Major R. Miles, M.Eng.
President, 1941–42.

Proceedings of the Institute of British Foundrymen

Volume XXXIV. 1940-1941

Containing the Papers prepared for the Thirty-Eighth Annual General Meeting of the Institute and a selection of the Papers presented to the Branch Meetings held during the Session 1940-1941.

Edited by J. BOLTON, Assistant Secretary

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The Institute of British Foundrymen

Founded 1904. *Incorporated by Royal Charter*, 1921.

Officers, 1941-42

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D. H. Wood, " Cotswold," Barnt Green, Birmingham.

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(*Surviving Past-Presidents are ex-officio members of the Council.*)

R. Buchanan. (Deceased, 1924.) 1904–1905.
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P. Longmuir, M.B.E., D.Met., 2, Queen's Road, Sheffield. 1910–1911.
C. Jones. (Deceased, 1923.) 1912.
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J. Ellis. (Deceased, 1930.) 1916–1917.
T. H. Firth. (Deceased, 1925.) 1918.
John Little, M.I.Mech.E. (Deceased, 1932.) 1919.
Matthew Riddell. 1920.
Oliver Stubbs. (Deceased, 1932.) 1921.
H. L. Reason. 1922.
Oliver Stubbs. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.
J. Cameron, J.P., Cameron & Roberton, Ltd., Kirkintilloch, Scotland. 1925.
V. C. Faulkner, F.R.S.A., 3, Amersham Road, High Wycombe, Bucks. 1926.
J. T. Goodwin, M.B.E., M.I.Mech.E., Grove Hill, Newbold Moor, Chesterfield, 1927.
S. H. Russell, Bath Lane, Leicester. 1928.
Wesley Lambert, C.B.E., " Aysgarth," Mayfield Avenue, Parkstone, Dorset. 1929.
F. P. Wilson, J.P., " Parkhurst," Middlesbrough. 1930.
A. Harley, " Ashlea," 11, East Ave., Stoke Park, Coventry. 1931.
Victor Stobie, M.I.E.E., (Deceased, 1940). 1932.
C. E. Williams, J.P., " Coniston," Cefn-Coed Road, Roath Park, Cardiff. 1933.
Roy Stubbs, 36, Broadway, Cheadle, Cheshire. 1934.
J. E. Hurst, D.Met., " Ashleigh," Trent Valley Road, Lichfield, Staffs. 1935.
H. Winterton, Moorlands, Milngavie, Dumbartonshire. 1936.
C. W. Bigg, " Selworthy," Burley Lane, Quarndon, Near Derby. 1937.
J. Hepworth, J.P., M.P., Woodhill Grange, Woodhall Hills, nr. Stanningley, Yorks. 1938
W. B. Lake, J.P., Albion Works, Braintree, Essex. 1939–1940.

HON. TREASURER :

S. H. Russell, Bath Lane, Leicester.

SECRETARY :

T. Makemson, Assoc.M.C.T.

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J. Bolton.

St. John Street Chambers, Deansgate, Manchester, 3.

Registered Office : 49, *Wellington Street, Strand, London, W.C.2.*

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A. Hares, 167, Ridgeway Road, Fishponds, Bristol, 5. (Wales and Monmouth.)
J. Jackson, Howard & Bullough, Ltd., Accrington. (Lancashire.)
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A. Phillips, 1, Melfort Avenue, off Edge Lane, Stretford, Manchester. (Lancashire.)
T. Shanks, Leslie Park, Denny, Stirlingshire. (Scottish.)
W. H. Salmon, Assoc. Met., 38, Glebe Road, Crookesmoor, Sheffield. (Sheffield.)
J. N. Simm, 61, Marine Drive, Monkseaton, Northumberland. (Newcastle.)
F. E. Steele, 130, Birley Moor Road, Frecheville, Sheffield. (Sheffield.)
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W. Williams, Alexandra Foundry, East Dock, Cardiff. (Wales and Monmouth.)
A. S. Worcester, Toria House, 162, Victoria Road, Lockwood, Huddersfield. (West Riding of Yorkshire.)

J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P., 21, St. Paul's Square, Birmingham, 3.

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(Ex-officio members of the Council.)

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S. A. Horton, Three, Mostyn Avenue, Littleover, Derby.

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W. Holland, 24, Tresco Avenue, King's Road, Stretford, Manchester.
A. Boyes, " Roseville," 7, Kirkstall Road, Davyhulme, Manchester.

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R. B. Templeton, White Cottage, Denham, Bucks.
V. C. Faulkner, 3, Amersham Road, High Wycombe, Bucks.

MIDDLESBROUGH AND DISTRICT.

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J. K. Smithson, The North Eastern Iron Refining Co., Ltd., Stillington, Stockton-on-Tees. (*Acting Secretary.*)

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A. L. Mortimer, 160, Levern Crescent, Barrhead, Glasgow.
J. Bell, 60, St. Enoch Square, Glasgow, C.1.

SHEFFIELD.

T. R. Walker, M.A., 11, Broomgrove Crescent, Sheffield, 10.
W. Webb, English Steel Corporation, Ltd., Vickers Works, Sheffield.

SOUTH AFRICAN.

J. Tonge, P.O. Box 48, Vereeniging, Transvaal, South Africa.

F. C. Williams, Mutual Buildings (Third Floor), Corner Harrison and Commissioner Streets, Johannesburg, South Africa.

WALES AND MONMOUTH.

J. F. Gist, The Paddocks, Frenchay, Bristol.

J. J. McClelland, 12, Clifton Place, Newport, Mon.

WEST RIDING OF YORKSHIRE.

W. Fearnside, Elmstone, Oakworth Road, Keighley.

S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford, Yorks.

Presidents and Honorary Secretaries of Sections

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.

EAST MIDLANDS—LINCOLN SECTION.

F. F. Mather, "Lindon Lea," 4, Harris Road, Lincoln.
E. R. Walter, M.Sc., The Technical College, Lincoln.

LANCASHIRE—BURNLEY SECTION.

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H. Buckley, "Ellesmere," Norfolk Avenue, Burnley, Lancs.

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G. Hall, 54, Tidings Hill, Halstead, Essex.
J. L. Francis, A.M.I. Mech. E., Ranelagh Works, Ipswich, Suffolk.

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T. Tyrie, B.Sc., c/o B.C.I.R.A., Foundry Technical Institute, Meeks Road, Falkirk.
T. R. Goodwin, "Viewfield," 126, Main St., Bonnybridge, Stirlingshire.

WALES AND MONMOUTH—BRISTOL SECTION.

F. Jackson, "Dunbar," The Hollow, Bath.
A. Hares, 167, Ridgeway Road, Fishponds, Bristol, 5.

Honorary Corresponding Members of Council

AUSTRALIA.

W. T. Main, T. Main & Sons (Proprietary), Ltd., Lambert Street, Richmond, E. 1, Victoria, Australia.

SOUTH AFRICA.

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

AWARDS 1940-41

THE "OLIVER STUBBS" GOLD MEDAL

1941 Award to Mr. J. J. SHEEHAN, B.Sc., A.R.C.Sc.I., A.I.C.

"in recognition of the valuable papers which he has presented to the Institute, to International Foundry Congresses and to overseas foundry technical associations, and in recognition of the outstanding contributions which he has made to foundry sands research as Convener of the Sands Sub-Committee of the Technical Committee 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, D.Met.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.
1935.—No Award.
1936.—F. Hudson / E. Longden } Two Awards.
1937.—P. A. Russell, B.Sc.
1938.—S. E. Dawson, F.I.C.
1939.—J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P.
1940.—A. E. Peace.
1941.—J. J. Sheehan, B.Sc., A.R.C.Sc.I., A.I.C.

THE MERITORIOUS SERVICES MEDAL

The 1941 Award was made to Mr. H. W. LOCKWOOD, in recognition of his valuable services to the Institute, particularly as Honorary Secretary of the London Branch and as a member of Council and standing Committees over a period of several years.

The Meritorious Services Medal has been awarded as follows :—

1933.—F. W. Finch
1934.—J. J. McClelland.
1935.—H. Bunting.
1936.—J. Smith.
937.—No Award.
938.—No Award.
939.—J. E. Cooke.
1940.—J. Bell.
1941.—H. W. Lockwood.

THE "E. J. FOX" GOLD MEDAL

1941 Award was made to Mr. P. PRITCHARD, Birmingham, in recognition of the scientific and technical contributions which he has made to the development of the foundry industry, particularly in aluminium and magnesium alloys.

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

1937.—Professor Emeritus Thomas Turner, M.Sc.
1938.—J. E. Hurst, D.Met.
1939.—Dr. Harry A. Schwartz.
1940.—W. J. Dawson.
1941.—P. Pritchard.

DIPLOMAS OF THE INSTITUTE

were awarded to :—

Mr. J. R. WEBSTER for his Paper on "Rope Pulleys," presented to the Scottish Branch.

Mr. A. E. McRAE SMITH, M.A., for his Paper on "Melting and Casting Problems in the Production of High Strength and Special Duty Alloy Iron Castings," presented to the Lancashire and London Branches.

Mr. J. M. STONES, for his Paper on "Some Notes on Bell Founding," presented to the South African 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, LL.D., 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.

1939.—"The Atomic Pattern of Metals" (delivered in London).—Prof. Sir LAWRENCE BRAGG, O.B.E., M.C., D.Sc., M.A., F.R.S.

1940.—Not delivered.

1941.—Not delivered.

CONTENTS

The Institute of British Foundrymen

ANNUAL GENERAL MEETING

The thirty-eighth annual meeting of the Institute of British Foundrymen was held at the Midland Hotel, Manchester, on Saturday, July 12. Mr. W. B. Lake, J.P., the retiring President, took the chair.

Minutes

MR. C. H. KAIN proposed, and MR. R. STUBBS seconded, that the minutes of the Annual General Meeting held in London on June 12, 1939, be taken as read and approved. The motion was carried unanimously.

Council Report, 1940-41

The report of the Council* for 1940-41 had been circulated among the members, and upon the proposition of the PRESIDENT, seconded by MR. H. WINTERTON, Past-President, was adopted unanimously.

Balance Sheet

The PRESIDENT called upon the hon. treasurer, Mr. S. H. Russell, to present the balance sheet and statement of accounts for the year ended December 31, 1940. MR. S. H. RUSSELL stated that, with regard to the income and expenditure account, he wished to point out that on the expenditure side practically every item indicated was smaller than in the previous year. This was due to more or less obvious reasons, in that the activities, both of the Institute and of the Branches, had been restricted owing to war conditions. The only item which showed any substantial increase was in respect to the expenses of the proposed Cheltenham Conference, which, very unfortunately, had to be cancelled at the last moment. Expenses amounting to £37 odd had been incurred and had to be met, while, of course, there were no receipts to set off against them.

On the income side, with regard to subscriptions received, he was very pleased to report a record result had been achieved. The Institute had never received so much in money in any one year previously, the amount being well over £3,000. The result was, there was a surplus of income over expenditure, otherwise profit, which was also a record amount of £658 8s. 8d. This had been carried forward on to the balance sheet.

With regard to the Special Technical Account Fund, shown on the liability side as loans of £150, this was, on the other side of the account, split up into three separate items. This was merely a book-keeping transaction which did not affect the Institute as a body. It referred to the work being done under the sponsorship of the Technical Committee, and particularly by Mr. Gardom. Money was sent to the Institute for that particular special work, and was recorded in the books. At the moment of striking a balance there was £150 in hand, but it was not the Institute's property and at the end of the war the item would disappear.

Of the surplus income over expenditure it was proposed to reserve the sum of £250 to meet the cost of a revision of the Institute's Charter which it was hoped would be obtained after the war. When the accounts were published for the next year it would be found that the balance sheet would show that amount had been allocated to that particular reserve fund, while the income would be placed in the Accumulated Fund.

Mr. Russell formally moved the adoption of the Balance Sheet and Statement of Accounts as circulated in the Annual Report.

MR. C. W. BIGG seconded the motion, which was carried unanimously.

Report of Technical Committee

MR. J. W. GARDOM presented the Report of the Technical Committee for 1940-41, a copy of which had been circulated among the members.* In doing so he stated it was the shortest report the Committee had ever published, but he could assure everyone that more work than usual had been done. The Committee had been responsible for the installation of plant in foundries in order to facilitate the production of war materials, and to effect war production extensions. Certain of those foundries were now nearing completion, and one was actually

* See page 6

* See page 12

in production at the present time. During the past few weeks, quite a number of problems had had to be solved in respect to starting up foundries, and in one case an appeal had been made to the B.C.I.R.A. for help which had been freely given

MR. V. C. FAULKNER, in seconding the adoption of the Report, said that much of the work of the Technical Committee at the present time was of a hush-hush character. He had some knowledge of what was going forward, and the work was now reaching to rather high proportions. He thought they might couple with the motion congratulations to the Technical Committee for the excellent work they had done for the Government during the past 18 months.

MR. D. SHARPE congratulated Mr. Gardom upon the enormous amount of work he had been able to do during the past year on behalf of the Technical Committee.

The Report was adopted unanimously.

Medal Awards

The PRESIDENT announced that the Council had awarded the Oliver Stubbs Gold Medal for the present year to Mr. J. J. Sheehan, A.R.C.Sc.I., A.I.C.

The fifth annual award of the E. J. Fox Gold Medal was made by the assessors to Mr. Percy Pritchard.

The award of the Meritorious Services Medal was made to Mr. H. W. Lockwood, of the London Branch.

Diploma Awards

The SECRETARY (Mr. T. Makemson) announced that Diplomas had been awarded to the following-named members of the Institute for Papers read before certain Branches: Mr. J. F. Webster, "Rope Pulleys," read before the Scottish Branch; Mr. A. E. McRae Smith, M.A., "Melting and Casting Problems in the Production of High Strength and Special Duty Alloy Iron Castings," read before the Lancashire Branch; Mr. J. M. Stones, "Some Notes on Bell Founding," read before the South African Branch.

ELECTION OF OFFICERS, 1941-42

President

The retiring President, MR. W. B. LAKE, announced that the Council had nominated as President for the next year of office Major Richard Miles. He had very much pleasure in proposing his election. Major Miles had been a member of the Institute for many years, and possessed great energy as well as a considerable gift of eloquence. He took a real interest in foundry work and in the Institute itself; so that he would make an excellent President for the forthcoming year.

DR. J. E. HURST, in seconding the motion, said that if he had not been requested to do so he would certainly have asked to be permitted the honour of doing so. He had had the honour of proposing Major Richard Miles as a Vice-President, and he did so with all the greater pleasure as that gentleman was an old colleague of his.

Major Miles was then elected President of the Institute for the forthcoming year.

MAJOR R. MILES said he felt very proud to succeed to the long line of distinguished foundrymen who had worn the regalia, and only wished he had a figure that would show it to better advantage. Perhaps the foundry trade did not lend itself to getting fat, though there were important exceptions among his energetic friends, even in this present company.

The programme of the meeting compelled this acknowledgment to be brief. It was quite impossible to be brief in recounting the good work that had been done by Mr. Lake, the retiring President, not only during his repeated terms of office, but for the many years during which he had been connected with the Institute.

He would, however, recall the outstanding success he achieved as President of the last International Convention in London. It was grievous to think that the members' dealings with a number of visitors to that Convention were now on a different footing; but friends and enemies alike must regard the genial President as having contributed to that happier international understanding that must, in time, arise.

It was his hope that Mr. Lake would have seen his way to retain the Presidency during the War, and it was only out of deference to his wishes that he was taking his turn. He could not replace him. Only with difficulty was it possible to emulate the good work he has done for the Institute.

He therefore proposed, and asked the members to accord to him, a very hearty vote of thanks for his able guidance of the affairs of the Institute during his terms of office, and to wish him and Mrs. Lake long life and every happiness.

In conclusion, Major Miles paid the following poetic tribute to the merits of the retiring President:—

A vote of thanks to Mr. Lake.
Let all the castings he may make,
From flaws and blemishes be free,
And all be good and sound as he.
No blowhole, draw, nor porous spot,
No sand inclusion, nor cold shot,
No tear, nor scab, nor shifted core,
No short run, run-out, and no more
Cross-joint, distortion, wrong dimension;
And in accordance with intention,
Every analysis and test;
And all inspection well suppressed.
In sum, best luck be always resident
With Daddy Lake, our loved Ex-President.

Mr. D. Howard Wood seconded the motion that a hearty vote of thanks be accorded to the retiring President for his services to the Institute during the past years. Two years ago, when Mr. Lake was elected President, he was undoubtedly one of the most popular members of the Institute. By his regular attendance at its meetings, by his conduct of the business of the meetings, and his genial and charming personality, he had further endeared himself to every member of the Institute. During the two years of his presidency, the interests of the Institute had been his main concern; business affairs and domestic affairs had been more or less put on one side.

The vote of thanks was carried unanimously by acclamation.

Mr. Lake, responding to the vote of thanks, wished to state how much he had enjoyed the two years he had been President. For many years he had been deeply interested in the solution of foundry problems, and there was no other medium in this country by which clear ideas upon such subjects could be obtained than among the members of the Institute of British Foundrymen. His time in office had been made exceedingly pleasant because of the unfailing kindness he had received from everybody from the day he was inducted into office.

He wished to thank all the members of the Institute for the way they had assisted him and borne with his, he would not say perhaps failures, but with his not doing quite so well as he might have done. He wished to thank the Council also for their great assistance and for the forbearance they had invariably shown towards him, and particularly he would like to thank the Executive Committee and the Past-Presidents for the ever-ready help and advice they had given him in most difficult times. His thanks were due also to his own Branch—the London Branch—for nominating him to the position, and for the unbounded assistance they had given him to make the International Congress a success.

Finally, though not least, he wished to thank the two secretaries and the treasurer for the help they had given him. He had enjoyed his term of office so much that, had his health permitted, he would have dearly liked to have carried on for another year.

Senior Vice-President

The President-Elect (Major Miles) then proposed that Mr. D. H. Wood be elected Senior Vice-President for the forthcoming year.

Mr. F. J. Cook seconded the nomination, which was carried unanimously.

Junior Vice-President

Mr. Lake announced that, in view of the unsettled state of affairs created through war conditions, the Council had decided that it would not be wise to nominate a Junior Vice-President.

Auditors

Messrs. J. & A. W. Sully & Company were unanimously reappointed auditors for the Institute.

New Members of Council

The Secretary (Mr. T. Makemson) announced that the result of the ballot taken was as follows:—Five members were elected for two years—Mr. V. Delport; Mr. Barrington Hooper, C.B.E.; Mr. E. Longden; Mr. P. A. Russell, B.Sc.; and Mr. D. Sharpe. One member was elected for one year to complete the remaining year of office of the late Mr. R. A. Miles—Mr. H. J. Roe.

PRESENTATION OF MEDALS

The E. J. Fox Gold Medal

Mr. E. J. Fox, in presenting the Medal to Mr. Percy Pritchard, said that the recipient's pioneer work for the industry was known to all who were in any way interested in foundry operations. He regretted that for the time being the Gold Medal would have to be represented by one which was silver-gilt. The only thing which puzzled him was why, having fallen from the high estate of gold, the Council did not select a metal which was used in the foundry industry, such as one of the aluminium or magnesium alloys. There might even have been a transformation into the vulgar cast iron.

Mr. Pritchard, in acknowledging the receipt of the medal and its accompanying certificate, said he would make no attempt to disguise the fact that when he received that morning a notification that the award was to be made it was one of the proudest moments of his life. It was now something over 30 years since he first entered the foundry industry. The foundry was his first love, and it was still his best love, in spite of the fact that attempts had been made to wean him from it. Like many others he had a great belief in the future prospects of the foundry industry, and he had done what he could in order to raise its status in the industrial world. Great progress had been made during the past 20 years, and the work of the Institute had in no small measure contributed to its success. Technical administration in foundry work was now regarded as being more essential than ever before.

In one sense he could be regarded as being somewhat of a mormon. His first wife, and still his favourite wife, was the cast iron foundry. Then he took unto himself the aluminium and later on the magnesium branches of founding. As knowing something of the technical and metallurgical developments which were taking place in the light alloys industry and the cast iron industry, perhaps he might be permitted to sound a word of warning on the competition which the latter industry might expect to meet from the light alloys. Light metals were going to prove to be formidable competitors of cast iron. In this connection he wished to pay a tribute to the work done by the British Cast Iron Research Association, which had been strong supporters of the Institute, along, of course, with the British Non-Ferrous Metal Research Association. It was deeply gratifying to learn that at long last the Cast Iron Research Association were likely to acquire headquarters and new laboratories worthy of such an organisation and of the cast iron industry.

Mr. Fox had wondered why the Medal could not have been made of cast iron; perhaps the answer was that it might have been too expensive.

The Oliver Stubbs Medal

Mr. W. B. Lake then presented the Oliver Stubbs Gold Medal to Mr. J. J. Sheehan, in recognition of the work he had done for the foundry industry during the past few years. In addition to many valuable Papers which Mr. Sheehan had presented to different Branches of the Institute, that gentleman had also been elected the Institute's representative on the International Committee on Defects in Iron Castings. Mr. Sheehan's work was of outstanding merit, and had been of great assistance both to the ferrous and non-ferrous foundries. Again, although the Medal was only silver-gilt owing to the unfavourable conditions prevailing, the Council were resolved, if it were at all possible, to substitute a gold one at the earliest opportunity.

Mr. J. J. Sheehan appreciated Mr. Lake's remark that the presentation of the Medal was due to the fact that he was considered an expert in foundry defects. (Laughter.) He could assure all present that if this was correct it was certainly not through an inherent desire to make defects, but owing to a long experience in the foundry industry.

Meritorious Services Medal

Mr. W. B. Lake then presented Mr. H. W. Lockwood with the Meritorious Services Medal, awarded by the Council of the Institute in acknowledgment of the good work done by Mr. Lockwood as secretary of the London Branch.

Mr. H. W. Lockwood acknowledged the receipt of the Medal and expressed his thanks for the same.

Investiture of the President

Mr. Lake then invested Major R. Miles with the Chain of Office and Badge of the President of the Institute of British Foundrymen, and the newly-inducted President presided over the subsequent proceedings.

Past-President's Medal

The President then presented the Past-President's Medal to Mr. Lake, and expressed the hope that that gentleman would wear it at many future meetings of the Institute.

Senior Vice-President's Medal

The President then inducted Mr. Howard Wood as Senior Vice-President, and invested him with the Senior Vice-President's Medal. Mr. Howard Wood had been for many years one of the leading members of the Institute in the Midlands, and he had been President of the Birmingham Branch. He was a most thoughtful and helpful member of the Executive Committee, and as far as his professional duties were concerned he was the managing director of one of the leading foundry constructional firms in the country.

Mr. Howard Wood expressed his appreciation of the honour which had been paid to him, and remarked that honours carried responsibilities with them. He hoped to be able to discharge the duties of the office of Senior Vice-President to the entire satisfaction of the members of the Institute.

Vote of Thanks

The President then proposed that a cordial vote of thanks be given to the secretarial staff and to Branch officers for their services rendered to the Institute and at Branch meetings. In this vote of thanks he wished to include overseas Branches. The conditions under which the work of the Institute had been carried on were far from easy ones. Mr. T. Makemson was now a most important official of the Iron and Steel Control Department of the Ministry of Supply, but nevertheless he had been able to do considerable work for the Institute as well. In Mr. J. Bolton they had a very able acting secretary, who possessed considerable initiative and was not afraid of responsibility.

The vote of thanks was carried unanimously by acclamation.

Mr. T. Makemson, in responding to the vote of thanks on behalf of all concerned, paid tribute to the way in which the assistant secretary, Mr. J. Bolton, had carried on the work of the Institute.

The President then presented his inaugural address.*

Upon the motion of Mr. F. J. Cook, seconded by Mr. H. Winterton, a hearty vote of thanks was accorded to the President for the address.

The President having suitably responded to the vote of thanks, the proceedings of the annual meeting concluded.

* See page 13.

Institute Luncheon

Prior to the Annual General Meeting a luncheon was held, over which Mr. Lake presided. Well over 150 members and guests participated. Amongst those present were Major R. Miles (President-Elect), Mr. E. J. Fox, Mr. Fitzherbert Wright (Director for Iron Castings), Mr. Percy Pritchard, Mr. D. Howard Wood (Vice-President), Mr. Barrington Hooper, C.B.E., Mr. C. W. Bigg (Past-President) and Mrs. Bigg, Mr. F. J. Cook (Past-President), Mr. J. G. Pearce (Director of the British Cast Iron Research Association), Mr. V. C. Faulkner (Past-President), Dr. J. E. Hurst (Past-President) and Mrs. Hurst, Mr. S. H. Russell (Past-President and treasurer), Mr. R. Stubbs (Past-President) and Mrs. Stubbs, Mr. H. Winterton (Past-President), Mr. P. H. Wilson (joint managing director of the Stanton Ironworks Company), Mr. G. E. France (President of the Foundry Equipment and Supplies Association) and Mrs. France, and Mr. T. Makemson (secretary and Deputy Director for Iron Castings).

