temperatures, later experiments may show somewhat better average figures. With regard to Izod tests carried out on forgings, the results are remarkable to a degree. Values of 50 to 110 ft.-lbs. according to composition and heat-treatment are quite common.

Mechanical Tests

Mechanical tests carried out on castings indicate that it should be quite possible to get consistent tensile strengths of from 36 to 42 tons per sq. in. and an elongation of 20 per cent. in 2 in. Composition materially influences tests on castings. It appears at present as though the best figures for ductility will be obtained on steels with 15 per cent. chromium content. In the forged condition, tensile strength ranges between 36 and 50 tons per sq. in., the yield being 75 to 80 per cent. of the ultimate value, and the elongation 20 to 25 per cent. Quenching raises the tensile strength to 70 or 80 tons per sq. in., and with subsequent tempering gives intermediate strengths with increasing ductility. Annealing without subsequent reheating will give an ultimate strength of 33 tons per sq. in. and a yield of 24.5 tons per sq. in.

Welding

Welding has presented no difficulty, and any of the following processes may be used:—Arc, oxy-

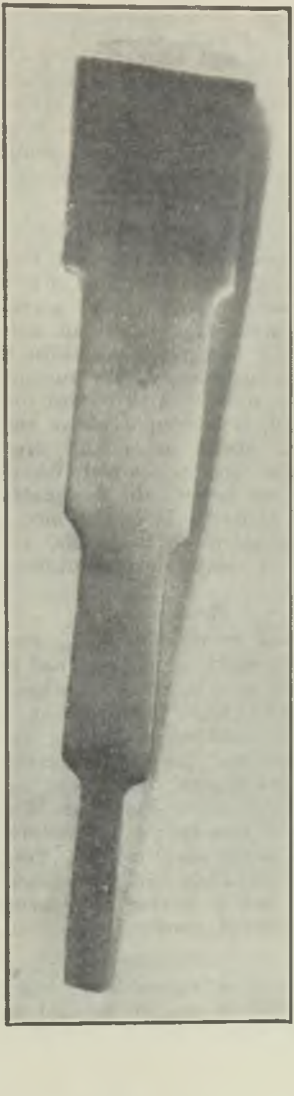


FIG. 7.—FORGING OF CYPRITIC STEEL.

acetylene, atomic hydrogen and spot welding Examination of welds on copper-chromium steels suggests that copper is effective in retarding grain growth at high temperatures. Comparative tests for intergranular corrosion with austenitic stainless steels showed the cypritic steels to advantage. A dependable weld is obtained without the necessity of subsequent heat-treatment a feature worth considering in structural work and fabrications.

Corrosion Resistance

It is obviously impossible in a Paper of this description to give the reactions of cypritic steels to the rather imposing list of corrosive media with which metallurgists are all now familiar. It may be said, however, that whilst it is not so good in some instances as the austenitic nickel-chrome steels, notably with regard to nitric and sulphuric acid, it is comparable in chloride solutions, lactic, acetic acids and organic acids generally. For some of the more corrosive media one may yet see it with the designation cypritic steel " with alloys." It is also now being used in the preparation of foodstuffs, and brewers have found it particularly suitable for their requirements.

Machinability

With regard to machinability, steels of this group may be sawn, drilled, turned and planed with the same ease as medium-carbon steels. It does not work-harden in machining, which is a feature of importance, since the sulphur and phosphorus content are low. Having in mind the initial grain size, it will be agreed that the authors did not contemplate forging with any degree of pleasure; the disasters predicted materialised in the early efforts. Yet, when the technique of handling had been acquired, forging became just a matter of observation to a carefully regulated routine.

Forging

Cypritic steel is amenable to working when hot, and whilst it cannot be said to work as easily as carbon steel, it has been brought down under the hammer from 4 in. square billets to ½ in. round. Bars of 1 in. diameter and 12 ft. long have been successfully made. Fig. 7 illustrates a forging, showing reduction; the clean edges and freedom from corner cracking are to be noted. The original ingot was of induction furnace steel, and had the normal markedly-dendritic periphery and coarse crystalline formation in the centre. It was noticed that, although

FIG. 8.—MACRO OF CYPRITIC STEEL INGOT FOR 2-IN., 1-IN. AND ½-IN. FORGINGS. × 6½.

the coarse crystallisation underwent such a transformation, it was not so apparent in the photomicrographs. Photomacrographs of $6\frac{1}{5}$ diameters and photomicrographs by 120 diameters are shown in Figs. 8 to 11.

Fig. 8 shows a macro of the ingot, and Fig. 9 a photomicrograph taken at its edge. It is unfortunate that this picture includes some of the finer grain at the outside of the ingot, and was not noticed until too late to replace. Figs. 10 and 11 show similar sections for the ½-in forging.

FIG. 9.—MICROSTRUCTURE AT EDGE OF INGOT SHOWN IN FIG. 8. × 120

Billets 9 in. square have been forged down to circular 4 in. billets and extruded into perfectly good tubes of 1½ in. dia., 8 ft. long, the wall thickness being $\frac{3}{16}$ in. Fig. 12 shows a section of extruded tube. Fig. 13 shows a photomicrograph of the longitudinal section of tube, and Fig. 14 the transverse section. Shafts of 4 in.

dia. and 9 ft. 6 in. have been successfully forged and are now in use.

Wire and Sheets

Ingots have been forged down to 2 in. dia. and 14 ft. lengths, which were subsequently rolled down to wire rod, and wire of 70 to 80 tons tensile strength produced. In drawing down to wire, reductions of 80 per cent. in area are obtainable before re-annealing is necessary.

FIG. 10.—MACRO OF ½-IN. FORGING IN CYPRITIC STEEL. × 6½.

Sheet and strip are being cold-rolled with the

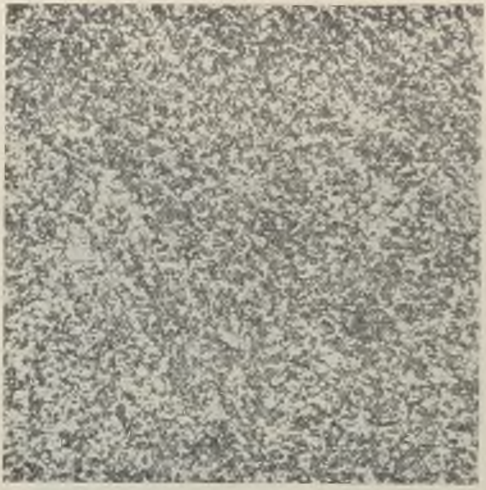


Fig. 11.—Microstructure of $\frac{1}{2}$-in. Forging shown in Fig. 10. × 120.

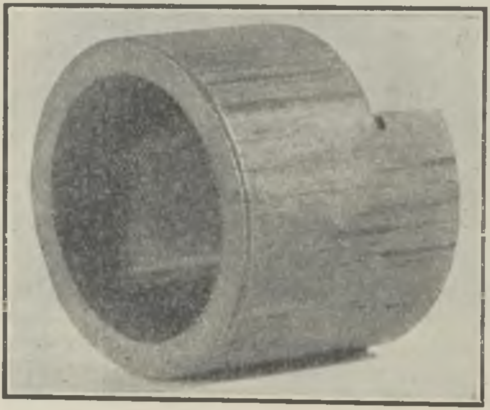


Fig. 12.—Section of Extruded Tube of Cypritic Steel.