There were two presentations made during the course of the luncheon proceedings. The first was by Mr. C. W. Bigg, on behalf of the Past-Presidents of the Institute, who presented a gift to Mrs. W. B. Lake. The gift—cut-glass tableware—was accepted on her behalf by Mr. W. B. Lake, the retiring President. Mrs. Lake was unable to attend the luncheon owing to ill-health.

The second presentation was made by Mr. W. Holland, President of the Lancashire Branch of the Institute, who, on behalf of the Branch Council and members, presented a silver tankard to Major R. Miles, President-Elect, in order to mark the commencement of his presidential year of office.

Major Miles, acknowledging the gift, mentioned that he was born in the Duchy of Lancaster, and expressed the hope that he would be able to visit the Lancashire Branch during his term of office.

THE 38th ANNUAL REPORT

This Report covers the period May 1, 1940, to April 30, 1941. The Statement of Accounts for the year ended December 31, 1940, and the Balance Sheet at that date are also included.

Finance

In spite of the difficulties associated with the operation of the Institute's activities during war time, these activities have been fairly well maintained. There has, however, been some curtailment of work, and this factor, together with the careful regulation of General Office expenditure and the satisfactory subscription revenue, has resulted in a surplus on the year's working of £650. This is the most substantial credit balance which the Institute has enjoyed. Out of this balance it is proposed to set aside £250 to form a special fund to be known as the Charter Reserve Fund from which will be met the additional charges to be incurred when the Institute renews its application for a new Charter at the conclusion of hostilities.

Membership

From Tables I and II it will be seen that there has been a slight decline in membership during the period under review.

It is with regret that the Council records the death of twenty-four members during the year. Amongst those who were widely known are the following:—

Prof. Sir H. C. M. Carpenter, M.A., Ph.D., F.R.S., A.R.S.M., an Honorary Life Member, who joined the Institute in 1919. His contributions to the knowledge of metals are, of course, well known. In spite of the many other calls upon his time, he always showed a keen interest in the Institute's affairs, and for the last four years of his life was a joint assessor, with Sir William Larke, of the E. J. Fox Gold Medal.

Sir Robert A. Hadfield, Bt., F.R.S., was elected an Honorary Life Member in 1910, and throughout his long association with the Institute he maintained a very great regard for and high appreciation of its activities and particularly its publications. His scientific attainments made him one of the country's foremost metallurgists, and the Institute and industry mourn his passing.

Mr. E. L. Rhead, M.Sc.Tech., F.I.C., F.C.S., was also an Honorary Life Member, being elected in 1919. He was widely known and greatly respected, particularly in the Lancashire area. His book on "Metallurgy" rapidly became a standard work of reference, and his many other contributions to scientific literature will long be remembered.

Mr. S. G. Smith became a member of the Institute in 1909 and was a Past-President of the Lancashire Branch. He made many scientific and practical contributions to the Institute's "Proceedings," and in this connection was awarded a Diploma. In recognition of his outstanding work, particularly on the educational side, he was elected an Honorary Life Member in 1935.

Mr. Victor Stobie, M.I.E.E., joined the Newcastle Branch of the Institute as an Associate Member in 1912, but transferred to Membership in 1925. He was a Past-Branch-President, and was elected President of the Institute in 1932. He was a pioneer of electric furnace steelmaking, and had contributed much to the knowledge and literature of this particular aspect of foundry science during his long membership. Apart from his scientific contributions to the "Proceedings," he was a prominent member of the Council for a considerable time, and greatly assisted in the administrative work in this capacity.

Mr. F. E. McGrah, who died as a result of a motoring accident in the autumn of 1940, joined the Sheffield Branch in 1918.

Mr. R. A. Miles, a Past-President of the Lancashire Branch which he joined in 1916,

TABLE I.—*Changes in Membership*, 1940–1941.

	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Total.
At April 30, 1940	78	996	1,122	130	37	2,363
Additions and transfers from other grades	1	29	76	6	2	114
	79	1,025	1,198	136	39	2,477
Losses and transfers to other grades ..	2	53	73	23	9	160
	77	972	1,125	113	30	2,317

had for many years served on the Council of the Institute, and was so serving at the time of his death. He rendered outstanding service to the Institute, and particularly to the Lancashire Branch.

Mr. J. B. Allan, M.A., did not join the Sheffield Branch of the Institute until 1928, but during his comparatively short period of membership he became widely known both in Sheffield and elsewhere. He became President of the Sheffield Branch in 1937, and was largely responsible for the organisation of the Patternmaking Competition which is now held annually by that Branch.

Mr. J. A. Laing, the co-author with Mr. R. T. Rolfe of a number of well-known books on foundry practice, joined the London Branch in 1933, but transferred to the Lancashire Branch a few years later. He contributed a number of Papers to the Branches, for one of which he was awarded the Institute's Diploma.

Mr. W. R. Wilson was one of the members of longest standing, for he joined the Institute in 1904, the year of its formation. He was widely known, particularly among Lancashire members.

The following are amongst those members who have been honoured during the period covered by this report:—

Mr. G. E. France, who was re-elected President of the Foundry Trades' Equipment and Supplies Association.

Mr. A. H. Guy, of South Africa, who was elected President of the South African Red Cross Society.

Dr. W. H. Hatfield, F.R.S., who was elected President of the Sheffield Society of Engineers and Metallurgists, and who has also been elected to the Council of the University of Sheffield.

Dr. Andrew M'Cance, who was awarded the Bessemer Gold Medal of the Iron and Steel Institute in 1940.

Mr. F. A. Melmouth, who received the Joseph S. Seamen Gold Medal of the American Foundrymen's Association.

Prof. Albert M. Portevin, an Honorary Life Member, who was elected an Honorary Member of the Institute of Metals.

Mr. W. J. Rees, Convenor of the Refractories Sub-Committee of the Technical Committee, who had conferred upon him the degree of D.Sc. (Tech.) in the University of Sheffield.

Mr. Frank Russell, who was elected President of the Yorkshire Firebrick Association.

Dr. T. Swinden, who has been awarded the Bessemer Gold Medal of the Iron and Steel Institute for 1941.

Table II.—*Analysis of Membership at April 30, 1941.*

Branch.	Subscribing Firms.	Members.	Associate Members.	Associates.	Associates (students)	Total.
Birmingham	8 (8)	160 (160)	160 (157)	16 (16)	6 (8)	350 (349)
East Midlands	5 (4)	80 (70)	110 (97)	5 (3)	2 (2)	202 (176)
Lancashire	13 (14)	119 (133)	196 (209)	22 (27)	2 (1)	352 (384)
London	10 (10)	205 (205)	132 (121)	3 (3)	— (—)	350 (339)
Middlesbrough	1 (1)	31 (30)	45 (48)	8 (8)	5 (7)	90 (94)
Newcastle	6 (6)	30 (32)	26 (27)	41 (55)	7 (11)	110 (131)
Scottish	7 (7)	91 (90)	191 (193)	3 (4)	1 (1)	293 (295)
Sheffield	6 (7)	87 (97)	62 (68)	2 (2)	— (1)	157 (175)
South African	13 (13)	45 (46)	35 (32)	9 (9)	— (—)	102 (100)
Wales and Monmouth..	3 (3)	46 (49)	50 (53)	— (—)	7 (6)	106 (111)
W.R. of Yorks. ..	4 (4)	58 (57)	98 (95)	4 (3)	— (—)	164 (159)
Unattached	1 (1)	20 (27)	20 (22)	— (—)	— (—)	41 (50)
	77 (78)	972 (996)	1,125 (1,122)	113 (130)	30 (37)	2,317 (2,363)

Figures in brackets are totals at April 30, 1940.

Awards

E. J. Fox Gold Medal.—On the recommendation of the Assessors, Sir W. J. Larke and the late Prof. Sir Harold Carpenter, the E. J. Fox Gold Medal for 1940 was awarded to Mr. W. J. Dawson, of Sheffield, "in recognition of his services to the industry as Chairman of the Steel Castings Research Committee, and in other capacities."

Oliver Stubbs Gold Medal.—The Oliver Stubbs Gold Medal for the year 1940 was awarded to Mr. A. E. Peace (East Midlands Branch), a member of the Council of the Institute, a Past-Branch-President and holder of the Institute's Diploma, "in recognition of the many valuable Papers which he has presented to the Branches of the Institute and at Annual Conferences, and in recognition of the considerable experimental work which he has carried out as Convenor of the Malleable Cast Iron Sub-

Committee of the Institute's Technical Committee."

The Meritorious Services Medal.—The 1940 award of the Meritorious Services Medal was made to Mr. John Bell "in recognition of his valuable services to the Institute, particularly as honorary secretary of the Scottish Branch, which position he has held for seventeen years."

Diplomas.—Diplomas were awarded to the following members during the year:—Mr. A. Hopwood; Mr. A. J. Shore; Mr. J. A. Laing; Mr. H. G. Hall; Mr. A. Marshall; Mr. F. G. Jackson; Mr. R. C. Tucker, M.A.; Mr. J. L. Francis, A.M.I.Mech.E.; Mr. E. W. Dowson.

John Surtees' Memorial Competition.—The examinations for the award of the John Surtees' Medals and Prizes are held alternately by the Scottish and Newcastle Branches.

The 1941 Competition, due to have been organised by the Newcastle Branch, was not held owing to war conditions.

Edward Williams' Lecture

In view of the situation created by the war, the Council felt it inadvisable to seek an author to present the fifth Edward Williams' Lecture. No lecture was, therefore, presented in 1940.

Annual Conference

The Thirty-Seventh Annual Conference, which under normal conditions would have been held in Middlesbrough, was arranged to be held at Cheltenham, and was to have been of two days' duration—June 7 and 8, 1940. The war situation which developed immediately prior to that time, dictated the cancellation of this meeting, and also the Annual General Meeting, which would have been held concurrently.

Subsequently His Majesty's Privy Council gave permission to the Institute to dispense with the holding of its Annual General Meeting during the present war period, and authorised the Council, during the war, to re-elect officers to the offices which they occupied in 1940. The Council availed itself of the Privy Council's authority, and no Annual General Meeting was held during 1940.

Branch Activities

Four of the Branches have carried out normal programmes of technical meetings and, with the exception of two, all the remaining Branches have organised some meetings for the presentation and discussion of Papers. Some Branches are transferring their meetings from the winter to the spring and early summer in order to overcome the difficulties associated with the blackout. Other Branches have transferred their meetings from week-day evenings to Saturday afternoons. These changes, together with the fact that the majority of those in the industry are working exceptionally long hours, have reflected to some extent on attendances at meetings.

The Council desires to express its appreciation of the work done by Branch Councils and secretaries, without whose co-operation it would have been impossible to maintain so successfully the Institute's activities.

The Council also wishes to congratulate the South African Branch, which, continuing the steady progress it has made since its inception, issued in 1940 a volume of its own Proceedings for 1938-40.

Educational Work

The following are the results of the examinations held under the auspices of the City and Guilds of London Institute and in conjunction with this Institute, in April and May, 1940.

	No. of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
Patternmaking— Intermediate grade	45	8	23	68.9
Patternmaking— Final grade ..	18	5	6	61.2
Foundry practice and science	42	15	15	61.5

PATTERNMAKING—INTERMEDIATE GRADE.

John Lawrence Younger, Gloucester Technical College: Bronze Medal of the City and Guilds of London Institute.

PATTERNMAKING—FINAL GRADE.

Ronald Hollingworth, College of Technology and Arts, Rugby: Silver Medal of the City and Guilds of London Institute.

FOUNDRY PRACTICE AND SCIENCE.

Thomas Joseph Parker, Department of Applied Science, University of Sheffield: Bronze Medal of the City and Guilds of London Institute.

Buchanan Medals and Book Prizes were awarded to:—

PATTERNMAKING—FINAL GRADE.

Ronald Hollingworth, College of Technology and Arts, Rugby: Buchanan Book Prizes.

Lancelot Bell, Constantine Technical College, Middlesbrough: Buchanan Book Prizes.

FOUNDRY PRACTICE AND SCIENCE.

Frank Lord, Accrington Technical and Art School: Buchanan Silver Medal.

T. J. Parker, Department of Applied Science, University of Sheffield: Buchanan Book Prizes.

J. L. Younger, Gloucester Technical College: Buchanan Book Prizes.

C. Webster, Keighley Technical College: Buchanan Book Prizes.

Kindred Institutions

The cordial relations existing between the Institute and kindred Societies continue, although comparatively few joint meetings have been arranged. The close associations which the Institute enjoyed with other Institutions overseas have, of course, been largely suspended. A happy exception has been the American Foundrymen's Association, with whom constant touch is maintained.

Publications

Volume XXXIII of the "Proceedings" was published at the beginning of April, 1941, in the new style adopted for the previous volume. It will have been noticed that a more modern type face has been chosen. The volume is smaller than that published in 1940, due to war-time restrictions in the consumption of paper, but contains about the same amount of matter as volumes published during the few years previous to 1940.

The British Cast Iron Research Association

The work of the British Cast Iron Research Association is almost wholly directed to assisting the national war effort, and the works of members are either fully engaged in this direction or are rapidly adapting themselves for the purpose. Details cannot, of course, be given while the war is in progress. The Council has been gratified to learn that the award of the E. J. Fox Medal for 1941 will be made to Mr. P. Pritchard, a Vice-President of the Association.

Council

Three meetings of the Council and nine meetings of the Executive and other standing Committees have been held in Birmingham, Derby and Manchester. Of the ten members of the Council who are elected by ballot for a period of two years, five retire each year. Those who retire at the Annual General Meeting to be held in Manchester on July 12 are:—Mr. V. Delport, Mr. E. Longden, Mr. H. J. Roe, Mr. P. A. Russell, and Mr. A. W. Walker. These gentlemen offer themselves for re-election and are eligible for re-election for a further period of two years.

Officers

The Council has unanimously decided to recommend that Major R. Miles, M.Eng. (Middlesbrough), be elected President, and that Mr. D. H. Wood (Birmingham) be elected Senior Vice-President. These recommendations will be placed before the Annual General Meeting on July 12, 1941.

The Council wishes to express its thanks to Mr. S. H. Russell, Past-President and Honorary Treasurer, for the careful manner in which he has conducted the finances of the Institute.

The Council is also indebted to Mr. J. W. Gardom for his work as Convener of the Technical Committee. During the past year the Technical Committee has made and continues to make important contributions to the war effort. Much of the work is of a confidential nature and details may not be given of this work. The Council desire it to be known, however, that through Mr. Gardom and various Sub-Committees of the Technical Committee, the Institute is able materially to contribute to the national cause.

Annual Conference

The Council has considered the advisability of holding an annual meeting, and has decided to combine two technical sessions with the formal Annual General Meeting. By this means it is hoped to provide not only a technical and business session for all members, but an opportunity to renew acquaintanceships which war-time conditions make it difficult to maintain. For the convenience of the majority of the members who do not wish to be away from their businesses for more than a short time, the whole programme has been included in one day. The meetings will be held at the Midland Hotel, Manchester, on Saturday, July 12, 1941.

W. B. Lake,
President.

J. Bolton,
Assistant Secretary.

April 30, 1941.

BALANCE SHEET 31st December, 1940

LIABILITIES.

	£ s. d.	£ s. d.
Sundry Creditors	477 12 0	
Subscriptions Paid in Advance	111 5 0	
Secretary's Policy Fund	18 8 8	
		607 5 8
The Oliver Stubbs Medal Fund :—		
Balance from last Account	215 1 1	
Interest to date	10 5 4	
	225 6 5	
Less : Cost of Medal	10 12 0	
		214 14 5
The Buchanan Medal Fund :—		
Balance from last Account	120 1 0	
Interest to date	4 11 0	
	124 12 0	
Less : Cost of Medals and Prizes	5 9 8	
		119 2 4
The E. J. Fox Medal Fund :—		
Balance from last Account	496 1 2	
Interest to date	16 4 0	
	512 5 2	
Less : Cost of Medal	16 0 0	
		496 5 2
Technical Development Fund :—		
Balance from last Account	518 14 0	
Interest to date	12 6 0	
	531 0 0	
Less : Cost of Melting Furnaces Sub-Committee Report	87 10 0	
		443 10 0
Special Technical Account Fund :—		
Loans		150 0 0
Accumulated Fund :—		
Balance 31st December, 1939	2,517 13 1	
Excess Income over Expenditure for the year ended 31st December, 1940	658 8 8	
		3,176 1 9
		£5,206 19 4

S. H. RUSSELL, *Hon. Treasurer.*
TOM MAKEMSON, *Secretary.*

19/21, Queen Victoria Street,
London, E.C.4.
15th April, 1941.

ASSETS.

	£ s. d.	£ s. d.
Cash in Hands of Secretaries :—		
Lancashire Branch	50 19 9	
Birmingham Branch	55 10 8	
Scottish Branch	40 11 5	
Sheffield Branch	39 14 3	
London Branch	102 19 9	
East Midlands Branch	23 2 5	
West Riding of Yorkshire Branch	24 12 4	
Wales and Monmouth Branch	25 12 3	
Middlesbrough Branch	16 1 5	
Newcastle Branch	27 3 3	
South African Branch	16 3 1	
		422 10 7
Lloyds Bank Ltd.		810 16 4
Cash in Hand—Secretary's Policy Fund	18 8 8	
Do. —Head Office Petty Cash	12 8 5	
Sundry Debtors, Etc. :—		30 17 1
Subscriptions due and subsequently received		75 15 0
Superannuation Insurance :—		
Unexpired premium	18 8 7	
The Oliver Stubbs Medal Fund :—		
£342 5s. 7d. Local Loans 3% Stock at cost	200 0 0	
Balance at Lloyds Bank Ltd.	14 14 5	
		214 14 5
The Buchanan Medal Fund :—		
£125, 3½% Conversion Stock at cost	98 6 9	
Balance at Midland Bank, Ltd.	20 15 7	
		119 2 4
The E. J. Fox Medal Fund :—		
£462 19s. 3d., 3½% Conversion Stock at cost	500 0 0	
Less : Overdraft at Lloyds Bank, Ltd.	3 14 10	
		496 5 2
Technical Development Fund :—		
Balance at Manchester & Salford Savings Bank		443 10 0
Special Technical Account :—		
Cash at Lloyds Bank Ltd.	125 18 7	
Cash in hand	23 11 5	
Recoverable expenses	0 10 0	
		150 0 0
Investments :—		
£650, 3½% War Loan at cost	630 8 4	
£653 19s. 0d., 3% Local Loans at cost	451 13 8	
£964 5s. 1d., 3% Funding Loan at cost	897 14 11	
£400, Leeds Corporation Mortgage	400 0 0	
		2,379 16 11
Furniture, Fittings, and Fixtures :—		
Balance from last Account	50 3 3	
Less : Depreciation 10%	5 0 4	
		45 2 11
		£5,206 19 4

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

J. & A. W. SULLY & Co.,
Chartered Accountants, Auditors.

INCOME & EXPENDITURE ACCOUNT for the Year Ended 31st December, 1940

EXPENDITURE.

1939 £ s. d.	1939 £ s. d.		£ s. d.	£ s. d.
165 4 9		Postages		155 5 1
1,101 12 1		Printing and Stationery including printing of "Proceedings"		866 11 10
110 4 8		Council Finance and Annual Meeting Expenses		64 1 11
		Branch Expenses :—		
	105 11 7	Lancashire	104 8 2	
	80 2 9	Birmingham	66 18 10	
	74 17 8	Scottish	68 8 7	
	32 2 1	Sheffield	7 5 9	
	46 9 4	London	37 3 7	
	51 12 4	East Midlands	57 7 7	
	30 3 10	Newcastle	2 19 11	
	43 3 2	West Riding of Yorkshire	37 7 8	
	20 6 3	Wales and Monmouth	6 14 3	
	23 15 0	Middlesbrough	24 3 2	
	69 14 8	South Africa	135 18 3	
577 18 8				548 15 9
12 12 0		Audit Fee and Accountancy Charges		12 12 0
148 5 11		Incidental Expenses		114 14 5
		Subscriptions :—		
	10 10 0	British Standards Institution	10 10 0	
	5 5 0	Joint Commission on Materials	5 5 0	
15 15 0				15 15 0
		Salaries :—		
907 11 11		Secretary and Staff		694 16 7
55 5 10		Superannuation Insurance (Secretary)		55 5 10
103 3 3		Rent, Rates, &c., of Office *less* Received		108 17 5
5 11 6		Depreciation of Furniture		5 0 4
		John Surtees Memorial Examination :—		
6 6		Grants to Branches		9 14 3
——		Expenses re Proposed Cheltenham Conference		37 7 11
3,209 11 7				2,688 18 4
25 18 3		Excess of Income over Expenditure carried to Balance Sheet		658 8 8
3,235 9 10				£3,347 7 0

INCOME

	£ s. d.	£ s. d.	1939 £ s. d.	1939 £ s. d.
Subscriptions Received :—				
Lancashire Branch		511 15 6		453 17 0
Birmingham Branch		408 2 6		477 8 6
Scottish Branch		364 17 6		373 5 6
Sheffield Branch		277 14 6		245 13 0
London Branch		547 11 6		503 9 7
East Midlands Branch		264 11 6		225 4 0
Newcastle Branch		115 13 0		133 11 0
West Riding of Yorkshire Branch		197 2 6		203 14 0
Wales & Monmouth Branch		165 11 0		122 1 0
Middlesbrough Branch		114 7 6		111 15 0
Unattached Members		41 4 0		51 11 9
South African Branch		175 7 0		156 9 0
		3,183 18 0		3,057 19 4
Add :—				
Subscriptions in Advance 1939	91 12 0		164 1 0	
Subscriptions Due 1940	75 15 0		33 1 6	
		167 7 0		197 2 6
		3,351 5 0		3,255 1 10
Less :—				
Subscriptions in Advance 1940	111 5 0		91 12 0	
Subscriptions Due 1939	33 1 6		74 3 6	
		144 6 6		165 15 6
		3,206 18 6		3,089 6 4
Sale of "Proceedings," Etc.		39 2 9		24 12 1
Interest on Investments and Cash on Deposits		97 16 6		96 0 10
John Surtees Memorial Examination Surplus		2 18 5		24 12 5
Profit on Sale of Badges		0 10 10		0 18 2
		£3,347 7 0		£3,235 9 10

NINTH ANNUAL REPORT OF THE TECHNICAL COMMITTEE

Only one meeting of the full Technical Committee has been held during the past year, but many of the Sub-Committees have been actively engaged upon the solution of war-time problems. There has also been close co-operation with various Government departments, notably the Ministry of Supply (Iron and Steel Control), and with the Department of Scientific Research of that Ministry.

Three members of the Technical Committee, Mr. J. W. Gardom (Convener), Mr. P. A. Russell, B.Sc. (Convener of the Cast Iron Sub-Committee), and Mr. E. Longden, A.M.I.Mech.E., have been elected to serve on the Director for Iron Castings' Technical Advisory Panel, as the result of an invitation sent to the Institute by the Director.

At the invitation of the Director for Iron Castings, the Technical Committee is assisting very considerably, in an advisory capacity, in the production problems associated with a new armament component, and for this purpose a special staff of technicians has been temporarily employed by the Institute. Arrangements have been made whereby the cost of this work will not be borne by the Institute's funds.

Through representatives elected to various of the British Standards Institution's Technical Committees, the Institute has been able to play its part in the important war-time specificational functions which have been fulfilled by that Institution.

Numerous technical inquiries from members have been answered during the year. The Technical Committee is anxious to assist members in this way, and invites them to refer their problems to the Committee.

J. W. Gardom,
Convener.

PRESIDENTIAL ADDRESS

Mr. Lake and Gentlemen,—When you honoured me by making me a Vice-President, it occurred to me that, in my presidential address, it might be appropriate to make a general review of the development, present position and prospects of our industry. For obvious reasons it is not opportune at the present time to disclose facts and figures of an industry that plays so important a part in war production. I will, therefore, restrict my remarks to a few general observations connected with the war; and later, perhaps, put forward a few suggestions concerning post-war conditions.

A foundryman is essentially a man who learns from experience, and our experience of previous wars, whether vicariously by our reading of history, or directly, as in the case of a number of us, who were engaged in the last great war, seems to show that, however dislocating they may be at the time, wars are only episodes in the general progress of mankind. If, therefore, we continue our habit of basing our future practice on experience, we must be led to the conclusion that whatever setbacks the present war may produce, whatever discomfort or sorrow we may feel as individuals, the general progress of mankind will not be impeded, and our efforts, as scientists, and producers of commodities for the amelioration and advantage of our fellow-men, will in the long run be in no wise diminished.

It may be difficult to realise this, when, on the one hand, the skill and labour of our industry contribute to the strength of the perverted activities of the dictators, and, on the other hand, to our own power that will assist the natural overthrow of all dictators. Both antagonists are engaged in mutual destruction, and the destruction of many physical concomitants—at any rate, we have habituated ourselves to regard them as such—of a happy life. Not only do I sincerely believe that, however tragic it may seem at the time, war is only a temporary retrogression, but feel that if, owing to the frequent recurrence of wars, a man were to regard life as meaningless, he would be, as Einstein says, "not merely unfortunate, but almost disqualified from living." He goes on to say: "Each of us is here for a brief sojourn, for what purpose he knows not, though sometimes he thinks he feels a purpose. From the point of view of daily life we exist for our fellow-men. In the first place, for those on whose smiles and welfare our happiness depends. A hundred times a day I remind myself that my inner and outer life depend on the labour of other men, living and dead, and that I must exert myself to give in the same measure as I am receiving."