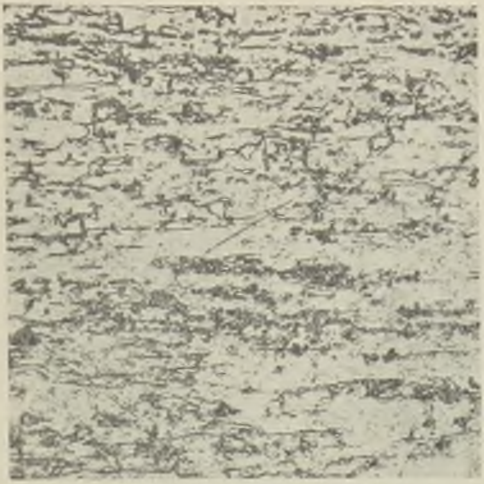


Fig. 13.—Microstructure of Longitudinal Section of Extruded Cypritic-Steel Tube. × 500.

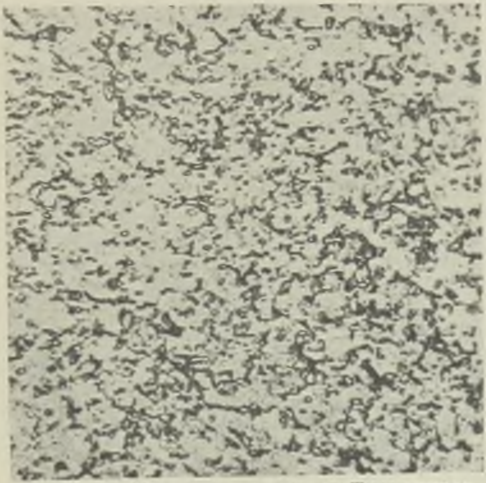


Fig. 14.—Microstructure of Transverse Section of Extruded Cypritic-Steel Tube. × 500.

same ease as mild steel, and with no greater hardening under the rolls. A number of deep pressings have been made from sheet 22 by 22 in. One was 16 in. by 3½ in. deep; a second, 13½ in. by 5½ in. deep; and the third, 11 in. by 7 in. deep. In the cold-rolling of strip, successive passes through the rolls giving a total reduction of 65 to 70 per cent. without re-annealing is normal practice, but it has been found possible to secure a reduction of 55 per cent. in a single pass. The authors are informed that very interesting data with regard to corrosion-fatigue values of rod, bar, and wire from this interesting steel with its revolutionary composition will be available shortly.

West Riding of Yorkshire Branch

MOULDING SAND, WITH SPECIAL REFERENCE TO BLIND SCABS

Paper No. 656

By S. CARTER and A. W. WALKER

Papers on moulding sand practice have recently occupied the most prominent position in foundry technical literature, and this appears to signify the growing importance which the foundryman attaches to the correct control of this raw material. There are still many otherwise enlightened foundrymen, however, who still seek to claim precedence for the old-fashioned, unorganised and inconsistent systems of sand treatment which were universal before the war. Generally speaking, the individual craftsman was then allowed to prepare his own sand from the raw materials to suit his own taste, with the result that a diversity of results was produced concurrent with the number of moulders employed. When all the arguments about the merits of present-day craftsmen (which are usually derogative) compared with those of a previous generation have been exhausted, there is surely so much in favour of direct supervision and control of sand as to inhibit entirely any discussion on merit.

Without entering into detail, it is sufficient to note that such points as consistency of sand supplied to the operatives, coupled with the certain knowledge that the best sand condition has been attained, the reduction in costs due to better moulding properties, the uniformity of product from man to man, and, what is most important, from order to repeat order, qualify sand control, in the authors' opinion, as representing an immense stride in the slowly proceeding scientific emancipation of the foundry industry.

It is certain that, in the future, foundries without some method of sand control will eventually become redundant, although the authors do not wish it to be inferred that they consider sand control purely from a mechanisation point of view. This method certainly facilitates closer and easier control, and for those who can afford the outlay there is no doubt that handsome savings, outside the scope of this Paper, can be effected. Sand investigation by the very uninitiated cannot fail to bring forth some enlightenment, and the absorbing and interesting results which are obtained usually whet the appetite for further research.

Jobbing Foundry Application

The Papers on sand control which have appeared recently appertain, with few exceptions, to foundries operating on repetition or standard lines. Mechanical systems are usually much more difficult to operate in a jobbing foundry, and with this in mind the authors decided to build this Paper around the practice obtaining in one of the foundries with which they are connected, where the work is strictly of a jobbing character of very wide variety.

Prior to the preparation of this Paper, the excellent articles on the subject of sand by Buchanan, Hudson, Sheehan and others were examined very thoroughly, and such points of interest and controversy culled from them which appeared to have a fundamental bearing on the work to be undertaken. The authors desire at this point to make acknowledgement to the various authors concerned, and to express their admiration of the value of the pioneer work so ably performed.

About three years ago, at the foundry under consideration, it was decided to institute control of the sand and its preparation, and to evolve, if possible, a sand which would function without radical alteration for the production of all classes of casting, *i.e.*, green sand and dry sand or loam. This was considered to be one of the most important points to be borne in mind, as it was felt that the operation of a mechanised plant would be very much simplified by operating a sand which could, with minor adjustment, be subjected to the same treatment without the interferences and stoppages which would be necessary when trying to obtain different mixtures and qualities. With the valuable co-operation of Mr. B. L. Broadbent, managing director of T. Broadbent & Sons, Limited, of Huddersfield, for whom the plant was designed, Pneulec, Limited, supplied the sand mixing and handling machinery, and operations were commenced on the foregoing basis.

On the assumption that a heavily bonded, highly permeable new sand would be necessary to provide the desired standard of mixed material, and also on account of the fact that less new sand additions were now contemplated, a proprietary sand, such as is used by many steelfounders, was chosen as likely to provide the desired results. The properties of this sand showed it to possess a remarkably high permeability value for so heavily bonded a sand, and in addition the bulk of the sand grains were so notably regular in size that it was thought an ideal base sand had been found. The properties of this sand at 6 per cent. moisture were permeability 120, and green bond strength 14 lbs. per sq. in. It should be noted that all test figures on sand shown in this Paper have been derived from the A.F.A. apparatus.

The figures sought for green sand were permeability 65 and green bond strength 6 lbs. per sq. in. at 5½ per cent. moisture. Trouble was experienced almost immediately due to the tendency of the sand to scab, and after investigation this proprietary sand was thought to be responsible. Although an apparently excellent material, it was found that the bond was so unevenly distributed as to cause a considerable amount of clay to exist as pellets, and even the intensive mixing now taking place was unable to blend them properly with the sand.