I doubt whether the benevolent scientist, when he said that he should exert himself "to give in the same measure as he was receiving" meant "an eye for an eye and a tooth for a tooth," but if the naturally pugnacious foundryman interprets the dictum literally in all its aspects, his justification will be that he is but hastening by apparently the only methods available, the return to sanity of those who have departed from it. In a world where abnormalities and aberrations exist, they must be dealt with whether they occur politically in a nation, or psychologically in any mass of people, in exactly the same way as they would be treated as a disease of the human body, or morbidity of an individual mind.

When such nations as the Huns have learned to shed their barbarity, other methods of dealing with diseased mass psychology will be employed, but in the meantime the surgical operation necessary requires the implements of war. "Give us the tools and we will finish the job." May such tools as we foundrymen provide be ample, and the job soon finished! Our immediate position, therefore, is clear. The future, however, is not so obvious.

The Future

When hostilities cease, and later, when the vast numbers of men and women engaged directly and indirectly for war purposes revert to peaceful pursuits, considerable forethought will be necessary to guide the change. The problem is exactly of the same magnitude as the change from peace to war, but operating in reverse, so to speak. Its speed will probably be no greater. The conclusion, therefore, is that it is almost inevitable that "Control" will persist for some years after the war.

For my own part, I regard this as desirable. Apart from war conditions, amalgamations into big units and co-operation amongst smaller units were growing tendencies. I am not convinced that schemes of nationalisation and socialisation of all industries have reached a stage of technique where it could safely be said that they would be accompanied by a higher standard of living; but I certainly am convinced that the popular school of economics to which the city in which we are meeting gives its name, is out of date and inapplicable to modern conditions. In other words, in large well-established industries such as ours, there will be no more *laissez-faire,* even though the devil may still take the hindmost.

A positive solution is particularly difficult when a fundamental economic basis is not clearly understood. The subject is a wide one, and it may be interesting for a moment to review our personal reactions. Though the ambitious and the materialistic minded amongst us may say that the monetary reward should be proportionate to our effort, the actual fact is, that most of us work because we have the habit of it, induced by the necessity for meeting our day-to-day responsibilities, and because we like it I remember an old foundry foreman, working under me, who said, when given an unpleasant job, "If I weren't doing that I'd be doing summat else," and he would depart, cheerfully grumbling, and do the job well. I will not assert that the monetary reward has no bearing upon the effort, but I do emphatically say it is not the primary consideration. I would put a sense of security before it, but even the apprehension of insecurity is frequently an example of meeting trouble halfway. Much more important is the sense of enjoyment and satisfaction in doing the job itself.

There is, it seems to me, a mean, where for a reasonable, possibly a chance of an increasing, reward, and a reasonable sense of security for the future, happiness may be obtained in the actual performance of a job well done, to give service directly or indirectly to our fellowmen. Giving such service, not the actual pursuit of monetary reward, or even of personal happiness, should be the primary motive for our activity; for happiness is rarely the objective itself, but a concomitant. I have given prominence to the inwardness of the effects, because I regard it is most important.

"If solid happiness we prize,
Within our breasts this jewel lies."

As far as the outward effects of post-war conditions upon us as members of the foundry industry are concerned, I have already alluded to the probability of the continuation of control. Control, in our case, will have to be particularly widespread, as we very rarely sell our products direct to the final consumer. For the most part, our products are raw materials upon which there are numerous operations, such as machining and assembly. Hence, from the point of view of the market—without which we cannot produce—any national plan to serve the foundry interests cannot restrict itself to the foundry interests alone. It will have to form part of a much wider plan. The same, however, does not apply to the actual operations of production, wherein we as a technical institution are mostly concerned. Here the industry must have individual consideration, though no doubt the methods employed will conform with the general principles that may be laid down for similarly placed trade. The characteristic feature of the foundry industry is one that will make any national plan of production very difficult. I allude to the participation in the industry of a comparatively large number of small, privately owned, foundries. Again, I am skirting a wide subject, but this question of the size of a producing unit can be determined simply on economic grounds. If the small foundry can deliver castings to the market better and cheaper than the large one, such castings will be made in small foundries.

In case it should be observed that this is the first time I have used the word "cheaper," I would interpolate that I am assuming that under any system of production, whether for private profit or otherwise, a product should be made with the least ultimate expenditure of man-power value.

Utilisation of Leisure

I would say that we have not yet reaped the full benefit of the release of man-power by mechanised systems of production. We have certainly reduced the working hours in the week, and must, of course, use further man-power in actually making the machines, and in the far more elaborate system of distribution now necessary. But I can visualise that we may be able, within this generation, to reduce the working week still further; to reduce the age of retirement; and to raise the school-leaving age.

I am not alluding to an immediate post-war period, when a starved world will probably be able to accommodate and consume goods that will require long hours to produce; but to a longer and more general trend, when interchange of commodities may again reach comparative stability.

This may seem irrelevant in an address to the Institute of British Foundrymen, and especially its corollary, that we should take our part in training ourselves and our workpeople to make proper use of any increased leisure. We have always had a strong educational bent in our Institute, and I have no doubt that we shall continue this, not only as an Institute in the specialised industrial direction, but as individuals in other directions, where the well-being of our workpeople is concerned. In this connection we should not forget ourselves, who for the most part, as far as my experience goes, have so very little time apart from our works' duties, that we only half-heartedly enjoy the little leisure available to us. What is the point of being, as I heard described a recently deceased foundryman, "The wealthiest man in the cemetery"?

I think that we have been especially favoured in this country, for my experience in many parts of the world is that our standard of living is comparatively high. The standard of education and the appreciation of the good things of life is certainly higher than in many other populous countries. This high standard, however, carries with it its obligation that it has to be earned. If, for example, our standard of education is higher, we should use our brains to give value in material advantages to those whose standard is lower, and who are willing to pay for such advantages in physical labour. Conversely, it is not possible to maintain the advantage of a higher standard of education if the outgoings necessary to attain this standard are lost in the production of commodities that require only physical labour to produce them.

Under to-day's rapid interchange, the lag in the adoption of ingenious mechanism is small. In other words, comparatively uneducated races can reproduce scientific methods of production quickly. We observe this in many parts of the world to-day, and this effect must be clearly envisaged when we endeavour to interchange our commodities, for the imported commodities we shall require, in the post-war period. Unless we have something of value, something that has risen out of our higher standard of living, involving higher educational attainment, and not the mere result of physical application which can be made by those with a lower standard of living, we obviously cannot maintain our standards.

Increased Research Effort Essential

Summarising this effect, to continue our higher standard, we must vigorously and successfully pursue our scientific research and development. We must not only bring such research to a successful academic conclusion, but we must see that steps are taken, by suitable propaganda, and otherwise, to ensure that a practical realisation of exchangeable value accrues from our efforts.

Hitherto I have presupposed a continuation of the requirement of our services, possibly on a restricted scale in some directions, but nevertheless continuing. That foundry products will be required after the war is certain, but their measure is not easy to determine. I have assumed that the foundry industry depends largely on the requirements for castings of other trades, and hence is normally largely dependent on such industries.

I think that foundrymen should not allow their work and their livelihood to depend on any third parties. We should ourselves take some initiative, in collaboration with these industries where necessary, and actively take all possible steps to ensure that the foundry industry participates in full measure in the post-war reconstruction. We are primarily a technical body, but all our technique will be of no avail unless the need for our production be assured.

The Institute of British Foundrymen is undoubtedly the strongest and most homogeneous comprehensive foundry organisation in the country. We have, on the one hand, research associations such as the British Cast Iron Research Association, entirely technical organisations, and, on the other, the various trade associations, becoming more comprehensive, in the industry. There have recently been attempts to consolidate the commercial side of the industry, which have not proved too fruitful, though such efforts are continuing, I hope, to a successful conclusion. A little display of sympathy by the Government would be encouraging.

The problems of post-war reconstruction are amenable, to say the least of it, to scientific approach. You gentlemen, for the most part, are scientists. I suggest, therefore, you bend your activities, when you are satisfied that, in accordance with the first part of my address, you are doing your utmost to end the war by producing the maximum means to that end, to devote your scientific minds to post-war problems; to take the initiative with your commercial colleagues to ensure that foundry services shall, in peacetime, continue to give the maximum benefit to the community.

It is a matter for our Council to determine whether we can take the initiative as an Institute, and continue a further and wider leading part in conditioning affairs so that the long-term trend of our industry shall be upwards. Whatever our conclusion, I repeat that *laissez-faire* will probably find us left without the fair deal, or we may revert to the situation where dog eats dog. With the elimination of wasteful internecine competition there will be more time to explore the infinite realms of progress. Within our short lifetime the art of founding has made revolutionary advances, and has embraced many new alloys and even several new metals; apart from the developments in the means of casting them, and all that it implies, which are our own special prerogatives.

I hope I end in an optimistic strain. We have a present duty to perform, to continue to take a leading part in helping to win the war. We have a future duty to perform: to use, jointly and severally, our scientific and other abilities, and our common sense, to ensure that our industry maintains its part in serving our fellow-men.

PAPERS PRESENTED TO THE

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Paper No. 730

American Synthetic Sand Practice

BY NORMAN J. DUNBECK*

[AMERICAN FOUNDRYMEN'S ASSOCIATION EXCHANGE PAPER]

DEFINITION OF SYNTHETIC MOULDING SAND

When metal is cast against moulding sand, the clay contained in the sand close to the casting is dehydrated and it loses strength. It is further weakened by normal accretions of burned core sand. This weakened sand often is discarded, although it may be as good in refractory value and grain structure as when it was new. This is costly and inefficient. Many foundries now add bonding clays to restore strength, and in this way, effect elimination of new bonded sand or a considerable reduction in the amount used.

Bonding clays are strong plastic clays which develop strength rapidly, even when used in small amounts. They may be added to new or burned silica sand to form synthetic sand. Some sand producers now manufacture what is called synthetic sand by the addition of bonding clay to unbonded or low-bonded sand at the sand pits. As generally used in American foundry practice, however, the term synthetic sand covers any sand which is made in the foundry, as required, from materials selected and proportioned by the foundryman to fit best his particular needs. A rebonded sand is one whose usefulness or life is prolonged by the addition of bonding clay.

A certain amount of burned sand is lost from the foundry each day by adherence to castings. Common practice in making the synthetic sand is to add to the used sand enough clay bond to restore strength and enough silica sand to maintain volume. Since this silica sand and the core sand used are the only new materials entering the sand they will eventually compose the entire heap or system. It is, therefore, essential to select a grain-size of this sand which will give the finish and permeability required.

Synthetic sand has been used in steelfoundry practice for a great many years. Its use is so common that steelfoundrymen do not often speak of their mixtures as synthetic sands. The term, of course, describes such sand, but probably is used more often by ironfoundrymen in describing their combinations of bond clay and sands. The general procedure followed in cleaning, classifying and rebonding used sands is termed sand reclamation. The term clay-bond is a general one and may refer to fireclay bonds, other plastic clays, bentonites or bentonitic clays.

The reclamation and rebonding of used iron-foundry sands reached substantial volume in the United States between 1925 and 1930 and has increased steadily since. It now seems probable that a larger tonnage of castings is made annually in synthetic sand than is made in naturally-bonded sands.

Some objection has been raised to the term "synthetic sand" because the word "synthetic" might imply that the material was a cheaper and inferior substitute for naturally-bonded sands. It has been suggested that the sand be called "artificial sand" or "manufactured sand." The term "synthetic" has been in use so long that it will probably be continued. It is worth noting, however, that the product is used because the user believes it to be superior as well as cheaper than the natural product.

The writer has also read occasional references in the British technical Press to the effect that synthetic sands are widely used in the United

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States because there is a scarcity of good naturally-bonded sands. There are deposits of high-quality naturally-bonded sands in almost all parts of the United States and they occur in enormous tonnages.

SELECTION OF MATERIALS

Base Sand

A synthetic sand may be made from all new unbonded sand and clay; from naturally-bonded sand and clay; from used moulding or core sand and clay or from combinations of these various materials. When it is proposed to rebond certain sand heaps it should be realised that there is a certain loss of sand on the castings of which only a portion is recovered. This loss must be replaced by daily additions of sand which may be any of the above materials. The original sand in the heap will eventually be entirely replaced by the sand in the daily addition resulting in a final mixture composed of the base material and bond. The final result is the same, therefore, whether a start is made with a completely new synthetic mix or whether rebonded old sand is the original material.

The base sand may be a bonded sand, a low-bonded sand or an unbonded sand. An unbonded sand is preferable since the clay in naturally-bonded sands is neither usually efficient nor refractory. The so-called bond in natural sands also frequently contains a substantial percentage of silt which adds little to strength, increases the amount of tempering water required and reduces permeability and flowability. Some low-bonded sands are desirable since the small amount of natural clay present provides a priming surface on the grains and substantially reduces the amount of bonding clay which must be added. Any final decision on base sand depends upon the delivered cost, a cheap local low-bonded sand being preferable to a costly distant unbonded sand.

The base sand is examined for these four properties: (1) Grain size, shape and distribution; (2) minimum clay content; (3) refractory value; and (4) minimum expansion.

The reasons for stipulating minimum clay content, minimum expansion and maximum refractory value are apparent. Some thought must be given to grain size, shape and distribution. While the type of bond clay used will have effect upon flowability and hence finish, it is true that fine finish is obtained only from fine-grained sands. While the type of clay will affect the permeability, it is still true that very high permeabilities are given only by comparatively coarse sands. One must, therefore, seek the proper grain size for the work to be done. In the search for such sand grain shape and distribution must also receive attention.

For some years a perfectly round grain was considered the ideal. It is now realised that such round grains require a comparatively higher amount of bonding material and cause greater difficulty from cutting and scabbing than do sub-angular grains, which are preferable. It has also been found that many sub-angular grained sands give satisfactory permeability, and may even give higher permeability than some round grained sands despite all theories to the contrary. Burned core sand from oil-sand cores is an excellent material to rebond, as the grains have a rough surface and accept bond readily.

It was once thought that all fines should be eliminated and the sand grains concentrated upon as few screens as possible. It is now known that a certain percentage of fines is desirable, and that too heavy a concentration of grain on a few screens may give a sand having a pronounced tendency to rat-tail or buckle.

TABLE I.—*Relative Value of Various Types of Clays.*

	Kaolinite.	Illite.	Montmorillonite	
			Southern.	Western.
Highest green compression strength	4	3	1	2
Highest dry compression strength	2	3	4	1
Highest permeability	4	3	1	2
Least tempering water required	4	3	1	2
Highest sintering point	1	4	2	3
Greatest durability	1	3	4	2
Highest flowability	3	2	1	4
Best collapsibility	3	2	1	4
Highest resilience	2	3	4	1
Least contraction at 1,370 deg. C.	1	4	2	3
Fewest lumps in shake-out sand	3	2	1	4
Least intensive mixing effort required	4	2	1	3

This is due to the close packing of uniform grains in a sand of high flowability. When the silica grains expand they break the mould face. A minor break causes a rat-tail; a larger break causes a buckle, and a still larger break causes a scab, although it is recognised that scabs are also caused by other factors. In the last case, the moving metal penetrates under the broken surface or removes a portion of the sand, replacing it with metal. These defects appear in maximum development in the cope of the mould.

The fines in sand have much higher expansion than the coarser grains, yet their addition to the coarser grains reduces expansion difficulties. It has been said that the fines provide a cushion between the larger grains, but the author believes that their corrective action is due to the simple fact that they reduce flowability, thus increasing the distance between the coarser grains in the rammed mould face. This seems corroborated by the fact that a very small addition of cornflour is the best-known method of stopping these cope defects, short of changes in the sand grain distribution; cornflour reduces flowability faster than any other common moulding material.

The present trend is to seek the bulk of the material on three adjacent screens with a few per cent. on possibly two more adjacent screens. Such a sand still gives high permeability in relation to its fineness, but the distribution is such as to reduce expansion difficulties. Some American foundries which use large quantities of oil-sand cores shake out as much as possible of the burned core sand into the sand systems and also return to the systems burned core sand which is carried away with the castings. It is then possible for them effectively to control the fineness of the system sand by varying the proportion of fine and coarse sand in their cores. This has been described more fully by Zirzow,[1] and his Paper is probably available in many United Kingdom libraries in the bound volumes of the A.F.A. Transactions.

In any moulding sand, foundrymen are interested principally in grain size, green strength, dry strength, hot strength, permeability, durability, flowability, moisture required, resilience, expansion, contraction and sintering point. In selecting a naturally-bonded sand, there is the difficult problem of finding as many of these twelve properties as well developed as possible within an economical radius of location. In compounding a synthetic sand, only three properties must be found—grain size, permeability and expansion—as they are to be established in the base sands, and foundrymen can control the other nine properties to a substantial extent by their selection of clay bond to be used. Since there are many types of clays available, the problem of making a synthetic sand is considerably simpler than the problem of finding an equally satisfactory naturally-bonded sand.

Bond Clay

Almost any kind of plastic clay will develop some binding strength. Special clays are used, because the clay should not only give green strength, but must also develop dry strength; have a high sintering point; the ability to mix rapidly; good durability; adequate strength at high temperatures; moderate contraction at high temperatures, and other special requirements for specific problems.

The selection of the proper clay requires a knowledge of the essential properties of the general group of clays. Until a few years ago, there was considerable mystery even among clay producers themselves as to the reason for different results given by different clays. Recent work indicates that the mineral composition of clay is the most important single factor in determining results. Thus, two clays each having the same percentage of clay substance might deliver approximately the same strength if kaolinite was the principal mineral in the clay substance of each clay. Two other clays, each having the same percentage of clay substance, might differ very sharply in bonding value if kaolinite was the principal mineral in one, while the second was a mixture of kaolinite and illite (beidellite). In addition, the strength of a clay bond is affected by the percentage of clay substance and the type of ion absorbed on the surface of the clay particles. The importance of the adsorbed ion is clearly indicated by Western and Southern bentonites. These materials, which differ radically in physical properties, are practically identical in particle size and mineral composition, but the Western deposit carries basic adsorbed ions while the Southern carries acid adsorbed ions.

Table II.—*Effect of Changes in Quantity of Clay and Water on Hot Strength.*

Base sand, unbonded silica. Average grain fineness, 53.

Bond or combination.	Ohio fireclay.	Ohio fireclay.	Ohio fireclay.
Per cent. bond	12	12	10
Per cent. moisture	4.0	3.5	3.3
Permeability	85	87	103
Green compression	8.5	10.5	8.7
Green deformation	0.019	0.017	0.015
Dry compression	71.5	52.0	47.5
Hot strength :—			
260 deg. C.	55	52	38
535 „	100	85	60
815 „	153	87	80
1,040 „	550	400	295
1,370 „	5	6	5

The high quality clays in each group can be expected to give generally similar results, but there is, of course, a wide range in quality between the best and worst clays in each group. If refractory clays of low bonding power are eliminated, the currently available American bonding clays may be grouped into three classes determined by their dominant mineral. These classes are given in Table I, together with their relative values for various properties in the production of synthetic sand. Comparison merely indicates the order from best to worst in each property.

Kaolinite Clays

Practically all of the refractory bond clays, such as fireclay and ball-clay, fall into this class and this is the most widely-used type of bond clay in the United States. Fireclays of excellent plasticity and refractory value are available in the United States and, as a result, the more costly ball-clays have not been able to justify entry into the market at their higher cost. The best of these fire clays have a fusion point of 1,675 to 1,705 deg. C.; a clay content according to A.F.A. methods (fineness 0.02 mm.) of about 95 per cent. and a clay content according to the pipette and hydrometer methods (fineness 0.005 mm.) of about 75 per cent.

There is a greater difference in value between the good clays and poor clays of this class than between the class itself and any other class. Any statements about these clays or the clays in following classes will refer to the best of the individual groups.

A specially-selected and prepared clay of this type is essential to good results. Since this type of clay is most refractory and gives the highest possible sintering point, it is particularly well-suited to heavy castings and the alloys which are melted at high temperatures.

More of this clay must be used for any given strength than of the high strength clays to be later described. Where very high permeability is required, it would, therefore, be preferable to use a higher strength clay. An exception to this would be the case of the foundry which could not cheaply secure a base sand of the exact fineness required. In such case, the greater volume of this type of clay which would be used would tend to smooth up the surface of a coarser sand giving the finish required.

The kaolinite clays give moderate green strength; moderate dry strength; good flowability; the highest sintering point and lowest contraction at high temperatures of any type of clay. They are also the lowest in cost and have the highest durability.

Illite Clays

Illite clays are not widely used in the United States, but they are here included because many naturally-bonded sands have illite as a major constituent in their clay content. There is wide variation in the value of various illites, but the best clays in this group have a finer grain size than the kaolinite clays and develop somewhat higher green strength. It is necessary to use a lesser amount which results in higher permeability. They give good flowability and reasonably high sintering point. They have a moderate dry strength and a rather high contraction at high temperatures, whilst they have low durability as compared to the kaolinite clays.

They may be considered an intermediate clay with higher strength than the kaolinite clays, but much lower strength than the montmorillonite clays. Their use depends upon comparative delivered costs at any particular location.

TABLE III.—*Hot Strength o Combinations of Bond Clays.*
Base sand, unbonded silica. Average grain fineness, 53.

Bond or combination.	S.B.	75 per cent. S.B.* 25 per cent. W.B.†	50 per cent. S.B. 50 per cent. W.B.	25 per cent. S.B. 75 per cent. W.B.	W.B.
Per cent. bond	4	3.8	4.3	4.8	5
Per cent. moisture	2.6	2.5	2.5	2.5	2.5
Permeability	178	180	171	160	167
Green compression	9.9	9.6	9.8	9.8	9.6
Green deformation	0.008	0.012	0.012	0.011	0.012
Dry compression	47.0	42.0	59.0	69.0	83.0
Hot strength :—					
260 deg. C.	21	31	38	43	75
535 "	35	42	53	55	74
815 "	30	70	160	175	195
1,040 "	25	65	90	95	490
1,370 "	3	4	5	4	8
Strength after cooling from 425 deg. C.	20	37	40	45	55

Retained strength after cooling from 425 deg. C. indicates quantity of lumps to be expected in shake-out sand.
* S.B. = Southern bentonite. † W.B. = Western bentonite.

Montmorillonite Clays

The montmorillonite clays used for bonding in the United States are the Western bentonites produced principally in Wyoming and the Southern bentonites produced principally in Mississippi. Both types of clays are available and carried in stock in the United Kingdom. These clays have the finest grain size of any bonding clays. They develop double the green strength of the best kaolinites. The Western bentonites swell when placed in water while the Southern bentonites are non-swelling. The bentonites give the highest permeability of any clays and the highest or lowest dry and hot strengths depending upon the type selected.

The most important recent American research work on sands has been on hot strengths and the most important recent development in practice has been the use of combinations of clays instead of a single clay.

Tables II, III, IV, V and VI show hot strength behaviour and will be discussed briefly since this information is important in choosing the single clay or the combination of clays to be used. Table II shows a rather startling increase in hot strength with only slight increases in clay and water content. This indicates that kaolinite clays have adequate hot strength for any job when properly handled. It may also indicate the source of some cracked castings in the malleable industry since an overtempered batch of sand has far higher hot strength than the same sand properly tempered.

Table III shows the gradual increase in hot strength from Southern bentonite, through combinations to Western bentonite. A foundry might have washes and cuts due to the low hot strength of Southern bentonite or difficult shake out, lumpy sand and cracked castings due to the high hot strength of Western bentonite. A combination of the two may be made to yield the exact strength required.

Table IV shows the same progression from low to high hot strength when mixing Southern bentonite and Ohio fireclay. When difficulty is experienced with either low or high hot strength from a single bond, certainly it is only common sense to use a combination that will give the hot strength required to stop cutting and washing and no more. This extends sand control into a hitherto untouched and frequently troublesome field.

Table V shows that combinations of Ohio fireclay and Western bentonite, instead of giving hot strengths intermediate to the bonds used, gave a peak strength more than twice as high as either component. This could hardly have been predicted from low temperature, dry strength testing. Such combinations should have excellent application for heavy iron or steel castings.

Table VI shows that additions of cereal binder (cornflour), pitch and rosin sharply increase the dry strength of Southern bentonite, although the increase in hot strength is such as still to provide a highly collapsible sand. Such a sand should be desirable for steel castings which have a tendency to crack. It is interesting to note that the addition of cereal binder to Western bentonite did not appreciably increase dry strength, and caused a sharp decrease in hot strength. This indicates that steelfoundry-

Table IV.—*Hot Strength of Combinations of Bond Clays.*
Base sand, unbonded silica. Average grain fineness, 53.

Bond or combination.	O.F.C.	75 per cent. O.F.C.* 25 per cent. S.B.†	50 per cent. O.F.C. 50 per cent. S.B.	25 per cent. O.F.C. 75 per cent. S.B.	S.B.
Per cent. bond	12	9.25	6.5	5	4
Per cent. moisture	4.0	3.7	3.2	2.6	2.6
Permeability	85	118	139	167	178
Green compression	8.5	11.0	10.4	12.9	9.9
Green deformation	0.019	0.015	0.015	0.012	0.008
Dry compression	71.5	83.0	71.0	55.0	47.0
Hot strength :—					
260 deg. C.	55	54	35	40	21
535 „	100	59	50	48	35
815 „	153	100	62	30	30
1,040 „	550	450	238	85	25
1,370 „	5	5	5	4	3
Strength after cooling from 425 deg. C.	65	74	43	27	20

* O.F.C. = Ohio fireclay. † S.B. = Southern bentonite.

men who have used such combination for increased strength have not benefited much in that respect, but have actually provided a more collapsible sand.

Choice of Clay

From the results in various tables, a choice of certain clays for certain work can be made.

Non-ferrous

(1) Light:—Southern bentonite for its combination of high permeability and high flowability.

(2) Heavy:—Fireclay for economy, if the permeability be not too important or to smooth up sand if only coarse sands be available. Western bentonite for highest permeability combined with high hot strength. Fireclay:—Southern bentonite for high hot strength and economy if slightly lower permeability be acceptable.

Grey Iron

(3) Light:—Southern bentonite for its combination of high permeability and high flowability.

(4) Medium:—Fireclay for economy if permeability be not too important or to smooth up sand if only coarse sands are available. Western bentonite for highest permeability combined with high hot strength. Fireclay:—Southern bentonite for high hot strength and economy if slightly lower permeability be acceptable.

(5) Heavy:—Fireclay for high hot strength and economy, particularly on dry sand work where permeability is not important. Western bentonite for highest permeability combined with high hot strength. Fireclay:—Western bentonite for highest hot strength.

Malleable

(6) Light:—Southern bentonite for its combination of high permeability, high flowability and moderate hot strength.

(7) Medium:—Fireclay for economy. Southern bentonite for highest permeability and flowability combined with moderate hot strength to prevent cracked castings. Fireclay:—Southern bentonite for moderate permeability and moderate hot strength. Western bentonite:—Southern bentonite for highest permeability, combined with moderate hot strength.

(8) Heavy:—Fireclay for high hot strength and economy, particularly on dry sand work where permeability is not important. Western bentonite for highest permeability, combined with high hot strength. Fireclay:—Western bentonite for highest hot strength.

Steel

(9) Light:—Southern bentonite plus cereal binder for its combination of high permeability and high flowability.

(10) Medium:—Southern bentonite-Western bentonite plus cereal binder for high permeability, high dry strength and moderate hot strength.

(11) Heavy:—Fireclay plus cereal binder for high dry strength, high hot strength, and high sintering point. Western bentonite plus cereal binder for high dry strength, high hot strength, and highest permeability. Fireclay:—Western bentonite plus cereal binder

TABLE V.—*Hot Strength of Combinations of Bond Clays.*
Base sand, unbonded silica. Average grain fineness, 53.

Bond or combination.	W.B.	75 per cent. W.B.* 25 per cent. O.F.C.†	50 per cent. W.B. 50 per cent. O.F.C.	25 per cent. W.B. 75 per cent. O.F.C.	O.F.C.
Per cent. bond	5	5.2	6.8	8.5	10
Per cent. moisture	2.5	2.3	2.8	3.5	3.3
Permeability	167	162	154	116	103
Green compression	9.6	9.1	8.7	8.8	8.7
Green deformation	0.012	0.013	0.017	0.018	0.015
Dry compression	83.0	75.0	125.0	120.0	47.5
Hot strength :—					
260 deg. C.	75	40	65	116	38
535 „	74	65	100	160	60
815 „	195	120	240	250	80
1,040 „	490	560	830	1,000+	295
1,370 „	8	5	6	8	5
Strength after cooling from 425 deg. C.	55	61	89	110	—

* W.B. = Western bentonite. † O.F.C. = Ohio fireclay.

for high dry strength and highest hot strength.

METHODS OF APPLICATION

In Sand Heaps

Several methods may be used to add bonding clays to foundry sand. A small amount of clay bond may be placed on each mould before it is shaken out. With most bonds, this is satisfactory on heaps where a sand-cutter is used for sand preparation only if the cutting and mixing is done most thoroughly. It also may be spread over a heap and cut in, but full efficiency is not obtained from the bonding material in such usage, and there is danger of clay balls forming. When this method is used, the clay and heap sand should be cut thoroughly dry before tempering water is added.

Fireclay and illite must be used in considerable quantity when mixed by sand cutter instead of muller, and there is a tendency for clay balls to form. Western bentonite mixes reluctantly because of its swelling nature on contact with water. Non-swelling Southern bentonite quickly slakes into a slurry on contact with water, and is a safe material for this type of application. This has some importance in that it makes the advantages of synthetic sand available to foundries that have not felt they could use bond clay because they do not have intensive mixers.

Some foundries mix the clay bond with water to form a slurry, and use this mixture as their tempering water. This gives high efficiency from the amount of clay so used, but it is not possible to introduce enough clay for very high strengths by this method because of the relatively small amount of tempering water usually required. The method is economical since it eliminates transportation and mixing costs as compared to machine mixing. The strength delivered depends not only upon the strength of the clay used, but also upon the quality which it is possible to carry in slurry form. This, in turn, depends upon the maximum viscosity of slurry which can be pumped. Such point of maximum viscosity for average conditions is given in Table VII.

Because Western bentonite immediately swells to a gel, only a relatively small amount can be incorporated in a slurry of pumpable viscosity. Southern bentonite, being non-swelling, readily slakes in water in the same manner as does fireclay. The figures for "relative effective strength" are arrived at by using Western bentonite as a base at 100 per cent., and computing other strengths from known relative values and amounts present in slurry.

TABLE VI.—*Hot Strength of Auxiliary Binders.*
Base sand, unbonded silica. Average grain fineness, 53.

Bond or combination.	S.B.*	4 per cent. S.B.* 1 per cent. C.F.†	5 per cent. W.B.‡	5 per cent. 1 per cent. W.B. C.F.	4 per cent. S.B. 3 per cent. pitch.	4 per cent. S.B. 1 per cent. rosin.
Per cent. bond	4	—	5	—	—	—
Moisture	2.6	3.6	2.5	3.5	3.5	3.5
Permeability	178	138	167	152	110	128
Green compression	9.9	8.2	9.6	9.3	11.7	8.1
Green deformation	0.008	0.034	0.012	0.027	0.013	0.012
Dry compression	47.0	133.0	83.0	87.0	158.0	145.0
Hot strength :—						
260 deg. C.	21	85	75	63	67	42
535 „	35	48	74	50	144	45
815 „	30	45	195	105	102	41
1,040 „	25	65	490	280	100	96
1,370 „	3	3	8	6	6	3

* S.B. = Southern bentonite. † C.F. = Cornflour. ‡ W.B. = Western bentonite.

TABLE VII.—*Clay Content and Relative Strengths in Slurries.*

	Per cent. clay in slurry.	Percentage relative effective strength.
Western bentonite	8.25	100
Southern bentonite	34.20	491
Ohio fireclay	52.30	288

In Mixing Mills

The best method of rebonding a heap of sand, where a muller mixer is available, is to manufacture a synthetic sand. This may be a mixture, in any proportions, of used moulding sand, burned core sand or new silica sand, with the proper amount of clay bond. Such a sand may be made with high or low permeability and with high or low strength, thus giving a very flexible control of sand conditions. Such a sand often is made by a night shift on the mixer, so as not to interfere with the daytime production of core sand or facing sand. When the proper sand has been prepared, it is added to heaps or systems exactly as is natural moulding sand, thus avoiding any change in sand handling methods.

When there is sufficient or excess volume of sand in the system or heap, a concentrated mixture of sand and clay bond may be made. This may vary from 20 to 40 per cent. bond. Such mixtures must be mixed very dry, usually with 2 per cent. of water or less. These mixtures reduce handling costs and aid in controlling the volume of the sand. Less efficiency is given by the amount of clay in such concentrated mixtures than is given when smaller amounts of clay are mulled thoroughly at their proper moisture content.

The statement is still sometimes made that the use of clay bond results in loading up a heap with clay with reduced permeability. This might be true if clay were added continuously to the same mass of sand. Actually, the sand is constantly changing. Each day a portion of it is carried away on the castings and an equal volume of prepared sand is added. A cycle is thus established where permeability is maintained at any desired point by varying the composition of the added sand.

Synthetic sand is so flexible that it makes sand control easier. The purpose of sand control is to permit prediction of results to be obtained through proper selection and testing of materials. If bad castings result, the fault is with the sand control and not with the sand, whether naturally-bonded or synthetic.

In Sand Handling Systems

It is a simple matter to add clay bond to any sand handling system if the system has any type of sand mixer. Any type of clay will work successfully, because the clay is added in small regular additions. The clay may be placed on top of each mould before it reaches the shake-out; it may be added manually or by any type of feeder at the shake-out; it may be fed to the mixers as a slurry; or it may be fed into the system in any convenient manner as a prepared synthetic sand of any desired strength.

Burned core sand which is shaken out into the system sand usually aids in maintaining necessary volume of sand. If additional silica sand be required either for volume or permeability, it may be added in any convenient manner.

In Facing Sands

Bonding clays are of particular value in preparing facing sands, since they permit great flexibility in the control of strength without the notable variations in permeability which would accompany similar changes in strength, if effected by additions of naturally-bonded sands. The usual facing mixture consists of used moulding sand, plus some casting cleaning element (such as coal dust for iron castings), plus clay bond, plus enough silica sand to give the required permeability. Burned core sand from oil-sand cores may replace the silica sand if its grain size be such as to ensure the necessary permeability. Since such silica or core sand is the only new sand material entering the foundry, it eventually will dominate the heap or system sand which comes back to the mixer to be made into facing or synthetic sand. As the permeability of this returned sand rises, the amount of burned core sand or new silica sand being added to the facing mixture is decreased. In foundries where it is essential to produce a very fine finish, a fine silica sand is used. In any case, the objective is to secure a sand of maximum fineness which will give the permeability required through its uniformity.

When a durable clay is used in the facing, it loses only a moderate amount of strength on pouring, and the remaining strength, upon mixture of facing and backing sand, is frequently sufficient to maintain the strength of the backing sand without further clay additions.

In many American iron foundries, some casting cleaning element, such as coal dust, is added to all the system sand as mixed, thus, in effect, making all the sand in the system into facing sand. This eliminates the cost of the separate mixing, storage and transportation of facing sand. No difficulty is experienced in the preparation and use of such sand except for the fact that the sand may become quite hot when reused several times per day. In such cases it is essential to use a bond clay which does not become sticky when hot.

Sand Reclamation

Many foundries have now installed sand-preparing and reclaiming units. Such units may have a floor-level grating into which is dumped excess or used moulding sand, burned core sand, gangway sweepings and, in general, any sand that can be collected around the foundry. A magnetic separator removes metal, a coarse screen removes hard core, wedges, etc., and a suction fan removes dust and fines. Vibrating screens may be installed to classify the sand. The amount of suction applied to the system is adjustable, and a greater or lesser amount of fines is removed, depending upon permeability and finish requirements.

This cleaned sand usually is stored in a bin directly over the mixer, into which it is fed as required for the production of facing sand or synthetic sand to be added to systems or heaps. Where a reclaiming unit is in use, permeability usually may be controlled by the amount of fines removed, with no additions of new silica sand.

General

In any application of clay bond, it is important to mix the bond and sand dry before adding tempering water. This results in much higher efficiency from the clay, and eliminates the possibility of clay balls being formed by the addition of water to the bond before it has been distributed through the sand.

There is also a growing tendency to keep some bonding clay available in all foundries even though naturally-bonded sand is the principal material used. The bond is used to bolster up weak natural sands; to add strength to facing sands, and to build up heaps which ordinarily require excessive additions of new sand. Such a heap would be one in which large quantities of burned core sand fell into the heap upon shaking out castings or where very heavy castings burned the sand badly on each pouring. The addition of the necessary amount of new sand to restore strength would result in a large surplus, and the daily discarding of enough old sand to make room for the new material. In such cases, clay bond is used in place of new sand, or in addition to the use of a reduced quantity of new sand.

TESTING AND CONTROL

A.F.A. Reprint 36-26[2] covers very thoroughly American practice in the testing and control of synthetic as well as natural sands. The methods used are covered in the volume "Testing and Grading Foundry Sands and Clays." Both publications are available through the A.F.A., and probably are available in many United Kingdom libraries. A few additional comments on testing seem desirable.

Clays

In testing comparative value of clays the following conditions are necessary for accurate results:—

(1) All materials must be carefully measured or weighed.

(*a*) The difference caused by careless measuring of several scoops of clay may be greater than the actual difference in strength of materials being compared.

(*b*) Different clays vary considerably in weight per unit.

(2) All materials must be entirely dry.

(*a*) A difference of ½ per cent. in water content in a damp silica sand cannot be detected by observation but may account for as much as 18 per cent. difference in results.

(*b*) A difference of a few per cent. in natural moisture content of a clay may cause up to 30 per cent. difference in strength. A fireclay may appear perfectly dry when containing 4 per cent. water and a bentonite may appear dry when containing 10 per cent. water.

(*c*) The moisture content of clay affects strength not only through its replacement of equal quantity of bonding material, but most importantly by its reduction of rate of distribution of the clay.

(3) Clays of the same type should be tested at exactly the same moisture content in the sand. The stronger sand will feel drier and may be too dry for moulding. Proper procedure is then to keep moisture the same and reduce amount of clay. Common and incorrect procedure is to add water until both batches have the same feel. Since synthetic mixes get weaker as they get wetter, such water addition destroys the difference in strength which it was intended to measure.

(4) Test specimens should be tested individually as produced to avoid the effect of rapid surface drying.

(5) Since variables are unavoidable in large-scale foundry tests, final report should average results from at least three batches or mixes.

(6) A standard should be run with each test because of the effect of atmospheric conditions. This important precaution is rather universally disregarded.

Sands

One important fact, which is not given sufficient consideration in the interpretation of test results, is the relation between various tests. There is too much of a tendency to consider each test by itself. To illustrate this, it is proposed to consider only one property: permeability, and the effect upon it of other factors. Some of these factors are:—

(1) *Water Content.*—Two foundries each reporting a permeability of 90 might be considered to be operating under similar conditions. Further investigation may show that one is using synthetic sand with 3.5 per cent. water and the other naturally-bonded sand with 7.0 per cent. water, when it is immediately realised that there is a difference in practical results. The venting efficiency of a sand obviously depends upon its permeability, which is a measure of its ability to promote gas escape, and its moisture content, which is the major portion of the gas to be evacuated. This simple fact is frequently overlooked.

(2) *Clay content* affects permeability in two ways, since in increasing amounts it reduces permeability not only because of the amount

present, but also because of the increased amount of tempering water required. Some types of clays yield much higher permeability than others, even when present in equal quantity and although the strength of one may be far higher than the strength of the second.

(3) *Grain size and shape* affect permeability in three ways:—(*a*) Percentage of voids in sand, (*b*) percentage tempering water required, and (*c*) percentage bond clay required.

(4) Amount of ramming or mould hardness affects permeability, since a hard-rammed mould will have lower permeability than one which is lightly rammed. The laboratory test specimen gives relative values, but foundrymen must think of permeability in terms of actual mould conditions. Dietert gives the following formula for determining mould permeability:

$$\text{Mould permeability} = \frac{H \times P}{h}$$

where: H = Laboratory specimen (average hardness); P = laboratory permeability (A.F.A.); h = mould hardness of mould.

(5) The sectional thickness of sand in the mould affects permeability in the same manner as hard ramming. The thicker the section, the higher the permeability which is required, and the less informative the relation between laboratory permeability and mould permeability. Dietert gives the following formula for determining the reduction in permeability with increased thickness of sand:

$$\text{Venting permeability} = \frac{25\sqrt{P}}{D}$$

where: P = permeability; D = depth of sand over pattern in inches.

Disadvantages of Naturally-Bonded Sands

Naturally-bonded sands conforming to the description of a more or less ideal sand are not available in all localities, and the carriage involved in transporting good sands may make them quite costly. In addition, the following objections are raised against some naturally-bonded sands:—

(1) It is costly to use a sand only until its strength is burned out and then discard all the sand, although the grain itself is still good and it lacks only bonding strength.

(2) Any naturally-occurring product is subject to considerable variation even when tested and controlled.

(3) Most naturally-bonded sands have a rather complex grain structure which is not uniform in distribution.

(4) Most naturally-bonded sands have a rather complex mineral composition, and contain impurities from the materials from which derived. On heating, the easily fusible minerals, becoming liquid, attack the more refractory minerals and the melting point of the aggregate is lowered. Naturally-bonded sands seldom approach synthetic sand in refractory value; sintering point or durability.

(5) All naturally-bonded moulding sands and particularly the finer sands have a high percentage of silt in the portion known as "A.F.A. Clay." This silt reduces permeability and requires a high percentage of tempering water to make the sand reach proper working conditions and "feel."

(6) Naturally-bonded sands are sometimes not available during the winter months, and arrive in bad condition when available. It is costly to store a winter supply of sand and, unless kept in heated bins, the sand frequently freezes, causing extra expense in preparation for use.

Disadvantages of Synthetic Sands

(1) Synthetic sands are workable over a narrower moisture range than natural sands.

(2) Synthetic sands dry out more rapidly than natural sands.

(3) Most synthetic sands require more extensive mechanical equipment than is essential for natural sands.

(4) There is more difficulty in finishing and patching synthetic sands than is the case with natural sands.

Advantages of Synthetic Sands

(1) They make possible substantial savings. The cost of hauling used sand to a mixer is no greater than the cost of hauling it to the dump. The cost of transporting rebonded sand to the point of use is no greater than the cost of taking in an equal quantity of new naturally-bonded sand. The handling costs cancel out, therefore, and the charges against synthetic sand are the cost of the bond clay, the cost of any silica sand additions, and the cost of mixing.

(2) Synthetic sands have much greater durability or life than naturally-bonded sands, and one ton of synthetic sand may maintain strength for 50 to 200 per cent. longer than a ton of naturally-bonded sand.

(3) Silica sands are much more uniform than naturally-bonded sands, and bonding clays are dependably uniform. Since the foundryman is making a definite mix to satisfy his own conditions from uniform materials, the result is a much better control over sand conditions.

(4) The base sand will be free of silt, and the bonding clay will be very low in silt. The fine material in the sand will be almost

all active bonding clay. This results in higher permeability, better flowability, and considerably less tempering water required.

(5) Synthetic sands are almost always more refractory, and give higher sintering points than naturally-bonded sands. This results in better stripping and lower cleaning costs.

(6) Being made from simple materials, synthetic sand is easy to control, and American practice shows a sharp reduction in scrap losses with a change to synthetic sand.

(7) Synthetic sand, being made as required, eliminates the investment in carrying a winter supply of natural sand in storage, and eliminates the difficulties due to such sand freezing in unheated bins.

REFERENCES

[1] E. C. Zirzow, "Sand Control in a Malleable Foundry," Transactions A.F.A., vol. 45 (1937), pp. 134 to 156.
[2] W. G. Reichert, "Present Status of Foundry Sand Investigation and Control." A.F.A. Reprint 36-26.

DISCUSSION

Mr. J. J. Sheehan, B.Sc., A.R.C.Sc.I., introducing the Paper on behalf of the author, said he appreciated the honour of presenting Mr. Dunbeck's Paper, which was of a very interesting character. Moreover, at present the subject matter was of particular importance to British industry, as the general principles outlined were in agreement with the best British practice; the consideration and discussion of such Papers as this should help to make the best practice the general practice.

The remarks on the selection of the base sand were in agreement with his own Paper, "Core Shop Control," presented to the International Foundry Congress held in London in 1939, particularly that section dealing with such defects as buckle and scab. The inclusion of a definite proportion of fines was recommended and the avoidance of the perfectly round uniform grain, once popular in text books, was stressed. Text-book misconceptions had a long life and a tendency to reproduce themselves by reference in subsequent publications. Papers like the present helped to inter them.

In compounding a synthetic sand Mr. Dunbeck sought only three properties in the base sand: Grain size, permeability, and expansion. It was necessary, however, to consider another important property: refractoriness.

Bond Clay

Under this heading much of interest was presented; it was obvious that Mr. Dunbeck was an expert in this section of the subject. Much work is being done in this country at present on identical lines to those outlined in the present Paper. In this connection mention must be made of the following Papers:—

"Fulbond as an Alternative Material to Bentonite for the Bonding of Moulding Sands for Green Sand Castings," by Dr. W. J. Rees.

"Trial Mixtures of Colbond," by Mr. T. R. Walker, M.A.

"Practical Trials of Fulbond No. 2," by Dr. R. J. Sarjant.

"Fuller's Earth for Green Sand," by Mr. D. A. Oliver.

The above-mentioned Papers had not yet been published, but permission had been obtained to quote from them should occasion arise in discussion. Particular attention should be given to the following remarks under the sub-heading "Kaolinite Clays": "This is the most widely-used type of bond clay in the United States" and "They are also the lowest in cost and have the highest durability." Illite clays of British origin had not been investigated here, and some attention might profitably be given to them.

Montmorillonite Clays

A bonding material of this type produced in Britain—used alone within the limits of its low sintering point or in combinations with other more refractory clays on the lines indicated by Mr Dunbeck for a greater variety of purposes—was receiving considerable attention and promised to be of considerable assistance to the industry.

This subject of the combination of clays was the most important recent development in American practice. The examples of such combinations given in this Paper indicate such possibilities here, and were a decided stimulus to intensive work in that direction.

Method of Application

Under this heading Mr. Dunbeck was so common sensed and clear that there was little to remark upon. In practice the method adopted was dependent upon the equipment available more than any other consideration.

Testing and Control

A most important remark under the above heading was "All materials must be entirely dry" when testing the comparative value of clays.

Paragraph (3) in this section said: "Clays of the same type should be tested at exactly the same moisture content." The following addition to that remark would be of assistance, *clays of different types should not*. Clays of different types developed their best-tempered condition with different amounts of water. This was indicated by Mr. Dunbeck in Table I. It was therefore misleading to compare the relative values of various types of clay at a moisture content suitable only to a particular one.

Sands

Under the above sub-heading in paragraph (2) Mr. Dunbeck stated:—"Some types of clays yield much higher permeability than others, even when present in equal quantity, and although the strength of one may be far higher than the strength of the second." For the words "and although" should be substituted the one word "because."

Some types of clays yielded much higher permeability than others, because the conditions of the permeability determination were such that, with three blows of the standard rammer, a stronger sand would be less compacted in the test-piece than a weaker sand, other conditions of the sands being similar.

The advantages and disadvantages of naturally-bonded sands and synthetically-bonded sands had been written about and discussed at length in many Papers. The many points considered were well summarised in this Paper. Altogether Mr. Dunbeck had provided a very stimulating Paper.

Availability of Type of Bentonite

Mr. F. J. Cook (Past-President) inquired which of the two bentonites referred to in the Paper was usually imported into this country. According to Table V, it was possible to get 25 per cent. of bentonite and 75 per cent. of clay to a very high compression and strength and with suitable permeability. What appeared to be most remarkable was the hot strength obtainable with such a mixture. If it were possible to use 75 per cent. of clay which could be obtained locally, and only import 25 per cent. of bentonite, it was a proposition which would be very attractive to every foundryman in this country at the present time, when shipping space so much required to be conserved. The two bentonites appeared to be outstanding in their difference of characteristics.

Milling Difficulties

Mr. J. H. Cooper said he thought that a good deal of synthetic sand was not reaching the requisite standard. Difficulties accruing in regard to the use of synthetic sands were very often side-tracked from other considerations. Recently it had been found that, when mixing a synthetic sand, more fresh sand had to be used than when using a natural sand containing a reasonable amount of bond. Synthetic sand enthusiasts said: "You must use a certain proportion of this and a certain proportion of that." Another innovation was that many bonding materials were added either in the form of a wash or to a heap of sand, but this application was carried out in a very careless manner. The consequence was that a synthetic sand was not really of the advantage it could be if more care was taken in application. In some mills the rollers were held up by springs, and there was an adherence of bentonite, Colbond or other materials to the mill pan.

He was not quite convinced as to whether any means had been discovered to prevent such accumulations of clay sticking not only to the side of the pan, but also to the scrapers and the side of the rollers. It would be very interesting to learn if Mr. Sheehan could give any information upon the subject, and it would also be of interest to the subject if he could explain what type of mill roller he preferred; whether he would use the plain or the grooved type. Also, was the mill cleaned systematically, say daily, and not merely when there was trouble with scabs and the like on the castings?