It has since been learned that, at the time, this sand was synthetically produced by adding lump clay to a naturally bonded sand, and that the addition of the clay in a finer state of division has improved the sand in this respect. Another reason for the cessation of the use of this sand was that, owing to the excellent preparation now taking place in the mixers, the inert bond in the floor sand was being developed so that little or no new sand was required for a period. Actually the plant operated for the first twelve months, in cycles of six to eight weeks, without the addition of new sand or bonding material of any description, interspersed with occasional weekly periods when small new sand additions were made.

With the reduction in the use of new sand, a marked improvement in finish was obtained, and when the time arrived for systematic new sand additions some twelve months after commencement of the system, the benefits of control were apparent. The point then arose as to which kind of new sand should be added to make up for the rising deficiency in bonding material. Hensall sand, cheaply obtainable in the locality and very popular in the district was tried first, but the results were disappointing owing chiefly to its lack of bonding power. The open nature of the sand also caused the permeability figures to rise and consequently prejudiced the finish on the green-sand castings.

In view of this, the more heavily bonded, finer grained Mansfield sand was substituted, and with the exception of occasional experimental runs with Pickering sand, the plant has operated until recent weeks on the following mixture, with periodic extra new sand additions when it was found that the bond strength was deteriorating:—Floor sand, 672 lbs.; Mansfield sand, 6 lbs.; and coal-dust, 12 lbs.

Such a mixture can only just maintain the sand in its desired state, and as all sand from whatever source was being put through the system, it was necessary from time to time to add higher proportions of new sand. Recently it has been found more efficacious to add the bonding material in the form of colloidal clay, and the results obtained so far have justified the departure from the previous system of using raw sand. When dry sand is required, the same mixture of sands is used with the elimination of coal-dust. The moisture is raised to $7\frac{1}{2}$ per cent. and wood pulp is added at the rate of 0.3 per cent. for providing the extra dry strength in the sand. Loam also is made from the same source, except that the moisture is of course much higher.

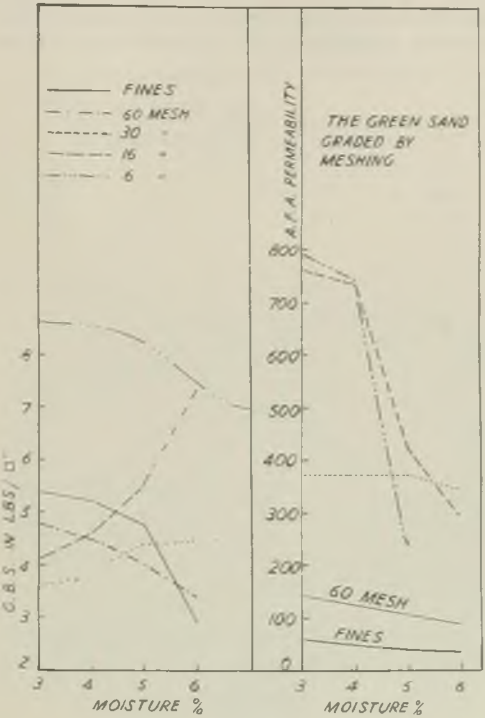


FIG. 1.

The Silt Question

A point worthy of note in view of the wide divergence of opinion on the silt question, is the covered bins situated above the sand mills. These bins are receptacles for the sand delivered from the foundry by way of the belt and elevator, and were originally made without tops. It was found, however, that the wind in the partially open building in which they are housed was exhausting the fine material in the sand to the detriment of the casting finish, and on account of this it was found necessary to protect the sand as it lay in the bins.

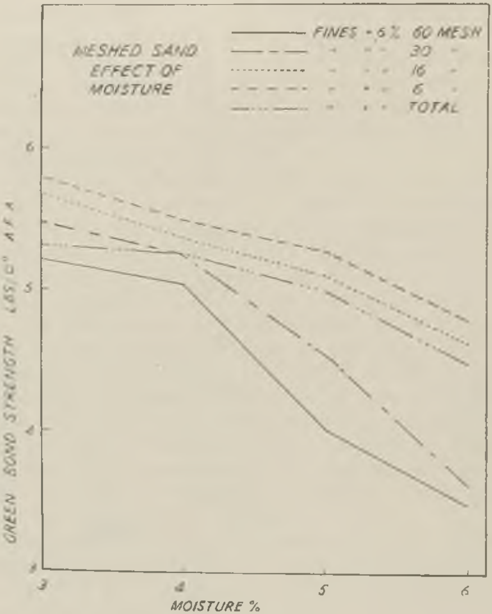


Fig. 2.

About this time several experiments were made in connection with the silt problem, and the breakdown and possible accretion of grain size were particularly studied. A series of cast-iron bars was made on twenty-one consecutive days, the sand used being that in general use throughout the foundry. After each cast, the casting was carefully removed, the adhering sand brushed off into the bulk, 5 per cent. coal-dust was added and after treatment the next cast was made. Samples of sand were taken from every cast and the bars produced, 1¼ dia. by 15 in. long, were examined to ascertain the effect on the skin. The castings obtained showed the increase in grain size which took place over the twenty-one casts, and the results are set out in Table I.

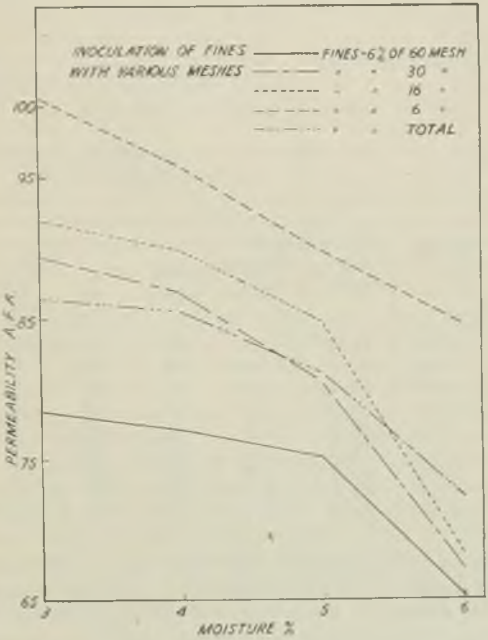


FIG. 3.

It will be observed that the sand grains gradually increased in size as the casts progressed, indicating that the fine material allies itself with the larger grained particles to form a larger composite grain. Other experiments on the same lines have since confirmed this result. It was then decided to find out how the bonding material was distributed throughout the sand which was used in the system. Samples were taken and meshed into their respective grades and Figs. 1 to 3 show the respective bonding values at differing moisture contents, also the effect of inoculating bulk fines with 6 per cent. of each of the other grades in separate ranges. The results of these tests indicate, that the bonding value of this particular sand lies in the 16-mesh grade, and not, as is commonly supposed, concentrated in the fine material. That this latter may not be the case in dealing with raw sand from the quarries the authors would not deny, but the effect of foundry conditions, with the continuous rubbing and movement, enables the larger grained material to lick up the finer sand and effectively to increase its size much in the way of a rolling snowball. These results indicated to the authors that when sand

TABLE I.—*Grain Growth after* 21 *Days, the Only Addition being* 5 *per cent. Coal-Dust after Each Cast.*

Moisture.	A.F.A. Permeability.	G.B.S. Lbs. per sq. in.	Grain size.		
			Pass. 60.	On 60.	On 30 and above.
5.75	64.6	5.1	38	47	15
5.75	66.7	4.8	38	45	17
6.0	66.7	4.7	37	50	13
5.75	58.9	4.0	36	43	21
5.75	66.7	3.8	30	47	23
5.5	64.6	3.3	33	40	27
5.75	62.6	3.2	30	40	30
5.75	62.6	3.0	29	36	35
5.5	64.6	2.8	28	36	36

is controlled the " problem " of silt need not arise.