It was found that the amount of burnt sand which adhered to the casting amounted to 12½ per cent. A British sand naturally bonded, free from admixtures, after milling and passing through the mixers, required only the addition of 12½ per cent. of new sand for the maintenance of standard. Would Mr. Sheehan say whether this 12½ per cent. addition brought about excessive silt content in the sand system?

Identification of Bentonite Types

Mr. Sheehan said that in this country the bentonite normally available was of the Western type. The Southern type had been introduced here recently under a trade name, but it could be readily identified by its property of a comparatively low dry strength to green strength ratio. Southern bentonite was a very valuable material.

With regard to Table V, Mr. Cook had remarked upon the hot strength of combinations of bond clays. This particular fact was new to him also; it was the first time he had seen any mention of it, and he did not know any explanation for it. Frankly, to suggest that it might be that the mixture of these two clays had a fusion point that made a glass between the grains giving a very high strength at that temperature, might be a possible explanation. The explanation, however, was not important. What was important was the fact. The combination of clays, either imported or domestic, made for more accurate control.

Superiority of Synthetic Sands

These remarks might be considered also by Mr. Cooper. Synthetic sand appeared to bear no relation in value to naturally-bonded sand. He could not understand Mr. Cooper even advocating naturally-bonded sands; because there was under control every property for an ideal moulding sand once a synthetic sand was established. There was a selection of the base grain; there was the necessary refractoriness; there was fineness if a good finish was required, and with the selection of the various bond clays which were now becoming available, all the properties could be obtained which were indicated in Mr. Dunbeck's Paper.

Overcoming Sand Mixing Difficulties

Most certainly attention must be paid to the manner of mixing synthetic sand. In the case of anyone who was not familiar with sand-testing equipment, a very little thing might cause a great deal of harm. The process, however, was so simple that once the sand-testing equipment was understood, the difficulties bore no relation to those associated with the mixing of a naturally-bonded sand.

He would give as an illustration the case of a partially-mechanised steel foundry where two mills of the Simpson type of mixer were used. When this foundry used naturally-bonded sand it required those two mills to work full time—in order to mix sufficient sand for the production of 20 tons of steel castings per week. Then synthetic sand was introduced, and as a result one mill was continuously idle, while the other mill was supplying enough synthetic sand for 40 tons of steel castings per week. This was an indication of the value of synthetic sands as related to time-saving potentialities, for the elimination of one mill and the doubling of output was very significant.

The adherence of the bonding material to the mill parts was due to wrong practice, *viz.*, adding the powder to a wet sand. The powder immediately took up moisture, became sticky, and made distribution difficult. It was necessary when mixing a synthetic sand to add the powder to the dry sand and allow a period of time for dry mixing. Then add water, and there would be no difficulty whatsoever in regard to sticking to the blades or to the bottom of the pan.

As a matter of interest, he had very little predilection regarding the type of sand mill. The mixing of a synthetic sand was so simple a matter that most types could operate. The mill he used was of the continuous type, and he did not think it could function properly if employed upon a heavily-bonded natural-sand, necessitating the breaking up of clay lumps. It worked very easily with synthetic sand, and he had seen it used extensively in this country. In no foundry in this country had he seen the addition of clays carried out by the slurry method, although he could not see why it should not prove to be an excellent method of adding clay. It did introduce another item for consideration, however, in that it was adding clay and water, and perhaps the water would not be under as accurate control as if the clay powder and water were added separately.

Mr. F. A. Harper said that Mr. Cook had emphasised the conservation of shipping space. At the same time, Mr. Sheehan had asked for the discussion of any other bonding materials which could be cited as being available. Perhaps he might be forgiven for pointing out that there was a proprietary article made from rich materials in Britain, and which was now on the market.

A Definition Sought

Mr. C. H. Kain wished to thank Mr. Sheehan for his able presentation of what was perhaps the best Paper they had had before the Institute of British Foundrymen for a very long time. He was particularly impressed with the paragraph in which Mr. Dunbeck pointed out he had read occasional references in the British technical Press to the effect that synthetic sands were widely used in the United States because there was a scarcity of good naturally-bonded sands, yet there were deposits of high quality naturally-bonded sands in almost all parts of the United States, and they occurred in enormous tonnages, if only the American foundrymen chose to use them.

He was also impressed with the summary in the last portion of the Paper, which contained a statement with regard to the well-known disadvantages of synthetic sands, as well as one or two seemingly new advantages.

The Paper was a very helpful one, and had been presented in a very pleasant way. It was divorced from much of the technicalities which tended to obscure understanding by the ordinary foundrymen, and moreover, it provided food for a great deal of thought.

What was the definition of bentonite? Bentonite in English technical literature was usually printed with a capital " B," meaning some definite article. He noticed that in the Paper it was printed with a small letter " b," as being one of a series of materials. It would help to clarify the position of sand practice, and particularly synthetic sand practice, if there was a definition of bentonite.

Mr. Sheehan wished to thank Mr. Kain for his very kind remarks with regard to the presentation of Mr. Dunbeck's Paper. Personally, he considered it was an excellent Paper, and he welcomed the appreciation of its merits from others. Bentonite should be spelt with a small "b." There were many bentonites. There were the Canadian, Wyoming, Southern, and New Zealand bentonites. They all varied somewhat. The name, as used in this country, probably referred to a particularly important Wyoming bentonite of a very good quality.

Everybody using synthetic sands would want to make sure what it was they were getting. Anything might be sold under the name of bentonite which had even a trace of montmorillonite clay in it. He welcomed the suggestion that bentonite should be more accurately defined; but he thought it would be best left to the Technical Committees of the Institute, the Cast Iron Research Association and the Iron and Steel Institute to settle on a definition.

Clay Mixtures

Mr. T. R. Walker said that the Paper certainly contained a great deal of information. It did not mention fullers earth, a clay which resembled bentonite, as it contained a considerable proportion of a mineral of the montmorillonite type, such as occurred in bentonite. Substantial deposits of fullers earth occurred in Great Britain, and recent foundry experience had shown that it could replace bentonite for the manufacture of steel castings, giving good moulding mixtures and excellent stripping. From a green strength point of view its efficiency compared with bentonite was between 75 and 80 per cent.

Mr. Kain had pointed out that in Great Britain most people whenever synthetic sands were mentioned associated them with bentonite. In the U.S.A., however, many foundries did not use bentonite at all but used other alloys, some of which were referred to in the Paper under discussion.

Mr. Sheehan had mentioned the mixing of clays in foundry moulding materials. This was a point which would receive much greater attention in the future than it had done in the past, because of the ease with which the green-strength/dry-strength ratio of the mixture could be varied. British clays gave mixtures which had a lower green strength than mixtures containing an equal proportion of bentonite. When the green strength was made adequate by increasing the proportion of the clay, some clays gave mixtures in which the dry strength was still low. In some foundries this was no disadvantage and might even be an advantage. In other cases British clays gave mixtures with a very high dry strength, whilst at the same time the green strength was much too low. Here the green strength could be improved considerably by the addition of a small amount of fullers earth. Mr. Sheehan also referred to reports giving the properties of sand mixtures, quoting one or two figures only, for water content. In any investigations of sand mixtures, a series of samples should be tested with a water content at one end so low that the mixture could not be moulded, and at the other end so high that the mixture was too sticky to give a clean draw. In between there was a narrower range of water content within which the mixture could be properly moulded.

Unfortunately, sand testing in the laboratory was not a complete guide to the behaviour of sand in a foundry. It was not sufficient to have adequate permeability and enough green strength and dry strength. The results did not show whether the sand was capable of making a good mould, that is to say, whether it had adequate plasticity. This property was not disclosed by the ordinary sand testing methods, and it was essential to try out new mixtures on the foundry floor before satisfactory conclusions could be drawn.

With regard to Mr. Cooper's difficulty with sand mills he quite agreed with Mr. Sheehan's remarks regarding the methods of mixing sand and clay. In a good foundry, however, the mills should be inspected regularly, especially the bottom plate and the scrapers. The bottom should be in good condition and the scrapers should touch the bottom as nearly as possible to avoid the formation of caked sand. Also, scrapers should be adjusted so that they reached as nearly as possible to the middle of the mill on the one hand, and to the edge of the pan on the other hand. If this were not done the moulding time would be prolonged unnecessarily and mixing would be less effective.

Mr. Sheehan noticed that Mr. Walker had again stressed the mixture of clays. He was glad he had done so, because it was a matter which would certainly be receiving increasing attention on the part of the technical institutes and by foundrymen themselves. It opened up wide possibilities for sand control in this country. He could assure Mr. Walker that his remarks with regard to the publishing of results obtained with a limited moisture range were not intended for his Papers. One frequently heard of results obtained not necessarily within a narrow range, but rather the comparing of bentonite at 3 per cent., with a clay of the fireclay type at 3 per cent. moisture. This was incorrect. The bentonite at 3 per cent. should be compared with the moisture content of clays which best suited the purpose.

Necessity for Standard Quality

He was in agreement with Mr. Walker's remarks concerning laboratory and foundry sand mixtures. It must be understood, however, that there was no intention to deprecate the work done in the laboratory, because the function of the laboratory was to control the sand and deliver it to the moulder or the foundry of a regular quality. If it was possible to deliver to the moulder on a set of moulding machines, or even on the floor, a regular quality, the moulder would be better served, having regard to his skill, with a bad sand of regular quality than he would with a sand which was good to-day and bad to-morrow, or good in the morning and bad in the afternoon. The great point was to deliver a sand of constant quality; the moulder would do the rest.

Mr. V. Delport, referring to the name bentonite being spelt with a capital " B " in this country, said it was not the custom in American literature to use many capital letters. They still spelt Diesel engine in this country with a capital " D," but in America they used the small one.

Mr. Kain said that bentonite referred to an entire range rather than to one particular wonderful proprietary material. He had had great difficulty in convincing men in the foundry that bentonite was a clay and not something special. Bentonites were now on offer by various firms which, in the light of the statements contained in the Paper, might be different classes of bentonite. This point had never been made clear previously in this country. A clear definition of bentonite was certainly necessary. Mr. Walker had helped to clear up the point as to whether bentonite should have a sodium or calcium base.

Mr. Sheehan agreed.

Mr. Clifford suggested that a greater use could be made of the figures stated in the Paper. They were certainly much more valuable than the ordinary dry compression ratios which were usually accepted. For example, foundries making large steel castings of quite considerable tonnage but comparatively small section required a sand which was of great adaptability. The ordinary dry compression test did not afford sufficient indication as to how the sand would behave after the steel was poured into the mould. The figures stated gave much better indication as to what sand should be used.

He would have liked to have heard more about refractoriness, and also of more details with regard to the choice of clays to be used for various types of metals. With regard to the hot strength figures, he assumed that the information given applied to the actual moulds. For example, it was stated that Southern bentonite should be used for moulds for light steel castings. It seemed to him that the figures obtained, using the mixtures of clays with bentonites, would have been more useful if Mr. Dunbeck had given a range of moisture content instead of only one.

Interpretation of Data

Mr. Sheehan particularly appreciated Mr. Clifford's remarks on hot strength. It should be clearly borne in mind that the value of the hot strength figures applied when the metal had reached the mould surface; they dealt with the behaviour of the mould under conditions when the metal had been introduced. The green strength figures were more an indication of the suitability of the sand for making a mould. He regarded the green strength figure as a measure of the quality of the sand for making a mould easily, and upon the dry strength figure and the hot strength figure as the value of the sand in respect to its behaviour in contact with the metal. It was useless having a sand which was well capable of withstanding metal impact if it were not possible to make a mould with it.

There appeared to be some confusion of thought with regard to the bentonites stated by Mr. Dunbeck for light and heavy castings. When he advised Southern bentonite for a light casting, he meant that as much of it should be used as was found suitable. Southern bentonite was recommended for light castings because it had a very low dry strength value, and therefore the casting could contract without cracking.

Refractoriness was a very valuable property of the clays, and in America, where the synthetic sand practice was widespread, it was clay with the greatest refractoriness which was most generally used. This should be borne in mind when making a mixture of clays, particularly in the case of a mechanised foundry system, where the accumulation of undesirable fusible fines would be very rapid when using large quantities of low fusion point material.

Facing Sand Elimination

Mr. J. A. E. Wells asked whether filling a box entirely with synthetic sand was recommended; also whether for the basic sand an entirely new sand backed up by old sand was recommended? When using fresh sand it would appear to be possible to have a drying operation occurring prematurely.

Mr. Sheehan said that when recommending synthetic sand the recommendation must not necessarily be taken to imply that all the established naturally-bonded sand practice would disappear. It would be a mistake to consider this to be the case. There was no necessity, except perhaps for a very special job, to use a new sand in a facing. The facing sand need not be used on every job. The control was so good that synthetic sands on the floor or backing sand was usually of sufficient quality to cast most jobs; but again this depended upon the particular foundry, the actual job being made, and the degree of finish required.

It would be desirable to dry the new sand, as a good many foundries did for their ordinary core practice. The best way of all in operating a foundry, if there were a good many cores in the work, was to select the sand with a view to it being the base sand, as well as the core sand.

The Fireclay Position

Mr. R. S. Turner asked whether the fireclays in America compared with those in this country. Were they a similar material?

Mr. Sheehan said they were the same. Mr. Dunbeck had mentioned a fireclay of very high plasticity. The fireclays in this country varied in themselves, as they did in America. Not every American fireclay could be used. He knew, from personal experience, that the companies which supplied these materials in America selected a fireclay which was suitable for a particular purpose, but they still retained the name of fireclay because of the refractory properties associated with the name. There was probably room for further investigation with regard to the fireclays used in this country with the object of discovering a plastic fireclay which would give a good dry strength, and a good green strength/dry strength ratio.

Water—A Variable

Mr. H. Haynes did not know what quality of water was used in America, but there did not appear to be much said about water and its composition. What would be the effect on the sand in the case of a foundry situated at the coast and sea-water were used, or near a river where river-water was incorporated, and, finally, if near a canal and canal-water was used? He had attended many lectures, but had never yet heard a discussion of troubles due to contaminated water.

Mr. Sheehan said there were almost as many qualities of waters as there were beers. Sea-water, of course, contained a great deal of minerals, particularly sodium chloride. Their accumulative effect in the foundry would probably be very deleterious. It might have an immediate good effect. It would cause slight fusibility of the surface, and a scab might be avoided, but he hardly thought that it was good ultimately.

There were waters which would have to be discarded, such as those which contained much alkali or a high percentage of lime. He had never experienced any difficulty in using a particular type of water, but this was probably because the supplies which had been available to him came from municipal water-supply undertakings, and could be relied upon not to have an excess of alkalis. When taking water from a river or a canal, some investigation should be made as to its quality.

Weathering of Fireclay

Mr. Cooper said that many foundry people, when using a fireclay, sometimes did so when it was still raw. Had Mr. Sheehan found, when using a fireclay which had not been very good in the first instance, if he allowed it to stand for six or twelve months, a condition of greater plasticity prevailed? Personally, he had found this to be the case with Stourbridge, Winchester and other classes.

Mr. Sheehan replied that, if a fireclay was damped and allowed to stand for some weeks or months, it became much more plastic. The water seemed to enter into its molecular composition, or at any rate some of it appeared to do so, and improved the quality of the clay. There was such a low green strength in some fireclays that it was necessary to do everything possible in order to improve it. With highly plastic fireclays, the improvement effected by leaving them wet for a long period would be slight, and would not justify the trouble.

Mr. Cooper said that the difficulty experienced with some fireclays made into bricks depended very much upon the length of time the clay had been weathered in the open. The atmospheric effect had an important bearing upon the subsequent condition of the clay.

Mr. Sheehan, agreeing, said for foundry use the percentage value of increase in strength of a higher grade plastic fireclay would be so little that it would not be worth the trouble of weathering it. If there was, say, a strength of 10, and by weathering it could be increased to 11, then the trouble would be justified if it enhanced the refractory properties as in brick-making, but not so in regard to sand practice. The percentage of improvement would not justify the extra trouble.

Mill Types

Mr. Wells asked for Mr. Sheehan's opinion on the relative values of a mill with a heavy roll and a mill with a light roll.

Mr. Sheehan said that so far as synthetic sand was concerned, either was suitable. What was required was a mixing action more than a milling action. Some milling action, of course, was necessary in order to obtain the full value of the clay. If it was desirable that there should be particular economy in regard to clay additions then a heavy roller type of mill was to be recommended; but there would be heavier wear and tear on the mill, and more power would be required to drive it.

Mr. H. P. Hughes asked what Mr. Sheehan would recommend if a foundry decided to change from a naturally-bonded sand to a synthetic sand. Would he regenerate the naturally-bonded sand with a synthetic mixture, or would he use an entirely new silica sand?

Mr. Sheehan would strongly recommend a gradual changeover, particularly in the case of a mechanised system. In the case of a floor, of course, the heap could be kept separate, the synthetic sand being on one side for experimental purposes, and the ordinary sand on another side. In a previous Paper he had read in Manchester he gave all the particulars of changing over from a naturally-bonded sand to a synthetic sand, even to the extent of stating the figures for the half-way changeover, at which point he designated the sand as a semi-synthetic sand.

Mr. Hughes asked whether it was not possible to offset the difference?

Mr. Sheehan thought it might be borne in mind. He imagined that anyone wishing to change over from a naturally-bonded sand to a synthetic sand would wish to retain the best qualities of the naturally-bonded sand, for instance, in regard to finish. If the foundryman was particularly desirous of a good finish, then in the changeover he should select a fine silica sand which would at any rate approximate to the fine finish previously obtained. It was not possible to state all the points with regard to changeover during the course of a discussion, and therefore he must refer to his previous Paper.

Vote of Thanks

The Chairman then moved that a vote of thanks be tendered to the American Foundrymen's Association for arranging that the Paper should be presented to the members of the Institute, and also to Mr. Dunbeck for the original and valuable information contained in it. He would like also to couple with that vote of thanks an appreciation of the extremely able way in which Mr. Sheehan had dealt with the discussion.

They were very fortunate in having Mr. Sheehan to present the Paper, because not only was he an acknowledged expert on sands, but he had had experience of them in America.

Mr. Cooper seconded the vote of thanks, which was carried unanimously by acclamation.

Mr Sheehan responded suitably to the vote of thanks.

Written Discussion

Mr. V. C. Faulkner (Past-President) wrote saying that from the inception of bentonite into foundry practice, he had invariably and consistently had the word printed with a small " b," because the material, like diamond or granite, was a definite mineral entity. Proprietary materials, on the other hand, carried capital initial letters.

AUTHOR'S REPLY

Mr. N. J. Dunbeck, in a written communication, replied to the discussion as follows:—

He had stated in the Paper that some types of clays yielded much higher permeability than others even when present in equal quantity. Mr. Sheehan had pointed out that a stronger clay might have higher permeability than a weaker clay because the stronger would be less compacted in ramming. This was true. It was also true that a stronger clay like Southern bentonite may have higher permeability than a weaker clay like Western bentonite, even though the Southern bentonite had much better flowability and rammed even more compactly than the Western bentonite. Similar behaviour had been observed in other clays, and represented a phenomenon which he had observed with interest but could not explain as yet.

As pointed out by Mr. Sheehan, any type of mixer may be used with satisfactory results. Intensive mulling yielded maximum economy. Some clays developed strength faster than others. Since a maximum mulling time may be imposed by local foundry conditions, comparison of clays should be made under foundry conditions, with the result expressed as pounds bonding strength per unit of cost.

Bentonite was named from the Fort Benton series of the Cretaceous system, in which it was first found. As mentioned by Mr. V. C. Faulkner, the material is a definite mineral entity and should be printed with a small " b." The United States Geological Survey had defined bentonite:—

> " Bentonite is a rock composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash. The characteristic clay-like mineral is usually the mineral montmorillonite."

This definition had resulted in confusion because it included all bentonitic materials, such as fuller's earth. It had been suggested that all non-swelling bentonites be called metabentonite, but the suggestion had not found favour. In technical circles the bentonites were usually described as swelling or non-swelling. Most American foundrymen referred to them as Western and Southern bentonites, and understood quite well the physical differences implied by the names.

The water used in the reported tests was distilled water. The amount of water used in sand conditioning was probably the most potent variable in foundry practice. The quality of the water was also important, and work on the effect of various waters was being done by the American Foundrymen's Association. The benefits obtained from the weathering of fireclay seldom justified the expense. Good clays were little improved and poor clays were insufficiently improved to compete with better clays at the necessarily higher price of poorer clays after weathering.

The company with which he, Mr. Dunbeck, was associated was the only American producer of fuller's earth for bonding sand. The material had been sold in limited volume for five years. Although that company had selected the best available fuller's earth, and although it was composed almost entirely of montmorillonite, the material seems to have certain basic deficiencies. It was very light in weight, probably due to the porous structure of the grains, which gave it efficiency in its work as a fuller's earth in decolorising oils. As a result, it was difficult to handle and dusty in use. It developed strength slowly in sand and required intensive mulling. It was as costly to produce as other bentonites, but was about 30 per cent. weaker. It had low dry strength and durability. Probably because of its porous nature, it required much more tempering water than other bentonites and dried out faster in use. It found a limited use because it yielded a sand having very high flowability. Each sand mixer should be carefully cleaned to a polished condition each night. Recent tests showed that such a clean mill requires 21 per cent. less power than the same mill with same load when operated in a dirty condition with sand caked and crusted on bottom and sides.

British and American Clays*

By FRANK HUDSON

From the geological point of view clay is classed as a sedimentary rock, and in foundry practice is used extensively in the form of fireclay, boulder clay, etc., and also occurs as an important variable in the bulk of natural moulding sands. The term clay as applied to fireclay or boulder clay deposits does not necessarily constitute material having similar properties to that found in naturally-bonded sands, and in this latter connection it is preferable to apply the terms " bond " or " clay substance."

Apart from " clay substance," the detrital constituents of common clay deposits differ little as regards kinds from those of the sandstones, being only in a state of more minute subdivision. This has rendered their examination a matter of some difficulty, but the following may be regarded as common constituents of clay: —

(1) *Quartz.*—Free quartz is often present in sufficient quantity seriously to decrease the plasticity of clays. As it does not absorb water, however, it decreases the shrinkage which occurs when clays are dried.

(2) *Felspars.*—Felspars are occasionally present in a sufficiently undecomposed state to admit of their identification under the microscope at high magnification. Orthoclase, which is less liable to decomposition than the lime and soda base felspars, is more frequently found than the latter varieties.

(3) *Mica.*—Mica, particularly muscovite, is often found in clays.

(4) *Iron Pyrites.*—This mineral and also marcasite are fairly common in clays and are objectionable. On weathering these sulphides of iron undergo oxidation, with the eventual production of sulphuric acid, which leads to the formation of gypsum and other undesirable minerals. They have also a low melting point.

(5) *Iron Oxides.*—When hydrated they exist as limonite giving the clay a yellow or brown colour, and when anhydrous as hematite (Fe_2O_3) they confer a red colour on the clays. Iron is also found in a partially oxidised condition as ferrous oxide (FeO), when it is particularly dangerous, reacting to form relatively fusible silicates.

(6) *Calcite.*—Carbonate of lime in this form results from the action of carbon dioxide, contained in percolating water, upon lime freed by the weathering of plagioclase felspars. Alternatively it may be present as intermixed chalk or shell particles.

(7) *Gypsum* (*Selenite*).—Hydrated calcium sulphate ($CaSO_4.2H_2O$). Its presence is objectionable.

(8) *Dolomite.*—Certain minerals containing magnesium, such as biotite mica, lead to the production of dolomite or calcium-magnesium carbonate.

(9) *Carbonaceous Matter.*—Organic matter is not uncommon in clays, and is an advantage in the case of those having low fusibility.

Clays can be described as aggregates composed of a variety of mineral fragments ranging in size from sand grains to particles under one micron (0.00004 in.) in diameter. The larger particles being principally composed of quartz, felspar and mica as previously mentioned, whilst the true " clay substance " is contained only in the particles of finest dimensions, probably not exceeding 5 microns (0.0002 in.).

TABLE I.—*The Clay Minerals (Grim, Bray and Bradley).*

Name.	Chemical composition.	Remarks.
Kaolinite . .	$Al_2O_3.2SiO_2.2H_2O$	Anauxite and kaolinite form an isomorphous series.
Anauxite . .	$Al_2O_3.3SiO_2.2H_2O$	—
Halloysite	$Al_2O_3.2SiO_2.xH_2O$	—
Beidellite	$Al_2O_3.3SiO_2.xH_2O$	Beidellite and nontronite form an isomorphous series.
Nontronite	$Fe_2O_3.3SiO_2.xH_2O$	
Montmorillonite	$Al_2O_3.4SiO_2.H_2O$	Montmorillonite, beidellite, and nontronite probably contain essential alkalis or alkaline earths.
Sericite-like	$K_2O.3MO.6R_2O_3$	—
Mineral . .	$18SiO_2.5–10\ H_2O$	—

In connection with true " clay substance," recent research has definitely indicated that this is not made up from any one mineral as commonly supposed. Much credit is due to C. S. Ross and P. F. Kerr[1] for the results

* Special contribution made as a supplement to the American Exchange Paper.

obtained in this direction, and their investigations show that many of the fine particles in clays represent identifiable minerals. As a class the clay minerals are hydrated silicates of alumina, with or without the alkalis or alkaline earths, having a general composition as shown in Table I. (At the present time it is not possible to give exact formulæ.) Recent work by Grim, Bray and Bradley[2] conducted on the constitution of American bonding clays indicate that kaolinite, beidellite, montmorillonite and a mineral resembling the sericite form of white mica are the most common clay minerals, and the properties of the clay are different according to the type of minerals present. For example, clays composed primarily of beidellite or montmorillonite have higher green-bond strength, and possibly better durability characteristics than those composed of the other clay minerals. This is of particular interest in modern foundry practice, and the tendency for synthetic sand production using bentonite, as this clay contains a high percentage of montmorillonite.

So far as clay substance is concerned, it should be very definitely recognised that whilst much additional research is required for a complete understanding of all the factors involved, sufficient evidence has been obtained to indicate the real importance of the mineral composition of the material and the need of further work in this direction from both foundry and geological aspects. In this latter connection Ries[3] draws attention to the fact that whilst one is apt to think of the clay minerals as products of weathering, wider observation has shown that some of them may originate by hydrothermal action or even under marine environment.

Little work has been conducted in this direction on British clays with the possible exception of that conducted in 1914 by Mellor[4] on certain fireclays which were found to belong to the kaolinitic type.

The distinctive property of clay is its plasticity, and most of its uses depend upon this property and upon the fact that it is entirely lost when the material is heated to a certain temperature, when it acquires rigidity of form. The reasons for this property of plasticity are as yet incompletely understood but are probably due to several factors connected with particle size and the presence of colloidal matter. A satisfactory definition of "colloids" is too technical and comprehensive to be desirable here and the reader is referred for further information to the work of Ries.[5] In a valuable summary upon the theories put forward to explain plasticity the above authority refers to that based on molecular attraction which, where such small bodies are in question, may not unreasonably be supposed to exercise some effect in holding the particles together while still allowing them to slide round one another. Thus it will be seen that electro-chemistry plays an important part in the matter and a full review of the factors have been recently outlined by

TABLE II.—*Analysis of Various Clays.*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	Na_2O	K_2O	CaO	MgO	TiO_2	Loss on ignition.	Fusing point, deg. C.
Surface boulder clay (British)	50.48	24.23	8.96	—	2.77	2.77	2.15	2.28	—	9.25	—
,, ,, ,, (U.S.A.)	66.08	17.50	8.00	—	1.22	1.22	1.00	1.58	—	4.62	1,310
Devon blue ball clay (English China Clay Sales Co., Ltd.) ..	51.5	33.90	1.00	—	0.68	0.82	0.58	0.26	1.25	9.80	—
China clay (English China Clay Sales Co., Ltd.)	46.86	38.75	0.37	—	0.10	0.56	0.46	0.05	0.01	13.00	—
Colloidal kaolin (Stockalite, English China Clay Sales Co., Ltd.)	46.25	39.15	0.64	—	—	—	0.20	Trace	—	13.76	—
Wyoming bentonite (American Colloid Co., U.S.A.) ..	64.60	20.80	3.05	0.46	2.60	0.40	0.53	2.30	0.15	4.74	1,340
Colbond (Colbond, Ltd., London)	61.57	18.56	3.08	—	0.65	0.65	1.07	0.62	0.96	13.41	1,490
Fireclay (Lower Kittanning, Ohio, U.S.A.)	58.45	26.95	1.58	—	2.76	2.76	0.30	0.49	0.47	8.80	1,650
,, (Kentucky, U.S.A.)	46.16	35.04	1.42	—	0.64	0.64	0.27	0.49	2.44	14.40	1,720
,, (Bollington, Lancs)	65.77	18.11	0.72	2.34	0.36	2.64	0.14	1.35	1.05	7.32	1,380
,, (Bonnybridge, Scotland)	47.95	32.74	1.22	0.75	0.10	0.97	0.28	0.61	1.51	14.02	Over 1,670
,, (Stourbridge, Staffs)	45.22	31.32	1.76	—	0.23	0.94	0.34	0.51	1.08	18.52	1,760

Clews.[5] Since the action is partly an electro-chemical function it follows that the presence of salts and other materials in the water have a profound effect, particularly when the water is in excess of the clay as in suspensions and emulsions such as might be employed in refractory mould washes. The impurities in the sand or clay play an important part in this reaction and it was shown in 1879 by Senfft[7] that the absorptive power of clay increases with the limonite content ($2Fe_2O_3.3H_2O$).

The water present in clay and clay-bonded materials exists in two ways. A certain amount is absorbed by the clay "cells" and is termed combined or "miscellian" water as distinct from the free moisture present which can be removed on drying at 110 deg. C. On heating above about 400 deg. C. clay begins to lose its combined water, becomes "dead" and cannot usually be retempered. The temperature at which combined water is removed, and the amount, varies with different clays according to their structure and composition. For example, a clay composed entirely of the mineral montmorillonite would contain approximately 20 per cent. combined water, whilst kaolinite contains 13.9 per cent. Montmorillonite is dehydrated gradually up to about 550 deg. C., at which temperature crystallographic changes begin. Kaolinite loses its water between 400 and 510 deg. C., whilst the hydrated ferric oxides, collectively designated as limonitic material, lose practically all their moisture below about 200 deg. C. These observations are extremely valuable when considering the durability of moulding sands and it would appear that latest evidence does not support the suggestions often put forward in the past relative to the longevity of certain sands having a bond made up from limonitic material.

On heating clays above 1,060 deg. C. the mineral mullite ($3Al_2O_3.2SiO_2$) is formed, together with one of the high temperature forms of quartz. The exact changes taking place are still unknown and it is highly possible that other reactions occur as well. The minerals formed, however, by the effects of high temperature possess none of the properties of the original clay and from the foundry point of view would remain in the moulding sand and increase the quantity of silt.

So far as moulding sands are concerned, their refractoriness appears to be determined by the fusing point of the clay bond. Skerl[8] has shown that the fusing point of the bonding material in a representative selection of British moulding sands varied from 1,270 to over 1,400 deg. C. and even the higher temperature is well below the fusing point exhibited by the sands as a whole. The same investigator also suggests that the refractoriness of the clay grade is governed by the percentages of silica (SiO_2) and alumina (Al_2O_3), and shows that an increase in the ratio of alumina to silica results in a higher fusion point of the clay grade. This confirms the work of others in connection with fireclays.

General chemical analysis of sand and clays is not now accepted as a satisfactory method of evaluation and accordingly it is not proposed to discuss this aspect in any detail, although typical results will be given from time to time in the text as a matter of interest.

Table III.—*Particle Size of Clay Materials.*

Source.	Per cent. particle size of clay materials.		
	Larger than 20 microns.	Between 2 and 20 microns.	Under 2 microns.
Wyoming bentonite	5	8	87
Finest ball clays	0 to 10	5 to 33	40 to 80
China clay (finest paper grades)	0 to 44	30 to 55	10 to 70
Fireclay (typical U.S. high plastic)	30	37	33
Passing 270 mesh substance extracted from Albany moulding sand	70	15	15

Typical deposits of clay of interest in foundry practice, apart from that associated with naturally-bonded moulding sands, can be outlined as follows:—

Boulder and Surface Clays

These as a whole vary enormously in character according to their origin and mode of deposition. They are principally used in foundry practice for the manufacture of "clay water" for use in black wash for coating mould surfaces. They are low in refractoriness and, apart from the above service, should not be used as an extensive addition to moulding sands although the fusing point is fairly satisfactory in the presence of excess carbonaceous matter such as exists in mould washes. For best practice their use is not recommended, as more uniform and consistent bonds are available. A typical analysis of boulder clay is given in Table II.

Alluvial and Ball Clays

These are used extensively for the manufacture of domestic and industrial earthenware and some deposits are capable of service as a bond in moulding sands when maximum refractoriness is not a principal consideration. The Devon blue ball clay deposits at Newton Abbot are possibly one of the best sources of this type of material in Great Britain but difficulty arises in obtaining satisfactory sand mixtures unless the clay is added in a dry pulverised state or, alternatively, in the form of a slurry.

China Clay (Kaolin)

China clay is a white material of low plasticity found in large quantities in Cornwall and Devonshire, Canada, Australia, the U.S.A., South Africa, and elsewhere. As the name implies, one of its chief uses is in the manufacture of pottery, although in modern times large quantities are used as a " filler " in paper making and for the sizing of textile fabrics as well as in many other branches of industry. The term kaolin refers to any clays having the general characteristics of china clay, quite independently of their origin, so that unless care is taken confusion may easily arise. China clay, as mined in Cornwall and Devonshire on a large scale, conforms nearly to the composition $Al_2O_3.2SiO_2.2H_2O$ and is chiefly formed by the disintegration of pegmatite—a kind of granite.

So far as foundry practice is concerned, china clay has been used for certain applications, although not extensively. It makes an excellent bond for refractory washes where high heat-resistance is desired, as, when pure, it has a softening point around 1,750 deg. C., but its low plasticity prevents it being used for many purposes for which the somewhat less pure, but more plastic, clays are in demand. It contains on an average about 42 per cent. alumina, 40 per cent. silica, with water and minor impurities (mainly iron) as shown in Table II. So far as composition is concerned, a carefully selected and refined china clay approaches more nearly to a pure clay than any other known.

Bentonite, etc.

Bentonite is a natural clay-like substance, originally discovered in Wyoming (U.S.A.) and named from its occurrence in the Fort Benton series of rocks. The material occurs in various forms throughout the world, having been reported in Canada, China and even Cumberland, but the bulk of commercial quantities at present available centre in the United States. Bentonite is of particular interest to the modern foundryman as a bond for synthetic moulding sands and mould washes. In recent years the name has been made to cover a range of materials so-called because they were formed under similar geological conditions or are mineralogically similar. It should be appreciated, however, that from the foundry point of view, all grades of " bentonitic " clays do not behave in the same way, and from tests conducted by the author, it would seem that the original Wyoming bentonite is at the present most satisfactory for general purposes, and the properties about to be described refer to this source.

Wyoming bentonite is composed chiefly (70 to 80 per cent.) of the clay-mineral montmorillonite, together with felspars (albite and oligoclase), and smaller amounts of calcite, quartz, volcanic glass, mica (biotite), gypsum, zeolite, and having an average analysis as shown in Table II. It occurs in beds from 2 to 4 ft. thick, usually holding 30 to 45 per cent. water, even in well-drained areas, and has to be dried down to 9 per cent. moisture and then powdered for commercial use, and is thought to have been formed through the decomposition of glassy ash of volcanic origin laid down thousands of years ago in Upper Cretaceous times. Probably one of the most interesting points about the material is the minute state of sub-division of its clay substance particles, as 65 to 70 per cent. are of colloidal dimensions, being under 0.2 micron (one micron is about 1/25,000 in.), and this is probably a much larger proportion of colloidal matter than possessed by the finest ball clays and kaolins. Indirect tests tend to point to the particles having a lamellar shape comparable with that of mica. The data in Table III, submitted by the American Colloid Company, are of interest in this direction:—

This accounts for its remarkable affinity for water absorbing 5 to 6 times its weight and swelling from 14 to 16 times its dry bulk. In 25 parts of water 90 per cent. of the bentonite remains in suspension indefinitely. These properties are unimpaired on drying up to 232 deg. C., they then begin to diminish but are not completely destroyed until a temperature of about 650 deg. C. is reached. The presence of an active alkali (such as Portland cement) exceeding 10 per cent. of the weight of bentonite will prevent retempering after heating. Other properties of bentonite are as follow:—

Specific gravity	2.79
Weight (pulverised)	60 lbs. per cub. ft.
Refractive index	1.53 to 1.56
Fusion temperature	1,340 deg. C.

The viscosity, suspending and bond-forming properties are greatly increased by the addition of 0.5 to 2.5 per cent. magnesium oxide but sodium chloride and certain other soluble salts act in the reverse direction.

Kerr[6] points out that mineralogical textbooks of the 18th century described a clay mineral known as smectite, which was regarded to be a prominent constituent of fuller's earth. Since it now appears that smectite and montmorillonite are identical, it has been suggested that the clays now called fuller's earth could be renamed and be mineralogically designated as bentonite. If this be correct, it would be of considerable interest to have a comparison with bentonite of the British fuller's earth deposits in Surrey, Kent and Bedfordshire.

At present the only home-mined colloidal clay which can be used instead of bentonite is that marketed under the name of Colbond. This has a similar chemical analysis as shown by Table II, but it is not so plastic nor does it absorb so much water. Actual tests in this connection conducted by the author indicate that for increasing the bond strength of moulding sands about double the quantity of Colbond is required over the best bentonite to obtain a certain strength figure. Tests conducted by Sheehan,[10] on the other hand, showed that the green-bond strength of bentonite and Colbond were in the ratio of 5:3. The fusion point of the latter material is higher than bentonite, being between 1,480 and 1,500 deg. C.

Fireclays

As the name implies, these are clays which have a notable resistance to heat and it is not customary to include materials under this term unless they have a fusing temperature above 1,580 deg. C. Fireclays are usually associated with the coal measures and are found in seams or beds varying from a few inches to about 5 ft. in thickness and as mined are in the form of irregularly shaped lumps of various sizes. Some of the best refractory clays are underclays of coal seams but it by no means follows that all fireclays are found in this position as, for example, the "pocket clays" of Derbyshire and Staffordshire. Typical chemical analyses of British and American fireclays are given in Table II. The majority of the British materials are of the siliceous type, *i.e.*, they contain more silica than is required to form kaolinite with the alumina present. The percentage of silica varies from about 45 to 80, the clay then passing with further increase of silica into a quartzose rock, which when mixed with clay often assumes the well-known material ganister. On the whole, the Scottish clays are decidedly less siliceous than the English or Welsh. No British fireclays have a refractoriness greater than 1,770 deg. C. and most of them are around 1,670 to 1,710 deg. C., although some have only a fusing point of around 1,580 deg. C. or less. The specific gravity is about 2.6.

The addition of fireclay to moulding sands is not uncommon in some districts, particularly for the founding of steel castings.

In Ennos and Scott's[11] report on the fireclay resources of Great Britain, the general survey of the chemical analyses and refractory tests gives the following important conclusions:—

(1) The greater the ratio of alumina to silica and the greater the percentage of combined water, the higher is the refractory quality of the clay.

(2) Basic oxides, such as ferrous oxide, lime, magnesia and alkalis, lower the refractoriness, but their influence as fluxes does not appear to be nearly so marked as that of silica.

(3) It is impossible, taking the whole series of fireclays, to find any relation between the refractoriness and the basic oxide fluxes, since the influence of the latter is often completely masked by the effect due to varying silica. Only when comparing clays of similar alumina

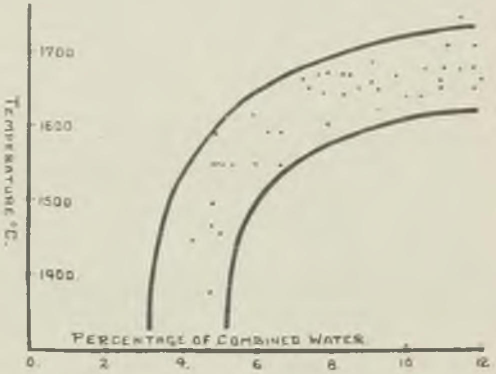


FIG. 1.—DIAGRAM SHOWING THE RELATION BETWEEN THE COMBINED WATER AND FUSION POINT OF FIRECLAYS. (ENNOS AND SCOTT.)

and silica content is the effect of basic oxide fluxes apparent.

(4) With one exception, all the fireclays investigated which contain less than 50 per cent. silica, over 30 per cent. alumina, and more than 8 per cent. of combined water, soften at or above 1,670 deg. C. The amount of basic flux present in these highly refractory clays may vary within limits, but where the percentage of silica is comparatively low (48 per cent.), the total of lime, magnesia and alkalis may be as high as 5.8 per cent. This does not preclude the existence of good refractory fireclays with less alumina and more silica (50 to 60 per cent.), but then much depends on the amount and nature of the alumina and basic fluxes present.

(5) When the percentage of silica rises to between 60 and 80 per cent., with a corre-

sponding fall in the alumina, the fireclay softens below 1,670 deg. C., even though the amount of basic oxide flux is comparatively small.

(6) The amount of alkali which a high-grade fireclay can carry seems to depend on the silica and alumina content, as shown below:—

Per cent. SiO_2.	Per cent. Al_2O_3.	Per cent. total alkalies (K_2O and Na_2O).	Softening point, deg. C.
57.4	26.4	2.60	1,670 to 1,690
53.3	28.0	3.20	1,670 to 1,690
47.9	30.05	3.99	1,670 to 1,690
47.5	33.1	4.5	1,670 to 1,690

(7) There is very little concordance between refractoriness and chemical composition in fireclays of lower quality, and it is not generally possible to grade these by means of chemical analysis with any degree of accuracy. Probably the simplest and most useful chemical method of estimating the refractoriness of fireclays is to determine the combined water. This constituent increases with rise in refractoriness, and it may be easily and rapidly determined on a sample of clay, no chemical separations being involved in the process.

With some exceptions the rule appears to hold that for clays with combined water greater than 9 per cent. the cone value to combined water ratio is very nearly three. When the combined water is between 7 and 9 per cent. the ratio approximates to 3.5; while for combined water less than 7 per cent. the ratio rises to four or more. This relationship is quite empirical and far from accurate, but it gives the quickest chemical means of distinguishing between good and bad clays.

Fig. 1 reproduces a diagram from Ennos and Scott's work showing the relation between the combined water and softening point of fireclays.

These results should be of considerable future value for assessing the quality of clay bonding materials, particularly those used for synthetic sand production, and they may quite possibly be adapted to the study of naturally-bonded moulding sands in general.

REFERENCES.

[1] C. S. Ross and P. F. Kerr. "The Clay Minerals and Their Identity." Jnl. Sed. Pet., 1931, vol. 1, pp. 55—65.

[2] P. E. Grim, R. H. Bray and W. F. Bradley. "The Constitution of Bond Clays and Its Influence on Bonding Properties." Trans. A.F.A., vol. 7, 1936, p. 211.

[3] H. Ries. "Geology and Clay Research." Bulletin of American Ceramic Soc., vol. 14, No. 9, 1935.

[4] J. W. Mellor. Trans. Cer. Soc., vol. 13, 1914, p. 83, vol. 16, 1917, p. 73.

[5] H. Ries. "Clays, Their Occurrence, Properties and Uses." New York, 1914, p. 127.

[6] F. H. Clews. "Settling and Anti-settling Properties of Clays." "Foundry Trade Journal," Dec. 5, 1935, p. 422.

[7] Senfft. "Thonsubstanzen." Berlin, 1879.

[8] J. G. A. Skerl. Proc. I.B.F., 1930—31, vol. 24, p. 195.

[9] F. Kerr. Amer. Mineralogist, 1932.

[10] J. J. Sheehan. Proc. I.B.F., vol. 27, 1933—34, p. 229.

[11] F. R. Ennos and A. Scott. Special Report on the Mineral Resources of Great Britain. Vol. 28. H.M. Stationery Office. London, 1924, p. 69.

Paper No. 731

Mould and Core Washes

By Wm. Y. BUCHANAN.

The materials used in manufacture of blacking have been listed at great length elsewhere, including many forms of carbon more or less rare, and, for that reason expensive, but usually the base material is coke breeze and possibly some additions of fireclay.

Where fireclay is added, it is usually the custom, especially when subsequently mixed by hand, to make no further additions except water in the making of blackwash. The author has for a number of years used blacking made from coke only and added to the resultant blackwash such materials as bentonite, Colbond, dextrin, semi-solid core oil, coal dust of high volatile content, and even crude oil. The object of the bentonite, Colbond, dextrin and core oil was to prevent the blacking rubbing away readily after drying, although the core oil acts in a manner different from the clays. The coal dust was used with the same object in view, it being intended that at the drying temperature the volatile matter would be driven off and during the process a slight coking or crusting would take place.

Special additions such as alkalis, intended to improve the suspension of the clays in water, were not used owing to their corrosive action on the mixing tank, but crude oil was tried because of its action on coke dust, as in the froth flotation process. The application of this crude oil is only possible when an emulsifier is used in the mixing process such as is described later in the Paper.

Coke has a specific gravity of about 1.3, *i.e.*, very near to that of water, is by nature very hard and abrasive towards metals even when finely ground, has a low percentage of volatile matter, high fixed carbon, and usually low ash. Blackwash consists essentially of blacking and water plus additions, varying in concentration from a thin liquid to, in some cases, a heavy mud.

Method of Mixing

Coke dust itself tends to settle in water and constant stirring becomes necessary during use. Up till recently, the usual method which has been practised without variation for generations consists of a rectangular tank or trough in which the blackwash is mixed and stirred by pushing backwards and forwards a wooden rake with a long handle and probably some holes in the blade. The dry materials are slowly added and stirred in. The moulder always stirs the liquid before removing a bucketful for his own immediate use. By this means the liquid is always drawn from the top and has a tendency to concentrate as the level drops. It is, or was, the usual practice to mix this

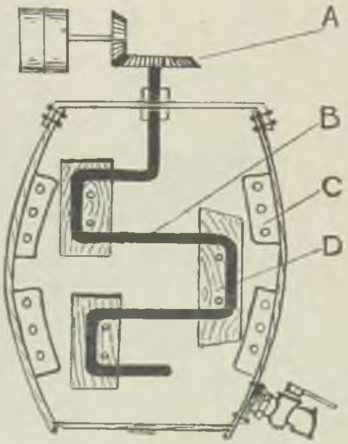


FIG. 1.—BARREL MIXER. A, DRIVING GEAR; B, STIRRER; C, BAFFLES; D, PADDLES.

blackwash in considerable secrecy using various personal tests, such as dipping the hand into the blackwash and observing this as it dried with "the air of a chef." Many additions were made, of course, such as clay water made from common red clay, and the preparation of the blackwash might occupy a man's time equivalent to about 8 hr. per week for a foundry employing 60 coremakers and moulders on dry sand and using two mixed lots of about 50 gal. each.

Mechanical Mixing

The author's experience of this problem covers a number of years, and details of methods actually tried out are included in the following notes. The first type (shown in Fig. 1) consisted of a barrel and stirrer. Where an overhead shafting is available for power drive, a barrel or circular tank is fitted with a simple type of stirrer and suitable gearing, and preferably a fast and loose pulley. Baffles are fitted to the sides of the vessel to assist mixing and prevent the liquid from swirling round bodily, as it thus tends to climb rather high at the outside. A draw-off cock is provided at the bottom of the barrel or tank.

This type of apparatus, which is essentially a stirrer, presents some difficulty in first obtaining a solution, as the partly-moistened materials tend to build up heavily on the baffles. With constant scraping down, the liquid becomes smooth and uniform, and, so long as the movement continues, tends to remain so, but if allowed to settle overnight or week-end, the mass becomes solid in the bottom and extremely difficult to start up.

Since the liquid is in this case drawn off from the bottom, and since the heavier liquid comes off first, the blackwash becomes thinner as the level falls. The upkeep on this barrel is not excessive, being mainly due to corrosion, wear, and perhaps the neglect of lubrication of the gearing and bearings which readily become contaminated with blacking dust.

Wet Grinder Type of Mixer

The machine shown in Fig. 2 first appeared in foundry advertisements about 1933 or 1934, and was put on the market by the British "Rema" Manufacturing Company, Limited. It consisted of one or two tanks and a system of piping and valves for drawing liquid from the bottom of the tank or tanks and passing this through a wet grinder unit, then delivering it to the top of the tank. The machine was belt or motor driven. It appeared to be very suitable for materials in which a mixing and grinding action was required. The claims made for it were that it produced 40 gal. of high grade blacking or other facing material in 15 min., and there can be little doubt that this output would be

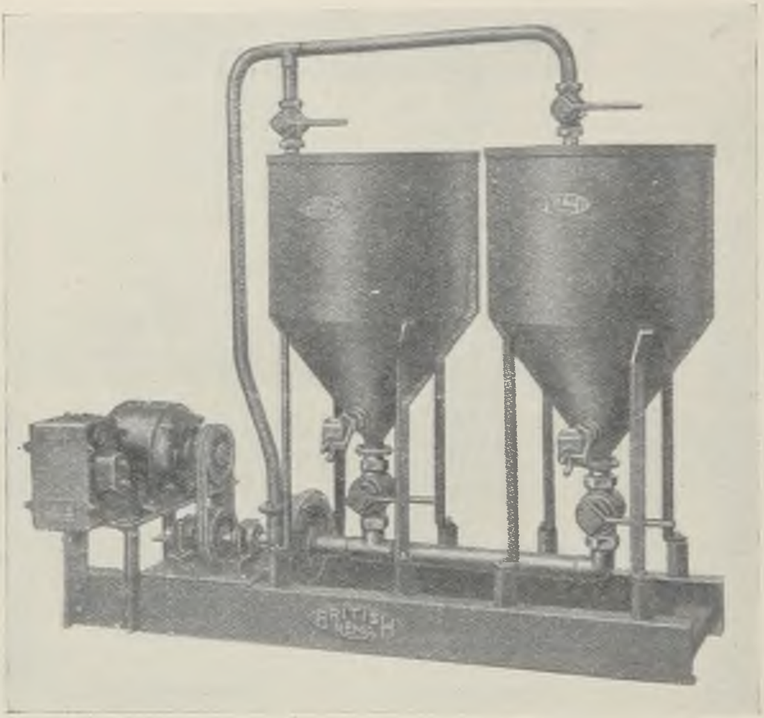


Fig. 2.—Mixing Machine designed by British "Rema" Manufacturing Company, Limited.

achieved. The machine was advertised as being in several sizes, but the author has no experience in the operation of these machines.