Sand Properties Compared

Incidental experiments in connection with this Paper have been carried out on three well-known types of sand popular in the West Riding area of Yorkshire. The object was to compare the properties of the sands at ordinary ramming, but increasing density and its effect on mould values attracted the authors, who have set out the results shown in Tables II, III and IV. Four series of each sand were tested at differing moisture, and it will be observed wherein lie the maximum advantages to be obtained from any of the sands, *i.e.*, the optimum condition. Obviously, any one sand cannot possess all the virtues of an ideal, so that the user must average the properties obtainable which the two extremes of green bond strength and permeability will permit. For example, series 2 of the Pickering results obviously indicates the best and most advantageous condition for the use of this sand. Table V is of the green sand used in the foundry, but only two ranges of moisture are shown, as anything above or below these extremes produces an unworkable sand. In fact, the high moisture of the second series has so seriously depreciated the value of the sand as to indicate that moisture control in this particular sand lies within very close limits. Such an indication points to the fact that all the available bonding material is being utilised to the fullest extent with the moisture at 5½ per cent.

In view of the results just outlined, it may be asked if Pickering sand would not fulfil the purpose of the new sand addition to the system sand to better effect than the Mansfield, and on the face of it advantages would seem to be apparent. Furthermore, a refractoriness test carried out on cones of these sands showed quite clearly that Pickering sand possesses infinitely superior properties in this respect than does

Mansfield. Incidentally, also, it is a very evenly graded material and easy working. In the first place, the authors have evidence from previous tests that yellow sands do not hold their bonding material so tenaciously as do the red sands, that is, they have not the same life; additionally, the full value of Pickering sand was not realised until the experiments were fairly well advanced, and opportunity to try it out in regular practice has therefore been limited. Fig. 4 shows a series of sand cones, placed on a slab of "Durex" together with Seger cones. The letters on the sand cones indicate the type of sand of which they are composed:—P, Pickering; M, Mansfield; H, Hensall; GS, green sand; DS. dry sand. It will be observed that the Mansfield has completely collapsed, while the Pickering has remained intact, the other sands having intermediate fusion temperatures.

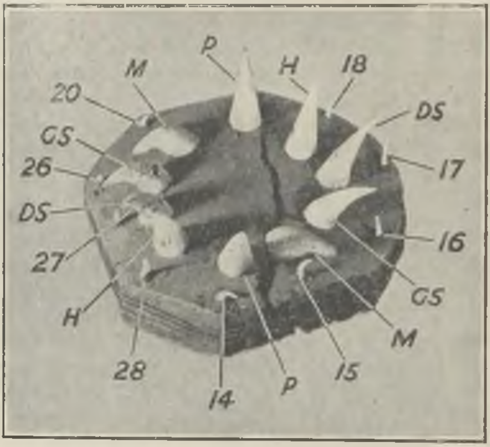


Fig. 4.—Sand Cones with Seger Cones after Refractoriness Test.

TABLE II.—*Effect of Ramming on Raw Hensall Sand.* (*A.F.A. Apparatus.*)

Test No.	Permeability.	G.B.S. Lbs. per sq. in.	No. of blows.	App. density.	
1	72.3	4.9	3	1.489	4 per cent. moisture content. 1st series.
2	66.0	5.7	4	1.540	
3	62.0	5.7	5	1.516	
4	60.6	5.7	6	1.522	
5	69.4	4.1	3	1.525	6 per cent. moisture content. 2nd series.
6	63.2	4.6	4	1.563	
7	61.0	4.7	5	1.560	
8	55.5	5.5	6	1.579	
9	73.0	3.6	3	1.533	8 per cent. moisture content. 3rd series.
10	65.2	3.6	4	1.562	
11	60.3	4.4	5	1.570	
12	60.6	4.6	6	1.588	
13	52.2	2.8	3	1.627	10 per cent. moisture content. 4th series.
14	49.1	2.9	4	1.642	
15	45.2	3.3	5	1.655	
16	40.8	3.3	6	1.761	

TABLE III.—*Effect of Ramming On Pickering Sand.* (*A.F.A. Apparatus.*)

Test No.	Permeability.	G.B.S. Lbs. per sq. in.	No. of blows.	App. density.	
1	52.8	9.9	3	1.455	4 per cent. moisture content. 1st series.
2	42.9	13.7	4	1.489	
3	42.7	15.8	5	1.508	
4	41.0	17.0	6	1.509	
5	67.5	12.7	3	1.473	6 per cent. moisture content. 2nd series.
6	53.7	15.6	4	1.535	
7	45.2	17.2	5	1.556	
8	44.2	17.2	6	1.653	
9	49.1	9.4	3	1.537	8 per cent. moisture content. 3rd series.
10	47.8	11.6	4	1.595	
11	40.8	13.8	5	1.604	
12	40.8	14.9	6	1.617	
13	40.9	8.6	3	1.630	10 per cent. moisture content. 4th series.
14	42.9	10.2	4	1.635	
15	36.0	11.1	5	1.681	
16	36.0	11.7	6	1.686	

TABLE IV.—*Effect of Ramming on Raw Mansfield Sand.* (*A.F.A. Apparatus.*)

Test No.	Permeability.	G.B.S. Lbs. per sq. in.	No. of blows.	App. density.	
1	35.3	6.9	3	1.527	3 per cent. moisture content. 1st series.
2	34.1	8.2	4	1.532	
3	30.1	9.2	5	1.536	
4	29.2	11.1	6	1.568	
5	37.0	6.7	3	1.532	4 per cent. moisture content. 2nd series.
6	34.0	7.1	4	1.545	
7	32.5	8.9	5	1.579	
8	27.5	8.3	6	1.580	
9	36.2	6.6	3	1.558	6 per cent. moisture content. 3rd series.
10	32.3	7.8	4	1.600	
11	29.4	9.2	5	1.624	
12	26.4	9.9	6	1.638	
13	33.9	5.4	3	1.58	8 per cent. moisture content. 4th series.
14	31.2	5.7	4	1.60	
15	26.6	5.4	5	1.60	
16	25.2	6.0	6	1.62	

Semi-Synthetic Sands

Recently, the sand additions have been substituted by bentonite. Although the system sand may now be considered on the same lines as synthetic sands, it is not truly of this order, the base being composed of naturally bonded material, whereas true synthetic sands are based upon the use of unbonded silica sands with the colloidal clay. The same principle, however, governs the success or otherwise of these mixtures, namely, the proper selection of grain size to suit the type of casting to be produced. Fig. 5 was produced to show the effect of increasing additions of bentonite on the sand in the system, and includes the grain size of the base sand. Figs. 6 to 10 have been introduced to show the comparative effect of bentonite and new sand additions, and with a view to ascertaining, if possible, if there was any essential difference in properties when the test-pieces had stood for varying periods before testing.

TABLE V.—*Standard Green Sand. (Moisture in Firs, Series, 5 per cent. Moisture in Second Seriest 8¼ per cent.)*

Test No.	Permeability.	G.B.S. Lbs. per sq. in.	No. of blows.	App. density.
1	67.0	6.3	3	1.55
2	55.5	7.1	4	1.56
3	52.2	7.5	5	1.56
4	52.1	8.8	6	1.58
5	38.5	3.1	3	1.68
6	38.5	3.3	4	1.69
7	32.3	3.5	5	1.72
8	24.4	4.0	6	1.75

Generally, it was found that the strength of the colloidally bonded sands increased more than did those bonded with new raw sand, and this supports the popular contention that sands of this latter type are not so prone to become

TABLE VI.—*Effect of Bentonite on Green Sand.*

Test no.	Moisture.	Permeability.	G.B.S. Lbs. per sq. in.	Dry permeability.	D.B.S. Lbs. per sq. in.	Bentonite. Per cent.
1	5.5	71.8	8	80.6	25.0	0.446
2	5.25	69.4	6.8	79.2	20.0	0.223
3	5.25	69.2	5.6	81.2	27.5	0.15
4	5.0	72.2	6.5	80.6	25.0	0.15
5	5.25	69.8	7.0	79.2	30.0	0.15
6	5.25	66.7	7.0	77.8	30.0	0.15
7	5.25	66.9	6.4	80.6	30.0	0.15
8	5.0	64.6	7.3	78.2	50.0	0.15
9	5.25	66.7	6.2	77.8	45.0	0.15

"murly" upon loss of moisture as are the bentonite sands. Table VI is a consensus of the results obtained on testing the first three weeks' production of sand when using bentonite. The addition of slightly less than ½ per cent. was at first thought to be necessary to produce the standard required, but after a few days it was obvious that fuller utilisation of the bond was being effected, with the result that the additions were cut down successively to approximately ¼ per cent. and later to ⅛ per cent. One important feature of this table is the effect on the

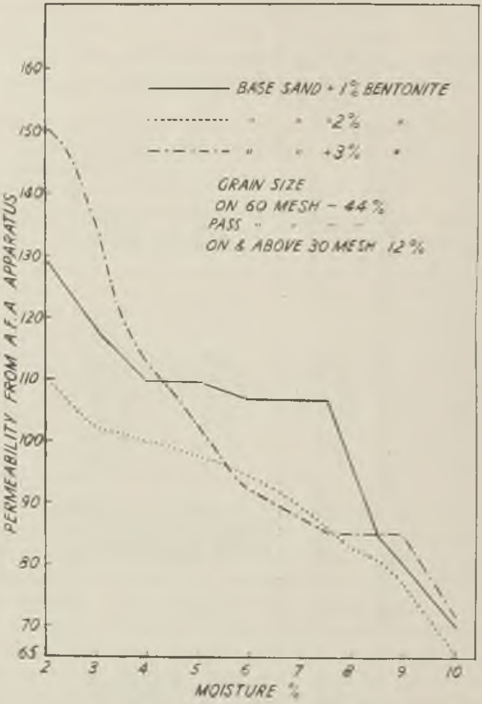


Fig. 5.

dry bond strength without deleterious effect on any of the other properties of the sand. An objection to the use of synthetic sands is their susceptibility to drying off quickly, a failing quite important to foundries making fairly large moulds. The only remedy is to use a slightly higher proportion of moisture in the sand than is actually required to offset the higher rate of loss.

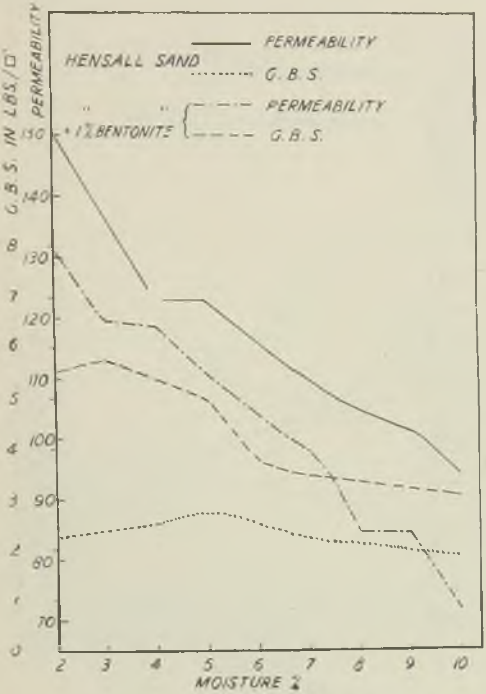


FIG. 6.

Dry Sand and Loam

The comments have so far mainly concerned green sand, but this foundry makes the greater proportion of its work in dry sand or loam, and it is here that the greatest advantages of sand control are evinced. The dried strength of the sand is such as to have reduced to a minimum the amount of mould reinforcement necessary, and face sprigging even in front of runners has been entirely eradicated. The casting skin is faultless, and sand troubles in this section are non-existent. The results obtained on dry sand alone have fully justified the installation of the plant, ignoring the economic considerations, which can be very considerable judged from the standpoint of the remarkably small new sand

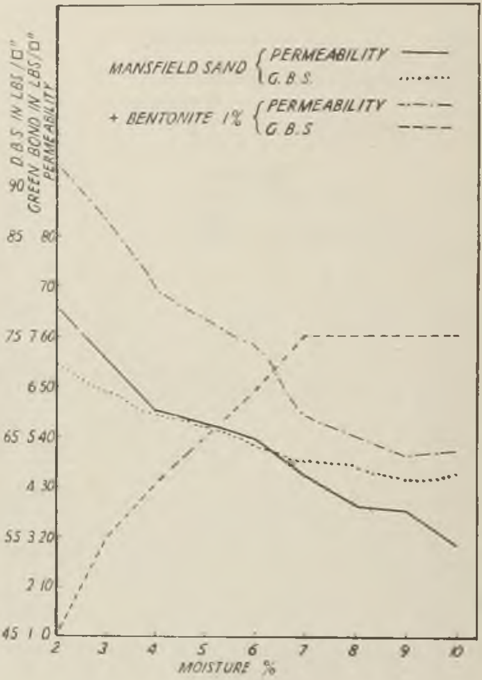


Fig. 7.

additions and the consequent reduction in the amount of surplus material to be tipped. The properties of the dry sand are as follow:—Green permeability, 66; green bond strength, 3.8 lbs. per sq. in.; moisture, 7½ per cent.; dry permeability, 80; dry bond strength, 65 lbs. per sq. in.