Emulsifier Type of Mixer

With the wet grinder type of mixer in mind the author had a plant constructed on a similar system, replacing the wet grinder unit with a centrifugal pump of the "chokeless" type, *i.e.*, one constructed to pump liquids in which an occasional solid piece of overall size up to 2 in. entered the pump and subsequently went through the system. The reason for having this machine constructed was that the materials used were ground and graded and therefore did not require further grinding.

The early trials of this machine fully justified the expectations, so much so that the makers manufactured a number of machines for other foundries, and an illustration of one of these machines appears in a Paper by R. F. Hudson* and illustrated diagrammatically in Fig. 3. The time for filling the tank, adding the dry materials, and mixing completely was 19 min. for 50 gal. of water, plus other materials, making in all about 60 gal. of blackwash. The action of this system seems ideal, and by keeping the delivery tube close to the side of the tank and fitting a right angle bend the stream of liquid round the side of the tank sets up a rapid whirlpool effect with a large vortex in the centre. The advantage of this right angle bend which was a later addition to the machine and the resultant whirlpool was that dry materials which normally float and do not wet quickly on a quiet surface in this case swirled round once or twice and then shot down the vortex, when it was immediately dispersed in the pump.

For a considerable time no mechanical trouble was encountered, and the usual practice was to mix the blackwash in the tank nearest the pump and deliver to the outer tank for storage and use; a new lot being always ready to follow the one nearly finished. Where blackwash had been unintentionally allowed to settle in the pump or occasionally due to severe frost and lack of shop heating during winter holidays, great difficulty was of course encountered in starting up.

It was usual to put the machine on mixing at the beginning of the shift, and possibly after the luncheon interval, for a few minutes and as would be expected, when the mixing process was not in operation for any length of time the small lots drawn from the tap tended to become heavy and consequently the blackwash got progressively thinner. Moulders were instructed to empty their blackwash buckets back into the tank so as to clear out the heavy cake which grows on the bottom, in the interests of economy, but unfortunately they sometimes forgot to remove the hemp swab before doing so, and this caused the partial dismantling of the tubing to get the system freed again. To guard against this a wire grid was suspended below the surface level of the liquid, but after a time this was discarded as it impeded the mixing process.

Water was connected to the tanks for convenience, and it was soon observed that with the plug cocks closed water leaked quickly from one tank into the other. The wear was due to the action of the blacking between the sliding surfaces, and when this leakage developed the plug cocks had to be renewed.

The pump impeller, although very robust, also wore out and, of course, the efficiency dropped off considerably before complete renewal was necessary. It is possible that extremely rapid mixing might have been sacrificed in the interests of longer life and less repairs, because the pump seemed to deliver the blackwash under considerable pressure, *i.e.*, much more than was strictly necessary. The most serious trouble from wear, however, arose from the difficulty of keeping the pump spindle packed tightly. Even with frequent renewal of the packing, the spindle became worn unevenly into grooves—and the leakage was thereafter constant in spite of frequent packing. Water tended to leak away, the mixture became concentrated and the surrounding floor was always covered with blackwash.

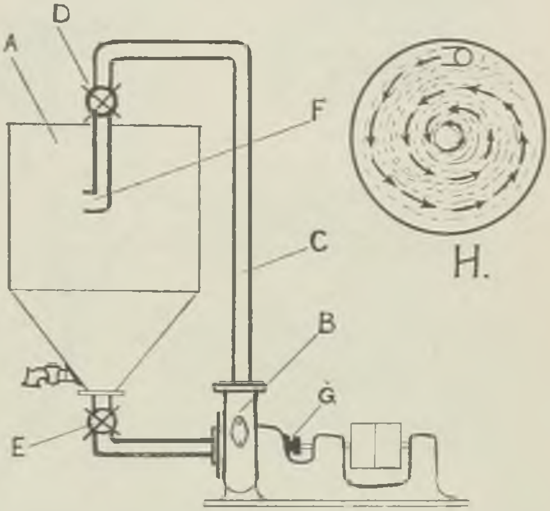
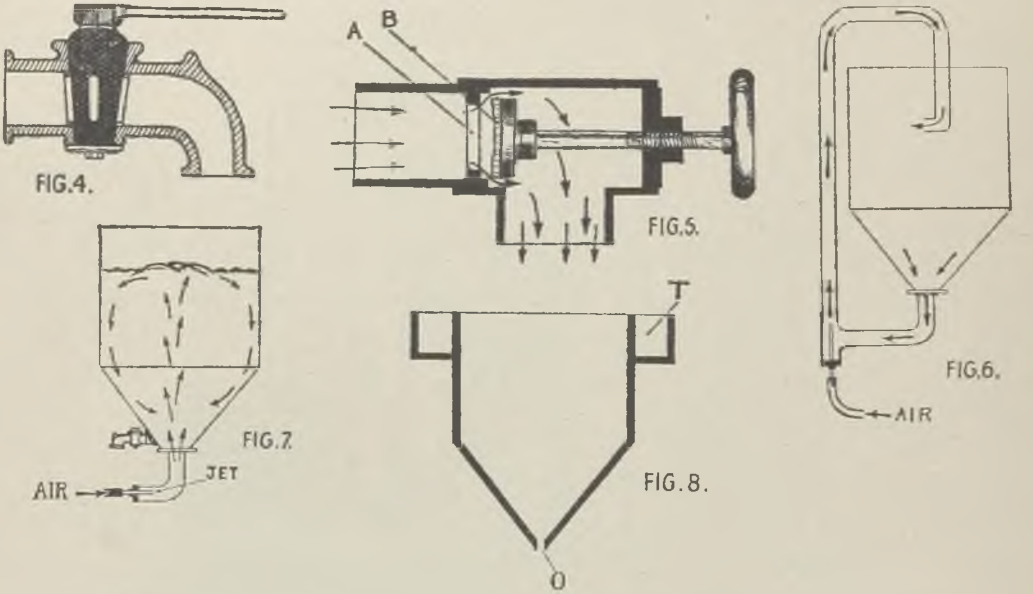


Fig. 3.—Emulsifier Type of Mixer. A, 70-gal. Tank; B, 2-in. Chokeless Pump; C, 2-in. Tube for Circulation; D and E, Shut-off Valves; F, Right-angle Bend; G, Packing Gland; and H, Whirlpool Action during Mixing.

* Proc. I.B Vol XXX, 1936-37, p .570

It may be argued that the savings in wages for mixing time as compared with hand mixing would allow of replacement parts being bought at reasonable intervals. On the other hand, special materials might be used in order to give increased wear resistance. However, it seems safe to say that in most foundries the mixing time by hand, even though excessive, would excite less attention than regular appearance of invoices for replacements.

On considering this matter of replacements carefully, it became obvious that the six plug cocks were a source of trouble, which was a matter of individual design and/or elimination where possible; secondly, that the leakage at the pump spindle would be due to the head of water acting, and consequently, if the pump were raised, this leakage would be reduced. If, on the other hand, the pump were eliminated altogether, the trouble would disappear.



Figs. 4-8.—Fig. 4, Design of a Common Plug Cock with a Restricted Bore through the Plug; Fig. 5, Valve suitable for running off Blackwash: A, Valve Seat in Ring Form; B, Rubber Washer. Fig. 6.—Circulation by Compressed Air, Injector Type. Fig. 7.—Circulation by Compressed Air, Simplified Type. Fig. 8.—Cup Viscometer: O, Orifice; T, Annular Trough.

Types of Control Valve

The plug cock type of valve (Fig. 4) is the commonest on the market, but is not suitable for blackwash. The action of turning off the liquid smears the blackwash into the space between the machined surfaces, thus wearing a ring clearance through which water can bypass round the plug in the closed position. Where two tanks are connected to a pump, this leakage of water from one tank to another causes trouble in mixing.

A plain type of valve, such as is used for heavy oil (Fig. 5), would be more suitable, provided it has a leather or rubber washer to ensure a tight joint when closed. If the bore at the smallest part of this valve is kept as large as possible, say at not less than 2 in., there would be little tendency for it to choke up and less need to clear it by pushing a rod or wire through from outside, as is required occasionally in the case of the plug cock valve.

There is an alternative type, intended for corrosive liquids, in which a rubber tube is incorporated in the pipe line, and the valve principle simply depends on the pinching or flattening of the tube. It might, however, be assumed that the rubber would "perish" in time, and without an actual trial it is impossible to say whether the life obtained would be any improvement on that of the other valves.

Compressed-Air Mixing

During repairs and temporary breakdown intervals compressed air was used in mixing, using a common 36-gal. wooden barrel to mix and contain the blackwash, into which was thrust an iron pipe connected to the air supply by means of a rubber hose and the usual off-on control valve.

The mixing, after the primary wetting of the dry materials was achieved, was erratic, since the common tendency was to use too much air and to "boil" the blackwash out of the barrel. As this type of power is easily handled, cheaply adapted, and requires no moving parts, it was decided to adapt it to this purpose, at the same time eliminating the undesirable features. The common wooden barrel is really too small for mixing a reasonable quantity; is rather awkward to mix in, and the distribution of compressed air uneven and inefficient, and for the most part wasteful.

The first idea (Fig. 6) tried was an adaptation of the injector to produce a sort of artesian well, by blowing high pressure air from a small jet upwards from the bottom of a vertical tube having a "T" piece branching off the bottom of the tank. By this means it was hoped to cause a circulation of liquid from the bottom of the tank up the tube to the top of the tank.

This was constructed with standard 2-in. pipe fittings, and did actually operate as expected, but the system would require considerable improvement in design. It is unlikely that it would have worked without some assistance in the initial stage of mixing, and the material tended to settle badly owing to the direction of flow. Settling of the solid material to the bottom of the conical vessel would, on choking, be aggravated by the suction in the same direction, but it was intended to close the top or delivery end of the tube and divert the air pressure in the reverse direction to clear the obstruction when necessary. This alone would be a welcome improvement on the high-speed circulating pump system which tended to pack the sediment harder, and after a week end there was often considerable trouble in restarting.

The experiment with the injector type of system was followed by a simpler design, which consisted of a jet of air introduced at the bottom of the vessel of the same conical design. The airline was fitted with a small screw valve of suitable design which incorporated rubber valve-facings. This allowed a very low air-consumption, the movement of the liquid being just sufficient to prevent continuous settling while the blackwash is being used and at the initial mixing stage, the air can be turned on so as to produce violent "boiling" if rapid mixing be desired. This system is now in continuous operation, making 60 gal. every day except Saturday. The usual practice is to mix a new batch of blackwash and leave it overnight while the previous batch is still in use, so that there is no break in the continuous supply.

A typical mixture in use at present is:—

Blacking	224 lb.
Plumbago	12 lb.
Bentonite	20 lb.
Water	500 lb.

The tank is filled with water to measured level by means of a gauge stick, the air turned on to produce a violent boil, and the dry materials added and dispersed. The whole operation of mixing takes about 35 min., at the end of which time there is still evidence of small lumps, but since these are all at the top they would present no trouble even if the blackwash were used immediately since the liquid is drawn off from the bottom of the vessel. After 35 min. mixing the air is turned down to a minimum, and presumably these few remaining small lumps become water-logged, and are then dispersed in the gentle current of liquid. The quality of smoothness in the blackwash improves to its best in about two hours after mixing. There are a number of advantages in this form of mixer. There are of course no working parts to wear out, and only one valve to each tank which might require replacement. The direction of flow in mixing, being upwards,

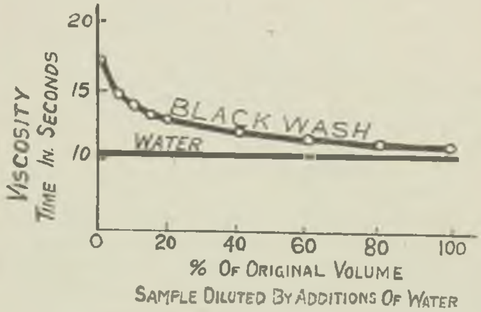


Fig. 9.—Showing Sensitivity of the Viscometer Readings to Changes in Blackwash.

automatically clears the bottom of the cone of settled solid material and any settling material returns to the concentrated part of the current caused by the air stream. The simple construction of this mixing unit makes the first-cost low. The cost of running continuously is very low. Careful measurements of the actual volume of air used in mixing were made as well as measurements of the current consumed in producing compressed air at 90 lb. per sq. in., and from these figures it was found that the cost of running at low pressure after the initial mixing stage was one penny for three hours.

Methods of Testing Blackwash

Defects in mould surfaces often throw suspicion on the blackwash used and previously the blackwash mixture would be blamed or exonerated equally without evidence of any reliable kind being available and this lack of any test-method usually kept the foundryman using a certain brand of blacking exclusively, irrespective of price and afraid to make any change.

The use of controlled mechanical mixing methods made it easy to reproduce the exact conditions each time and so blackings could be prepared and compared on exactly the same footing. It was thought desirable to develop some form of routine tests which could be applied at a moment's notice in order to detect careless interpretation of instruction regarding weights of materials given to workmen.

Specific gravity is the first obvious method and several forms of hydrometer, including some specially made, were tried but these were discarded, being found very unsatisfactory since the hydrometer usually failed to respond to very obvious changes in concentration and the reading of these instruments in blackwash is anything but accurate.

The specific gravity bottle was also used. The usual size is unsuitable and that used was of 1,000-ml. volume. To measure specific gravity by this method takes much longer than the measurement by hydrometer but provided that it is done carefully the figures are accurate but are extremely insensitive to heavy additions of solid material to the blackwash. This is unavoidable where these materials themselves have such a low specific gravity.

Viscometer Measurements

In his Paper* dealing with oilsand core manufacture, Sheehan illustrated a viscometer which he had used but did not give a detailed description, which would be helpful in obtaining or making one. After a little trouble, however, the author obtained one which appears to be the same (Fig. 8). It consists of a brass cup with a conical bottom, a definite volume of 113 m.l. and having an orifice 0.146 in. diameter. A trough runs round the top so as to catch the overflow on filling completely. Its application would consist of rapid checking of any particular lot of blackwash to test for undue settling, improper mixing, or unauthorised changes in the proportions of materials. The value of such a test is more important than may appear at first sight because the fact that an immediate check is available acts as an efficient deterrent on carelessness in measurement of materials used. The manipulation of this viscometer is simple and the results very satisfactory; for example, the triplicates of measurements made are five times out of ten exactly the same and when variations do occur they are of the order of 17.2, 17.0, 16.9 seconds, or 15.0, 15.0, 14.8 seconds. The time for each measurement of viscosity is about 20 seconds whereas specific gravity by weight takes a considerable time and although the hydrometer is as fast, the results are useless. In order to test the sensitivity of the test by viscometer to changes in the blackwash, a convenient sample was taken and diluted progressively with water, thus altering the percentage of solid materials, and the results are expressed in the graph, Fig. 9, showing that small alterations of concentration affect the viscosity reading considerably. It was found that water gave a reading of 10.4 seconds and consequently as the graph approached this figure large additions of water would make less difference. However, at normal concentrations the viscosity test is very sensitive. Though some foundries use a much heavier blackwash than 17 seconds yet it is felt that the viscometer will apply equally well to all these mixtures.

In sampling for this or any other test on blackwash it is of course essential when taking the sample, to see that it represents the batch to be tested and the sample should be drawn while the liquid is actually mixing, unless in cases where it may be desired to test the rate or degree of settling when samples would be drawn at different levels as required.

The usual procedure would be to run off at least the volume of the delivery pipe, return it to the tank, and then run off the sample. To keep the sample uniform during testing it is best to pour it quickly from one container to the other immediately before filling the viscometer. The orifice is closed by placing the finger under it and filling the cup till it overflows into the annular trough, then using the stop watch, to take the exact time from the instant of release till the small stream breaks. With blackwash there is no doubt about the end point as the stream ceases very sharply.

Check by Analysis

In making blackwash and testing by the old method of dipping the hand into the liquid and gauging its quality by what stuck to the back of the fingers, it is doubtful what property was actually tested, if indeed anything was tested at all other than a rough idea of the concentration, and perhaps some idea of clay content, where this is added, measured by colour. It was thought worth while to attempt some form of rational analysis by which a sample could be resolved into its relative percentages of water, blacking and clay. This was done by first taking a known weight of blackwash and filtering off the solid material which gave the correct proportion of water to solids. The original materials, blacking and clay, were then tested for "loss on ignition" at red heat, and this loss would include water of combination and volatile matter. With this information available, the loss on ignition of the mixture of blacking and clay filtered off from the sample is obtained, and the proportions of clay and

* Proc. I.B.F. Vol. XXXII, 1938-39, p. 43

blacking found by calculation, as in the following example.

Weight of sample of blackwash = 122.64 grm.

Weight of clay and blacking in sample = 45.344 grm.

Therefore 100 grm. of sample contain 37 grm. of clay and blacking.

Loss on ignition on the mixture of dry clay and blacking, 82.98 per cent.

Loss on ignition of "Colbond" = 18.05 per cent. (as received).

Loss on ignition of blacking = 85.38 per cent. (as received).

In order to find the proportions of clay and blacking: Let x = percentage of clay in the mixture, and $(100 - x)$ = percentage of blacking. Then 18.05 x = loss due to Colbond; 85.35 $(100 - x)$ = loss due to blacking.

$$\text{Now } \frac{18.05\,x + 85.38(100 - x)}{100} = 82.98$$

$\therefore\ x = 3.56$ per cent. (clay in dry solids).

Therefore:

Clay in blackwash sample = 1.32 per cent.

Blacking in blackwash sample = 35.68 per cent.

Water by difference = 63.00 per cent.

After extended trial this method of check by analysis based on the method illustrated appears to be reasonably satisfactory, and as an occasional check has been found very useful.

DISCUSSION

Mr. H. T. Winterton (Chesterfield), opening the discussion, said he was pleased to notice that the author of the Paper recommended the use of mixers of some type rather than the old-fashioned method of using a blacking bosh, into which much extraneous material could get.

Mention was made of the use of coal dust as an ingredient in blacking. For how long and how did Mr. Buchanan mix the coal dust, and what percentage of it was he able to get into his blacking without frothing?

It was stated also that most blackings were made with a base of coke breeze. This might be correct in regard to the old-fashioned blackings and of common blacking, but it was probably not generally true of modern blackings. A typical mixture of blacking was given as being 224 lbs. of blacking to 12 lbs. of plumbago, which was something in the order of 6 per cent. of plumbago. Had such a small addition of plumbago any real effect upon the skin? If it had, it was because the common blacking, being used, required a small amount of plumbago in order to give it some sort of smoothness, which should not be at all necessary with the modern type of blacking.

Mr. Buchanan thought there could be no doubt concerning the value of using a mixer in place of the old methods. There was little or no frothing when coal dust was used in blacking; in fact, he did not know whether such an effect would be likely to occur. Personally, he had not noticed any, and the mixture appeared to be quite uniform and free from separation or even any form of frothing on the top. The length of time of mixing was not altered in any way by the addition of coal dust. The idea originally was that it might help to prevent the usual flaking off or blowing away of the dry black wash. What was hoped would result was a slight coking or fritting together of the coal dust at the usual stoving temperature. He did not know whether it actually took place or not, but the blacking he was using was of a cheap quality, consistent with giving reasonably good results. Probably this would be considered to be an advantage in the case of most foundry managements, as there was no useful purpose served by using an expensive material if a cheaper one would serve. A small addition of plumbago effected a slight improvement which might again be dependent upon the particular type of blacking, and might not apply when a more expensive type was used. He thought the particular mixture used was arrived at gradually by a method of trial and error and bearing in mind the original cost of the blacking.

Silica Washes

Mr. O. G. Wilson mentioned that there had been an absence in the Paper of any allusion to silica washes as distinct from blacking washes or carbon washes. He understood that Mr. Buchanan was conversant with a wide range of silica washes.

Mr. Buchanan replied that silica washes did not enter very much into the particular subject, although he had tried one or two with not very good results. There was more success experienced with the kind of black wash dealt with in the Paper. As far as mixing silica washings was concerned, no difference in technique appeared to be necessary; the purpose and application, he thought, depended upon individual practice.

Bentonite Additions

Mr. Clifford asked how Mr. Buchanan added the bentonite, and whether he preferred it to be dry before he added it to his mixture? The reason for adding bentonite appeared to be in order to keep the particles in suspension in the liquid, and by using a mixer the amount of bentonite in suspension was reduced.

If there was an addition of a thin oil to the blacking would it serve the same purpose?

What would happen, when using a heavy compo wash in conjunction with a suitable mixer?

Mr. Buchanan said that dry bentonite could certainly be added to the water provided there was some form of pump or grinder incorporated in the equipment. He had not tried mixing with air alone. The process was certainly hastened if the bentonite was mixed preliminarily with water in a bucket, or at any rate made into a soft mud and thoroughly wetted.

Core oil of any type of linseed-oil base could certainly be used to replace bentonite as long as it was borne in mind that the core oil might be completely burnt out at some of the stoving temperatures. At a high temperature bentonite was much better.

Preparation of Thick Blacking

Mr. H. Haynes inquired whether Mr. Buchanan adopted the new method of mixing blacking of the "stiffer" type. At some foundries with which he had been associated they had had to cast jobs in which they could not use liquid blacking; it had to be applied as a thick paste. Had Mr. Buchanan any method he could recommend of mixing such a thick blacking?

Mr. Buchanan had not pursued his investigations to the extent of seeing what sort of mud could be mixed in a mixer of that type. If there was a strong pump in the arrangement he believed it could be done. The material mentioned in the Paper had been prepared solely for application by spraying, and was of a consistency suitable for the purpose. It would certainly be too thin for the purpose mentioned by Mr. Haynes.

Mr. H. Winterton (Past-President) thought it was quite possible that in striving after cheapness in facings production Mr. Buchanan was adding to his costs in another part of the foundry. The object of having facings on moulds was to prevent the molten metal from seeping into the sand walls. So long as this was prevented, even though there was an extra cost of ½d. per ton of castings, or thereabouts, it would be an extra expense which would be thoroughly justified. It was not always advisable to strive after a cheap article when better and more economical results could be obtained by the use of a material which was based upon something which was a little more refractory and a little more calculated to carry out the duties required of it than the coke breeze which Mr. Buchanan assumed to be the best of all facing materials. This may have been the case many years ago, but he could assure Mr. Buchanan, and he believed he knew something about the subject, having spent all the working years of his life in the study of it, that to-day the basis of the facings in general use was not coke breeze, but something very much more of a refractory nature. Mr. Buchanan had admitted that, in order to obtain the results referred to, he mixed in a certain proportion of a high-grade material. This would make the cost of his production very much dearer.

Mr. Buchanan would have to revise some of his opinions with regard to the bases which were introduced into the make-up of modern facings, one of which contained seven ingredients, only two of which were mentioned in the Paper.

Mr. Buchanan said it had certainly occurred to him that it was possible to be penny-wise and pound-foolish. Unfortunately, he was responsible for both ends of the problem; the castings going out as well as the materials bought for the facings. Therefore he could not make a good showing in one department and put blame on somebody else in another. He had to shoulder the responsibility in both cases.

The question of whether the sand would peel away properly from the castings would very quickly be brought to his notice. He thought Mr. Winterton would have to take it as definite that the condition of the casting was the first consideration. Probably they would be in agreement that, no matter how good a blacking was, it would not get a proper chance unless it was mixed by some mechanical method which was free from the old troubles. It was certainly possible to get a good machine which would mix everything properly, but there were others which were not particularly effective.

Another point he wished to make was that the few notes he had prepared were merely a record of his own views from the experience of the past ten years or so. Most of those present would have arrived at similar opinions during that course of time.

Coke breeze was one of the commonest materials to use. He had listened very carefully to Mr. Winterton in case he mentioned anything else, but he had not done so. It was useful information to learn that some other blackings were actually better and justified their higher expense.

Salt in Blacking Mixtures

Mr. H. Morris noticed that Mr. Buchanan had stated that the object of the bentonite admixture or that of core oil, dextrin, crude oil and Colbond was made in order to prevent the blacking rubbing away after drying. Had he tried common salt for this purpose? It was probably a much cheaper method than using up core oil, etc.