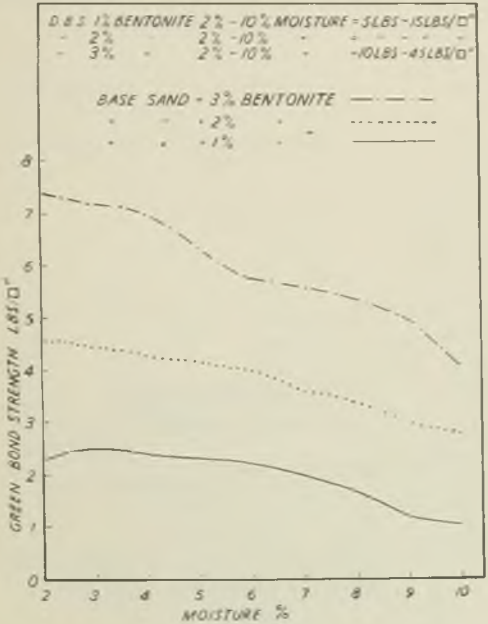


Fig. 8.

Blind Scabs

Foundrymen on the whole, however, are less inclined to listen to figures than to judge a sand from the effect it has on the quality of the castings which they produce, and the limitations which it imposes on their practice. One of the most difficult and irritating problems with which the foundry has to contend is the occurrence of blind or dumb scabs. Every foundry has had this type of defect, and even in the most well-ordered establishments this trouble occasionally shows itself.

What is the nature of the occurrence which leads to the formation of blind scabs? Every foundryman knows that ramming against the pattern, gaggers too near the face, sleeking newly-wetted faces and excess moisture give rise to scabs of this type. Not many have been able to offer a tangible explanation, however, when it comes to the normal use of an apparently suitable sand. The question of running a mould has an important bearing on the formation of this defect, but as running facilities are limited on most jobs, it seems necessary to understand the combination of reactions which produce this

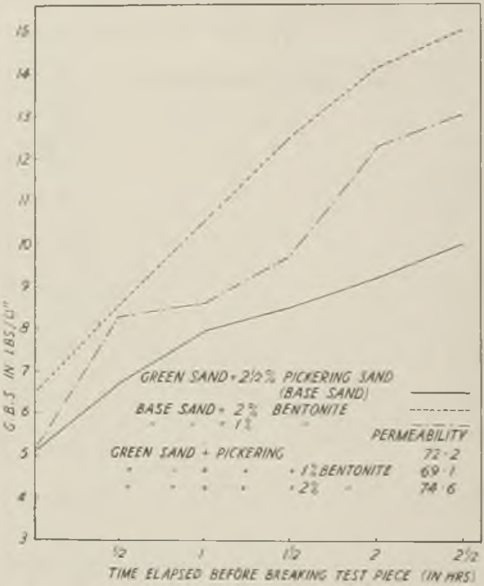


Fig. 9.

phenomenon, if only to devise means of counteraction.

Hudson has studied this particular phase, and has contributed articles on the results of his examinations. He bases his opinion chiefly on certain practical work carried out on a dry-sand mould, and comes to the conclusion that sand expansion is the cause of blind or dumb

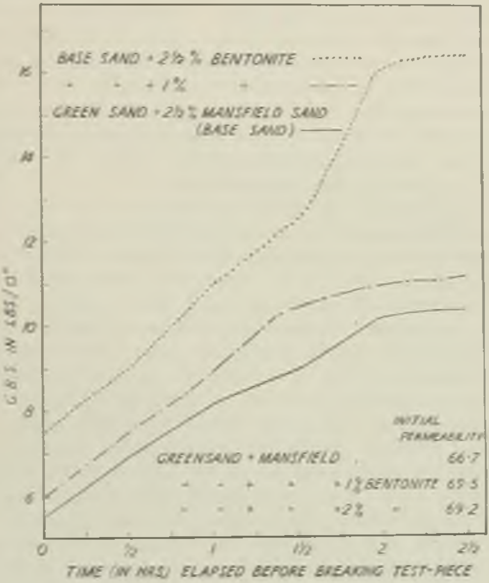


Fig. 10.

scabs, or sand buckles as they are termed. On the surface, the feasibility of this explanation provided such a complete answer to this problem as to convince most intelligent foundrymen that herein lay the solution of this difficult question, and the authors confess that they themselves were completely carried away when first the theory of sand expansion was propounded.

Examination of an actual defect served only to support the probability of the theory, and it was only at a later period when actual practical work was undertaken that the authors utterly discountenanced the tenure of this belief. An exhaustive study has compelled them to disagree entirely with the theory of sand expansion as it affects the utility of a mould. While no actual work on the expansion of silica was undertaken, Buchanan, in subsequent contributions on the subject, brought out points that were sufficient to throw some doubts upon the question of sand expansion as published by Hudson, but even granting that the latter's figures were absolutely correct, observation of the phenomenon has indicated that silica expansion has little or no effect in producing a blind scab.

To take a simple illustration, assuming the sand expansion in a green-sand mould of one square foot surface area to be equal to that of a dry-sand mould of the same size, it should follow that scabs would be produced with equal facility in a dry-sand mould as in a green-sand mould. Most foundrymen would disagree with such an inference, which is surely discredited in everyday dry-sand practice. Were it possible to arrange the sand grains laterally and longitudinally cheek to jowl, it might then be possible to produce something akin to this defect of the blind scab, but air spaces and non-siliceous material in the interstices give any amount of freedom for movement were such an expansion to take place. It is, of course, quite as easy to produce scabs on dry-sand work if the moulds are not properly dried, but throughout the whole course of these experiments a thoroughly dried mould has never blind-scabbed.

Experimental Evidence

It is essential for anyone who wishes to study this problem actually to see the defect in course of formation, and though it would be safe to say that every foundryman has experienced this trouble at some time or other, very few indeed have succeeded in studying its action visibly. Having evolved a theory upon this matter, the authors devised a means whereby the production of blind scabs could be easily watched.

A mould in green sand was made in the shape of a plate 18 in. sq. by $\frac{3}{4}$ in. thick to cast open, *i.e.*, without cope. The mould was given a 2-in. bank to allow the stream of metal to flow across the plate unhindered until it reached the lip of the mould at the low side which formed the other edge of the plate. At this point, a run-off was cut to allow some of the metal to flow from the mould, thereby preventing the building up of the metal at this point which would ultimately reduce the length of flow across the plate.

One cwt. of hot metal was poured from a single gate about $1\frac{1}{2}$ in. wide, and when the operation of casting was complete, the level of the metal in the mould formed a plate approximately half the size of the mould itself.

Where the rising edge of the metal becomes stationary, the sand immediately in front of it begins to rise up, and a small evolution of gas can often be observed through the broken surface. This self-made vent can often be seen to run along the whole width of the fringe of metal, and when metal is poured over it, a typical dumb scab is made, reproducing perfectly the rift which takes place in the sand.

What appears to occur is that at the edge of the metal stream, either down the side of the runner stream or across the front of the partly-made plate, the sand under the metal, having become relatively dry, is linked up with the green sand still outside the metal with a narrow intermediate crust or scale of sand. Where the dry sand joins the green sand a feather edge of dry material is formed, and this, being the weakest point and subject to the pressure of the gases from under the adjacent metal, is pushed up until the pressure opens the face of the eruption and emits the gas. The light caking action on the sand for a very small distance in front of the metal causes the sand to rise in a very thin layer, and this seems to support Hudson's statement that anything which has a tendency to weaken the sand on casting helps to reduce blind scabbing.

It should be noted that not only is the sand on the edge of the metal in a weak condition due to the crusting effect, but it has to withstand the greatest exertion of pressure generated in the sand underneath the metal adjacent to it. In green-sand plates of large area, portions of the mould which are only sporadically covered with metal show evidence of this effect, an exact corollary of the position when casting the small test plates.

The same evidence is forthcoming on many green-sand plates down the side of the stream of metal as it crosses the plate, and emphasises the desirability of pouring such castings as quickly as possible. Where it is possible to run a plate casting along its whole length by a runner of the "flash" type, or by banking the mould to restrict the metal flow across the plate, sound castings can be produced with regularity. The chief point to be borne in mind is that the blind scab is formed before the metal reaches the actually defective area, and, moreover, standing metal appears to produce the effect to a greater extent than does flowing metal. Balanced runners do a great deal to mitigate the trouble when it is found to be due to stationary pools of metal on the mould surface.

It is one thing to find out how a defect is caused and quite another to devise remedial action. Quack cures which may function in a particular sphere, but which are generally detrimental in other respects, or the extravagant use of poorly-bonded raw sands do not commend themselves, as they are unnecessarily expensive and show no regard for the issue in question. The authors admit quite frankly that they are not yet in a position to prescribe an absolute cure for the trouble, which they have both experienced, but are in the midst of experiments which indicate the possibility of positive results.

Hudson has stated that sawdust reduced the tendency to blind-scab, but, as mentioned above, he attributes this to the reduced expansion from sands made with sawdust additions. The authors suggest that this investigator has attained this result for a different reason from the one advanced, and that while sawdust does tend to reduce blind scabbing, it does so not because of the reduced expansion values, but because sawdust cannot be effectively bonded with sand and so breaks up the continuity or homogeneity of the sand, and in places where such scabbing is likely to occur thus prevents the formation of the lightly baked crust of bonded material by its weakening action thereon. The very nature of sawdust, however, makes it foreign to the functions of a moulding sand, and in the authors' opinion difficult to control, and although undeniably a palliative, it savours very much of being "any port in a storm."

TABLE VII.—*Dry Strength and Permeability of Loam.* (*Moisture* 20.4 *per cent.*)

Test no.	Dry strength.	Permeability.
1	65	22.8
2	65	30.1
3	50	38.0
4	53	30.8
5	57	26.5
6	62	25.0
Average	58.6	28.86

Non-Scabbing Sand

Many foundrymen differ in their opinions about the effect of temperature or permeability on the production of this defect, but the authors are prepared to state quite categorically that blind scabs are not a reciprocal of temperature or correlated with permeability. The tests carried out have embraced aluminium and brass plates as well as iron, the lowest pouring temperature being 600 deg. C. and sand permeability values from 22 to 295 A.F.A., and blind scabs have resulted with equal facility from both extremes. During the whole of the series of tests, in whatever sand, the only moulds to stand definitely perfect were made from a mixture of floor sand of approximately 40 permeability to which was added 10 per cent. mineral blacking, the moisture content being 6 per cent. Such moulds have to be cast immediately after preparation, however, otherwise the sand is inclined to run after losing moisture.

An old-established claim for coal-dust in connection with blind scabbing also merits attention. Hird, in his notable articles on this material, attributes this property of coal-dust to the formation of a tarry residue produced when coal is heated, the result being a sort of bond which is said to provide elasticity and reaction against the expansion of the sand. The fundamental reason, of course, why coal-dust is incorporated in sand is to produce the carbon film which affords some protection from the metal. Blind scabs are formed, however, in outlying sand, that is, not under the metal, and the tarry substance said to be produced would not be present in the thin scale of sand which is just in front of the metal stream. Therefore it is evident that the defect is in existence before the coal-dust has functioned in this respect.

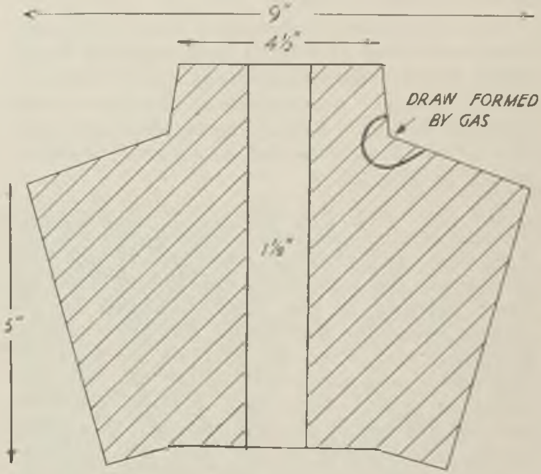
A further point which goes to disprove this theory is that the firing point of coal-dust is about 97 deg. C., with varying flash-points depending on conditions, up to 500 deg. C. There would, therefore, be no tarry matter in existence within the temperature range which Hudson has proved to be the silica expansion period. The authors are of the opinion that any non-bonding material of the same nature, such as coke dust, or coal ash, would produce the same effect on scabbing for the reasons which apply to sawdust. It is considered that far too much use is made of coal-dust in the general foundry as a palliative for defective practice in other directions, and one wonders when the average foundryman will be educated to the proper use of this material which he uses so slavishly and about which he really understands so little. Metallurgically, foundrymen have been trying consistently to eradicate gas from the metal, while at the same time they continue to use an essential gas producer in the position where it has the best possible facilities for entering the metal.

Coal-dust in excess has been responsible many times when the blame has been attached to the metal for such defects as draws, sinks, dirty and blown castings. An example of this came to the authors' attention during the making of a quantity of bevel gear blanks, a sketch of which is shown in Fig. 11.

The sand used was made up of 10 per cent. Hensall sand, 8 per cent. coal-dust and the rest floor sand, and when the defective castings were examined, the conclusion was formed that the draw existing in the neck, indicated in the sketch, was a gas formation. The order was for 81 pairs, and after the first six castings had been made and the defect found, the rest were made in milled floor sand without coal-dust, without the loss of a single casting. In a subsequent repeat order of the same job, the same result was obtained, the first half-dozen castings exhibiting the defect when using the sand containing coal-dust, and afterwards the balance being made up quite satisfactorily from treated floor sand as in the previous case. The same trouble has been experienced with high-pressure valves cast in green sand; what appeared at first sight to be shrinkage trouble from the metal transpired to be due to coal-dust, which caused a hot spot to be formed at the sharp corners of sand where the flanges meet the body. Elimination of the coal-dust cured the trouble. One axiom to be borne in mind is that the lower the permeability of the sand, the less can coal-dust be used with any degree of safety.

Loam Sands

Some tests on loam have been incorporated with a view to showing the widely differing properties obtainable from one kind of sand when varying the moisture content. The loam is made from the same sand as the dry sand used at this foundry, with the exception that the wood pulp is omitted. Facing loam as set out in Table VII is made up with 20 per cent. moisture, and for the benefit of those who are not conversant with this type of sand it should be pointed out that the low dried permeability value is the result of the excess moisture which thins the bonding material to such an extent as to obtain the maximum cementing action upon the body of the sand. The relatively high dry-bond strength figures are attributable to the same reason.



BEVEL BLANK PINION

FIG. 11.

In conclusion, the authors would say that they consider this Paper largely as an introductory effort which could undoubtedly have been enlarged upon at a later date, but they hope that they will have contributed sufficient data to arouse the interest and criticism which any work on such an important subject requires.

The authors' thanks are due in large measure to Mr. B. L. Broadbent, managing director of T. Broadbent & Sons, Limited, for permission to present this Paper and for the unstinted support which he has accorded, also to the directors of Kaye & Company (Huddersfield), Limited, for permission to carry out certain practical work. The authors are also indebted to Mr. F. Poole, of Keighley Laboratories, for his kind assistance in the preparation of slides, and to Pneulec Limited, for the loan of slides of the plant.

BALANCE SHEET, DECEMBER 31, 1937.

Liabilities.

	£	s.	d.	£	s.	d.
Subscriptions paid in advance				223	19	0
Sundry Creditors				454	15	6
Secretary's Policy Fund ...				18	8	8
The Oliver Stubbs Medal Fund :—						
Balance from last Account	211	9	7			
Interest to date	8	18	6			
	220	8	1			
Less Cost of Medal ...	9	15	0			
				210	13	1
The Buchanan Medal Fund :—						
Balance from last Account	122	17	1			
Interest to date	4	12	0			
	127	9	1			
Less Cost of Medals and Prizes	4	14	3			
				122	14	10
The E. J. Fox Medal Fund :—						
Balance from last Account	500	0	0			
Interest to date	12	5	1			
	512	5	1			
Less Cost of Medal ...	15	0	0			
				497	5	1
Qualcast Gift Fund :—						
Cash received				500	0	0
International Conference Fund :—						
Surplus (included in General Investments)				40	18	11
Accumulated Fund :—						
Balance at December 31, 1936	2,032	10	10			
Add : Excess of Income over Expenditure for the year ended December 31, 1937	372	9	3			
				2,405	0	1
				£4,473	15	2

ASSETS.

	£	s.	d.	£	s.	d.
Cash in hands of Secretaries :—						
Lancashire Branch ...	16	17	0			
Birmingham Branch ...	34	10	9			
Scottish Branch	21	19	9			
Sheffield Branch ...	34	9	0			
London Branch	63	8	5			
East Midlands Branch ...	20	1	11			
West Riding of Yorkshire Branch	16	2	7			
Wales and Monmouth Branch	5	17	9			
Newcastle Branch ...	1	0	2			
South African Branch ...	18	4	10			
				232	12	2
Cash in Hand :—						
Secretary's Policy Fund				18	8	8
Sundry Debtor's :—						
Subscriptions due and subsequently received ...				82	2	0
Lloyds Bank, Ltd. ...				749	15	3
The Oliver Stubbs Medal Fund :—						
£342 5s. 7d. Local Loans £3 per cent. stock at cost	200	0	0			
Balance at Lloyds Bank, Ltd.	10	13	1			
				210	13	1
The Buchanan Medal Fund :—						
£125, £3 10s. 0d. per cent. Conversion Stock at 78¼	98	6	9			
Balance at Midland Bank	24	8	1			
				122	14	10
The E. J. Fox Medal Fund :—						
£462 19s. 3d., £3 10s. 0d. per cent. Conversion Loan at Cost	500	0	0			
Less : Overdraft at Lloyds Bank, Ltd.	2	14	11			
				497	5	1

	£	s.	d.	£	s.	d.
Investments :—						
£650, 3½ per cent. War Loan at cost	630	8	4			
£653 19s. 0d. Local Loans 3 per cent. Stock at cost	451	13	8			
£964 5s. 1d., 3 per cent. Funding Loan at cost	897	14	11			
				1,979	16	11
Qualcast Gift Fund :—						
Balance at Lloyds Bank, Ltd.				500	0	0
Furniture Fittings and Fixtures as per last Account	68	16	2			
Less : Depreciation 10 per cent.	6	17	7			
				61	18	7
Superannuation Insurance :—						
Unexpired premiums ...				18	8	7
				£4,473	15	2

S. H. RUSSELL, *Hon. Treasurer.*

TOM MAKEMSON, *Secretary.*

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

J. & A. W. SULLY & Co., *Chartered Accountants. Auditors.*

19–21, Queen Victoria Street, London, E.C.4.
March 29, 1938.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1937.

EXPENDITURE.

	£	s.	d.	£	s.	d.
Postages				128	17	6
Printing and Stationery, including printing of "Proceedings"				783	4	6
Council, Finance and Annual Meetings Expenses ...				120	2	2
Medal for Past President ...				3	0	0

Branch Expenses :—

	£	s.	d.	£	s.	d.
Lancashire	115	3	0			
Birmingham	74	1	8			
Scottish	87	8	4			
Sheffield	39	11	0			
London	45	10	3			
East Midlands	47	18	4			
Newcastle	36	10	8			
West Riding of Yorkshire	32	7	5			
Wales and Monmouth ...	33	3	8			
Middlesbrough	34	18	3			
South Africa	42	5	5			
				588	18	0
Audit Fee and Accountancy Charges				12	12	0
Incidental Expenses ...	134	10	0			
Subscription, Joint Committee on Materials and their Testing	5	5	0			
Subscription, British Foundry School	5	0	0			
Subscription, International Committee on Testing C.I.	3	0	0			
				147	15	0
Salaries—Secretary and Clerks				702	10	10
Superannuation Insurance (Secretary)...				55	5	10
Rent, Rates, &c., of Office, *less* Received				91	5	0
Subscription, International Committee...				2	10	0
Depreciation of Furniture				6	17	7
John Surtees Memorial Examination Grants to Branches				5	12	8
				2,648	11	1
Excess of Income over Expenditure carried to Balance Sheet				372	9	3
				£3,021	0	4

INCOME.

	£	s.	d.	£	s.	d.
Subscriptions received :—						
Lancashire Branch ...				462	0	0
Birmingham Branch ...				456	1	6
Scottish Branch				389	0	6
Sheffield Branch ...				247	0	0
London Branch				448	17	6
East Midlands Branch ...				197	2	6
Newcastle Branch ...				126	11	0
West Riding of Yorkshire Branch				174	6	0
Wales and Monmouth Branch				117	17	0
Middlesbrough Branch ...				81	2	0
Unattached Members ...				32	11	0
South African Branch ...				121	0	6
				2,853	9	6
Add : Subscriptions in advance, 1936 ...	219	2	0			
Subscriptions due, 1937	82	2	0			
				301	4	0
				£3,154	13	6
Less : Subscriptions in advance, 1937 ...	223	19	0			
Subscriptions due, 1936	51	13	0			
				275	12	0
				2,879	1	6
Conference Registration Fees				33	0	0
Sale of " Proceedings," &c.				19	10	1
Interest on Investments and Cash on Deposit ...				63	9	4
John Surtees Memorial Examination Surplus ...				23	3	5
Profit on Sale of Badges ...				2	16	0
				£3,021	0	4

NAME INDEX

SUBJECT INDEX

HARRISON AND SONS, LIMITED
PRINTERS TO HIS MAJESTY THE KING,
44-47 ST. MARTIN'S LANE, LONDON, W.C.2.