Mr. Buchanan had not tried common salt, and would be rather scared of doing so unless he heard of someone else trying it first. The soda contamination of sand was one of the worst materials for reducing refractoriness. He would like to hear of salt being tried on at least a small scale. Salt might contaminate the floor sand for a long time, and then perhaps unexpectedly its refractoriness would be reduced and it would have to be renewed. He was thinking of tests at elevated temperatures.

Mr. Haynes said he had tried salt water on a casting which cost £300 to make. It was as blue as any casting could ever be expected to be. The practice had now been introduced throughout the foundry, and salt was a regular constituent of the blacking. The core-man could rub his jacket against the side of a mould and not rub off any blacking. This was the reason why he had mentioned the point concerning sea-water acting on the sand in his contribution to the discussion of the American Exchange Paper.

Mr. Buchanan was pleased to hear of a large-scale confirmation of the statement. His point was that he was scared of its ultimate effect on the sand. If there was a reasonable certainty that there would be no deleterious effect, he would certainly try the method, as it was rather novel, but would have to bear in mind the ultimate effect rather than the effect on any particular casting. His own practice, however, did not call for much improvement in cost or results.

Mr. Haynes said he used an ounce or $1\frac{1}{2}$ ounces of salt to a quart of water, and he suggested to Mr. Buchanan he should try it in his mixtures and ascertain how the method worked.

Vote of Thanks

Upon the proposition of Mr. H. Winterton, seconded by Mr. F. A. Harper, a hearty vote of thanks was accorded to Mr. Buchanan for his extremely interesting Paper.

Mr. Buchanan responded.

Moulding Steam Valve Lids for Marine Service

By FRANK HUDSON

For many years, cast non-ferrous alloys have been widely used on board ship for lids in boiler stop and manœuvring valves. The lid, in a marine valve, is that disc-shaped casting attached to the operating spindle which forms the valve component controlling the flow of steam between boiler and turbine. For this important duty it is obvious that the alloy employed should possess certain properties at elevated temperatures in order to withstand the effects of superheated steam, and castings made from it must be perfectly sound in every way. The necessary service conditions are being met by the use of nickel alloys of one kind or another, the melting of which is not unduly difficult, providing a good furnace is available and full use made of correct melting technique, embodying those principles which have received considerable mention in technical literature during the past few years, namely, the need of an oxidation followed by adequate deoxidation treatment. The supply

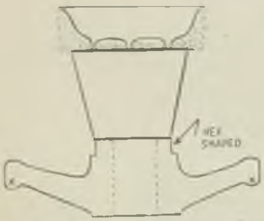


Fig. 1.—Large Boiler Stop Valve Lid.

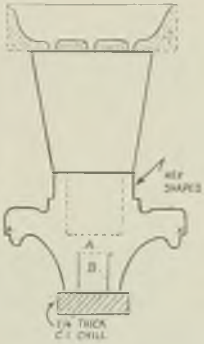


Fig. 2. — Large Manœuvring Valve Lid.

of good metal, however, constitutes only one problem out of many in the production of sound castings and no one will deny that moulding methods introduce a problem of equal, if not greater, importance in obtaining practical results. This is particularly true in connection with the type of casting under review, as not only is very little published information available on moulding methods, but the need of such is emphasised by the variety of awkward designs in service. Consideration of moulding methods known to give good results will obviously, therefore, be of considerable value to many non-ferrous founders at the present time in facilitating production of a type of casting playing an active part in the national effort.

PRELIMINARY CONSIDERATIONS

Machining and Contraction Allowance

Before describing moulding methods in detail there are one or two preliminary factors worthy of consideration. In the first place, adequate, but not excessive, machining allowances should be made on patterns. As a general rule, $\frac{1}{16}$ to $\frac{1}{4}$ in. on the seat, and $\frac{1}{8}$ to $\frac{3}{16}$ in. per side on pintle, boss and other machined diameters will be sufficient, and wherever possible the seat should be cast down, as any entrapped dirt, slag or sand, however small, on this surface will lead to rejection. The main body of the valve lid should be cast as near to size as possible. The need of greater machining allowances than those stated above indicates something wrong elsewhere, such as gassy or sluggish metal, too low a pouring temperature, poor sand or imper-

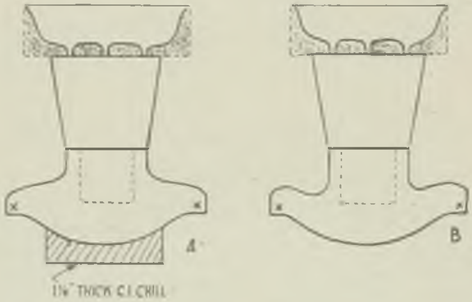


Fig. 3.—Boiler Stop Valve Lids.

meable mould, incorrect method of running, etc., and an attempt should be made to find out the cause of the trouble rather than to add extra machining and hope for the best. A contraction allowance of $\frac{3}{16}$ to $\frac{1}{4}$ in. per ft. should be allowed on patterns, according to the type of alloy employed.

Pouring Temperature

Pouring temperature for all the nickel alloys used for valve lids is high, being between 1,450 and 1,550 deg. C., according to the composition employed. Unlike gunmetal, however, there is a wide latitude in this direction, and the relation between pouring temperature and casting section is not critical. Every endeavour should be made to pour as hot as possible. The temperature range required is outside the scope of the most suitable foundry type of immersion pyrometer, but a very good guide can be obtained by testing the metal with a ¼ in. mild steel bar. If the molten metal just melts the end of this bar, bringing it to a point, it can be assumed that the temperature is around 1,500 to 1,550 deg. C. If the bar does not quite melt, but evolves sparks, then the temperature is in the lower range of 1,450 to 1,500 deg. C. No metal of the types mentioned should be poured into castings lower than 1,450 deg. C.

Moulding Sands

In view of the high pouring temperatures entailed, care must be taken to ensure fairly refractory and permeable moulds. The best results are obtained by the use of dry sand moulds, but green sand can be utilised for small castings if necessary. The majority of natural

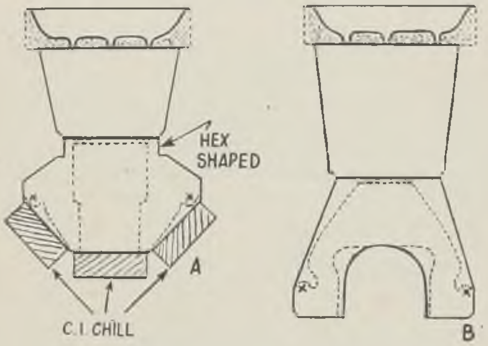


Fig. 4.—Gradual Opening Valve Lids.

moulding sands in brassfoundry use, such as Mansfield, Bromsgrove, Belfast, Erith, etc., by themselves are neither refractory nor permeable enough to give the best results, but it by no means follows that they cannot be employed. Satisfactory results can be obtained by ensuring dry sand moulds made from the above are well wire vented, thoroughly dried, and have their surfaces protected with a good plumbago wash. The latter should be made from the highest grade plumbago bonded with the necessary amount of china clay and water to which a small amount of core gum, dextrin, molasses or wood extract has been added. Just enough of the latter should be used to prevent the dried wash coming away on the fingers when rubbed. Blacking, boulder or common red clay should on no account be employed as alternative constituents, as they lower the refractoriness of such a protective wash. Furthermore, the addition of the organic binder should not be omitted, as this also materially improves refractoriness. The best dry sand for the job is, however, one of the more open mixtures as used for the production of iron castings made from naturally bonded or synthetic sand having an A.F.A. permeability number of not less than 80 with a dried compression strength of not less than 50 lbs. per sq. in. Good results can also be obtained by making the mould in oil sand using four parts of sea sand plus one part of red sand as a base.

For the production of the smaller valve lids in green sand the usual finely textured brassfoundry sands are not satisfactory unless they are opened up with sharp or sea sand and incorporate an addition of around 5 per cent. plumbago or a good grade of blacking in the facing to improve refractoriness. Good results are again obtained by the use of an open ironfoundry type of green sand containing coal dust, but the latter ingredient should not be added to the more common brassfoundry green sands as their permeability as a rule will not take care of the additional gas evolved at the high casting temperatures entailed. Lightly dusting the mould surface with plumbago and printing back the pattern is a useful precaution where this can be conveniently arranged.

For the production of the majority of the castings under review, cores will not usually be required. Although drawings may outline a design where a simple core could be used, it will be found cheaper and better in the long run to machine from the solid as the introduction of cores invariably prevents progressive solidification being obtained with consequent porosity on the hydraulic test which is on an average around 600 lbs. per sq. in.

Fig. 5.—Method of Moulding Bar for Making Very Small Lids (1-in. Bore Valve).

Valve Lids of Simple Design

Before commencing production, the foundryman should have in his hands a drawing of the finished part showing all machining limits in order to check that allowed on the castings. Furthermore any outside patterns or core-boxes should be carefully examined to ensure that they agree with subsequent remarks relative to the best method of moulding. In many instances, for example, it has been found that patterns and core-boxes are designed in order to facilitate machining operations rather than the production of sound castings. In such cases the foundryman should not commence moulding until satisfactory modifications have been effected. This particularly applies to the provision of core-boxes, the use of which has often to be omitted if the best results are to be obtained.

Fig. 1 illustrates a common and fairly simple design of lid for the larger type of boiler stop valves. Such castings will have overall diameters between 10 to 12 in., with a 4-in. diameter centre boss bored out to $1\frac{5}{8}$ in. dia., and a body section tapering from $1\frac{1}{4}$ in. down to $\frac{7}{8}$ in. adjacent to the seat portion. The stresses these lids have to withstand are often very high, and the importance of obtaining castings of the best quality cannot be too strongly emphasised. No attempt should be made to core out the hole through the centre boss, as this may interfere with the proper feeding of the casting at the junction of the body with the boss, a point where maximum solidity and strength is most needed.

Very satisfactory results have been obtained in practice by moulding the seat face down in dry sand and casting the boss solid, as shown in Fig. 1. A large tapered riser is attached for feeding purposes, and the casting is poured through this riser from a runner bush by a number of $\frac{3}{8}$ in. jets, arranged circumferentially so that the metal streams do not strike the mould wall. The height of the riser should be greater than the depth of the boss underneath. Direct pouring into the feeding head is the only way of ensuring the hottest metal at this point, and the use of a pouring bush with jet runners minimises the ingress of slag and also has the additional advantage of acting as a "hot-top" which materially assists in keeping the metal in the riser fluid until the casting has solidified. There is, of course, no need to allow the runner bush to retain metal, and pouring can be stopped before the feeding head is full so that the runner bush empties itself into the casting.

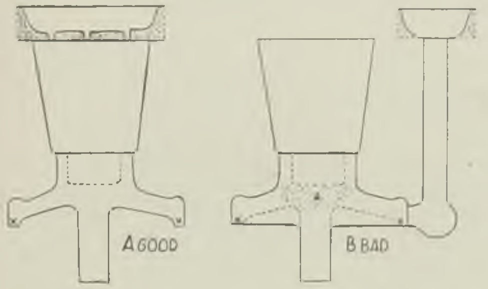


Fig. 6.—Heavy Lids (Pintle Type).

Figs. 2 and 3 illustrate smaller types of lid castings for boiler stop and manœuvring valves. The moulding methods employed in principle are similar to those already described, namely, to cast solid and pour direct through a feeding head, with the exception that recourse should be made to the use of chills in order to assist progressive solidification. For example, in the design shown in Fig. 2, there is some doubt as to whether the head will feed the entire depth of the long centre boss, and the use of an external base chill is indicated. An internal chill, made from a steel bar, acting as a core for the threaded section B (Fig. 2) would be still more effective, and if necessary this can remain in the casting and be removed in subsequent machining operations. In the case of domed type lids as outlined at A, in Fig. 3, the section of the casting at the centre is much too heavy in relation to the diameter of the boss to obtain satisfactory results by top feeding alone, and progressive solidification should be again arranged with the assistance of chills or carborundum sand.[1] It is interesting to note that the use of the latter is steadily increasing, and quite a few foundries are finding it a more convenient substitute for chills in the production of pressure castings. If design can be modified to give a more even section, as shown at B (Fig. 3), the use of chills, etc., obviously becomes unnecessary.

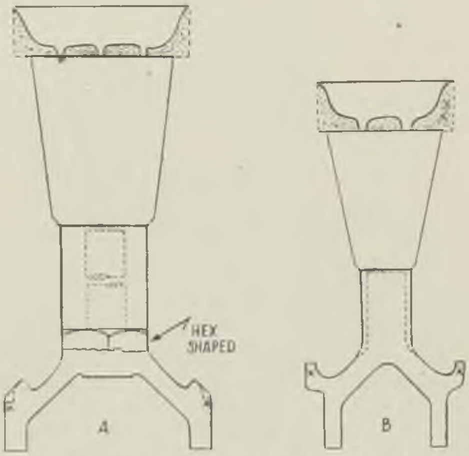


Fig. 7.—Light Lids (Pintle Type).

Fig. 4 outlines the method of moulding small valve lids of somewhat different design as required for certain types of control valves. The main point to note in both the examples given is the fairly wide pattern modifications entailed over the finished machined product. It will be observed that in the design shown at A the pattern has been altered to facilitate the use of chill segments, whilst the core has been omitted. In the case of example B, there is little alternative but to cast the valve with the seat up, so that the heavier section can be directly fed by the head. In this instance there is an obvious advantage in having the pattern form its own core and, due to the modifications made in the

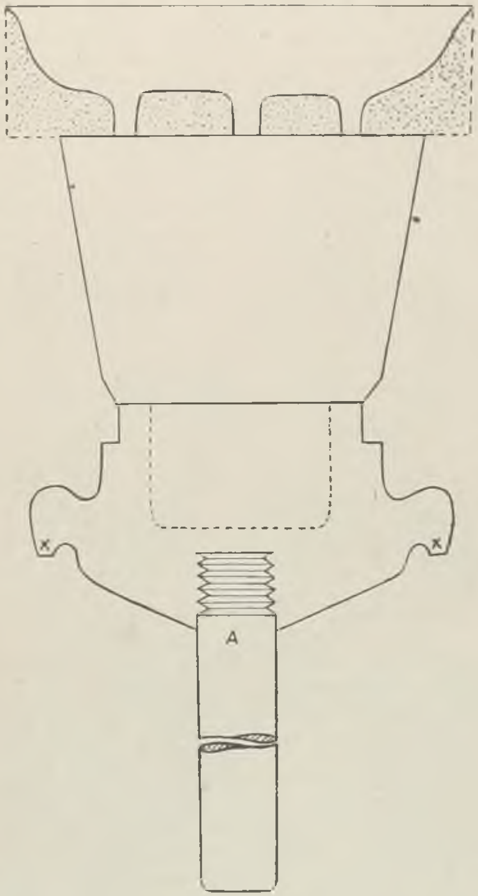


Fig. 8.—Suggested Method for "Casting-in" Pintle.

seat area (x), little trouble need be anticipated regarding the possibility of dirt, etc., being trapped at this point. It might be noted that the design of the feeding head has been modified in Fig. 4, over the examples previously given, to embrace a sudden thickening as it leaves the casting instead of a gradual taper. There is no doubt that this materially improves feeding action and also provides a guide for cutting off operations in the fettling or machine shop.

In the manufacture of very small lids, say, for 1-in. bore valves, there is little advantage to be gained in making individual castings. The most convenient method is to machine from sand cast bars moulded vertically, as shown in Fig. 5. Chill casting is not recommended, due to the tendency towards centre porosity, and even with sand cast bars care must be taken to ensure that the length of the bar is not too long, otherwise trouble of a similar kind will arise. Normally a bar 6 to 7 in. long, with a head of similar length, is about the maximum which can be employed in conjunction with any guarantee of soundness.

Valve Lids of More Difficult Design

All the lid designs so far dealt with have been free from pintles, and founding difficulties increase when this fitment is incorporated as an integral part of the casting. Fig. 6 illustrates a typical pintle type valve lid, and provides an interesting comparison of good and bad moulding methods. If the casting is poured as shown at B (Fig. 6), *i.e.*, with a heavy runner on the seat portion, porosity will invariably be found in the centre of the lid at A, even when ample feeding heads are employed. This is due to the fact that, when pouring is completed, the metal at this point is hotter than that in the head, which consequently solidifies before fully feeding the central portion of the castings. The tendency to porosity is further aggravated by the use of a feeding head having an open top and by the extra metal sometimes allowed on a line xx, where the pintle joins the valve body. By adopting method A (Fig. 6) solidity and pressure tightness are ensured.

The latter method works extremely well when the pintle is not too long and when it is attached to a fairly heavy body section. Unfortunately, certain designs of lids exist in which most of the body is of lighter section than the pintle, as outlined in Fig. 7, and it becomes necessary to cast the pintle up in order to get the centre of the casting properly fed. The matter is further complicated by the fact that the valve seat is nearly always on the pintle side, and this must be cast up as well. Fortunately, by exercising a little foresight in slightly modifying the design at this point, as shown in A (Fig. 7), or increasing the machining allowance to about $\frac{1}{8}$ in., as in B (Fig. 7), any trouble due to dirty seats can be eliminated. The business of getting the pintle and central body section sound is not so easy a matter. In the design shown at A in Fig. 7, incorporating a relatively light pintle and body section attached to a heavy hexagonal shaped centre, it is necessary to increase the diameter of the pintle to equal that of the centre section and subsequently machine the pintle down to size. In castings having no heavy central portion, as illustrated at B (Fig. 7), the pintle need only be thickened enough to ensure progressive solidification. In any case of doubt, however, one should err on the safe side by over-thickening, as on no account should the pintle, when cast up, be allowed to solidify before the body section below.

There are a few designs of lids in existence incorporating a very long pintle where doubt will exist as to whether any method of moulding will produce a satisfactory casting. In such cases it is worth while taking the matter up with the designer as to whether the pintle cannot be made from wrought bar, and subsequently fitted by mechanical means, or cast into the lid in the foundry. In the past there seems to have been very little effort made to "cast-in" pintles, but it should be quite a practical operation providing the body section is heavy enough to ensure the passage of enough metal to effect welding of the pintle with the body. The pintle (A, Fig. 8) can be made from Monel bar, and the end going into the casting should be machined with a series of deep knife-edged parallel grooves to facilitate its union with the molten metal in a similar manner to that employed for a certain type of chaplet, as shown in Fig. 8. The high pouring temperatures employed for the type of castings under review should promote satisfactory fusion, but if any difficulty is experienced recourse could be made to coating the grooved end of the pintle section with pure tin. In many designs of lids the attachment of pintles by a casting-in operation will also materially simplify moulding methods and assist the production of sound castings by their acting as an internal chill.

Test-Bars

The methods outlined in this Paper for moulding valve lids do not readily lend themselves to the production of "cast-on" test-bars, and the supply of separately cast bars should be adopted. Whilst some controversy may arise on this latter point in connection with specification requirements, certain facts stand out very clearly in defence of this argument. In the first place the foundrymen's primary consideration is to produce a sound casting, and this is seriously jeopardised by enforcing the use of "cast-on" bars, particularly in view of the type of alloy employed and the size and design of casting being made. Secondly, all valve lids are invariably subjected to a hydraulic test of at least double their normal working pressure, which in conjunction with an indication of metal quality as provided by a separately cast test-bar, should be amply sufficient to differentiate between suitable and unsuitable material.

Fig. 9 illustrates various moulding methods which can be adopted for the production of test bars required in conjunction with valve lids. The I.B.F. bar, as shown at A, recommended for gunmetal castings, is not altogether satisfactory for nickel alloys, as there is a tendency for the bars to break at the shoulder and give erratic results on test. This is caused through the presence of slight porosity at the end of the bar nearest the riser brought about by inadequate feeding due to the colder metal at this point, and also probably due to strains arising through restricted contraction.

The modified method of moulding the I.B.F.

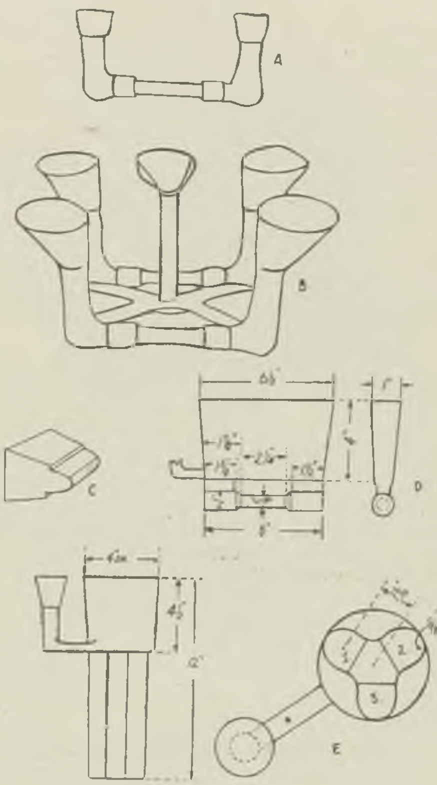


Fig. 9.—Moulding Methods for Test-Bars.

bar outlined at B undoubtedly improves feeding by delivering hot metal to both ends of the test-bar, but contraction strains and cracks can still arise unless the sand between the risers is eased soon after pouring. If this operation is not carefully done there is still the danger of the test-bar being damaged through rough handling, and probably the simplest way of producing consistently sound bars is to adopt either the wedge or clover leaf[2] type of pattern, as shown at C and E. Furthermore, these two methods produce test-bars moulded in a similar manner to the actual lid castings, and the test figures attained are therefore more nearly representative of the metal quality in the actual casting. Some foundrymen may grumble about the increased machining entailed in removing the head from the test bar portion in the latter types, but this becomes a relatively simple matter if a high speed slitting wheel or one of the latest types of fast metal cutting circular saws is available. Admittedly, without some such assistance the removal of the test-bar portion is a tedious operation, and matters can be facilitated by adopting the moulding method illustrated at D in Fig. 9. This method is widely used in the United States, and providing the test-bars are kept short good results are obtained. The mould is gated at the base of the head portion as shown and two bars poured from a common runner.

One last thought in conclusion. Remember that steam valve lids for marine service are required to stand up to arduous conditions these days, and only the best is good enough. If a casting is not wholly satisfactory, then scrap it without compunction, and on no account attempt to patch it up by welding, nor disguise its solidity by peening or any other means.

REFERENCES.

[1] Metal Industry, May 21, 1937, page 573.
[2] Proc. I.B.F., vol. XXXIII, 1939–40, page 61.

Mr. V. C. Faulkner, who presided over the session, introduced the discussion by complimenting the author on the practical value of his Paper, and remarking that the Institute was fortunate in having Papers of such interest and scope being presented at the present time when all foundrymen were fully occupied in the war effort. Mr. Hudson introduced his Paper with some additional notes, which are given below, together with a full report of the ensuing discussion and a written contribution by Mr. N. McManus.

AUTHOR'S SUPPLEMENTARY NOTES

Moulding methods covering the application of top pouring to non-ferrous castings are not new. Brisbois and Cartright gave a Paper on the subject in 1938 at the national convention of the American Foundrymen's Association and followed this work by contributing the American Exchange Paper, "Developments of Some Gating and Feeding Methods for High Duty Alloys," to this Institute last year. In view of the good results obtained in the above Papers, it is natural that such methods should be tried out by other foundries, and in the "Iron Age" for May 8, 1941, the results obtained by Brisbois and Cartright were amply confirmed by Higgins, metallurgist to the Allis Chalmers Manufacturing Company, of Milwaukee, U.S.A.

The present Paper gives an outline of top pouring methods tried out in several foundries in this country on nickel alloys with very successful results. The production of pressure castings in such alloys in the past has not been an easy matter and the moulding methods suggested have definitely been found materially to assist production. So much so, that it is felt the non-ferrous foundrymen will benefit by studying the effect of top pouring methods on other types of castings and alloys. The principle of direct riser pouring offers many advantages over the more common methods employed for running non-ferrous castings. Probably the outstanding advantage is the greater degree of feeding action obtained due to the head being

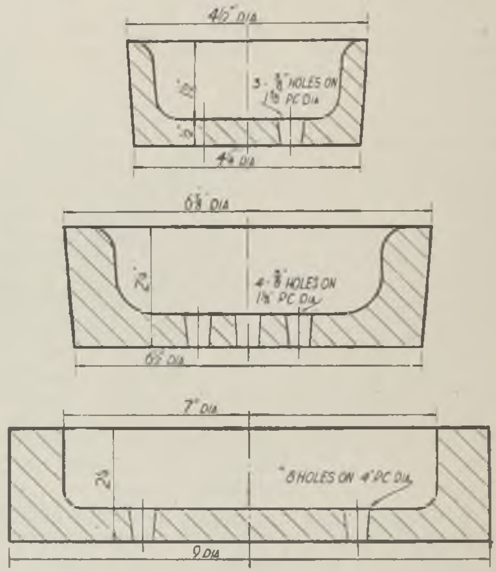


Fig. A.—Three Sizes of Runner Cores.

filled last with the hottest metal and the maintenance of feeding head temperature by virtue of the head being covered by a heated pouring bush or basin. This is well exemplified by comparison of the methods shown in Fig. 6. Many foundrymen will consider the method shown at B satisfactory for the production of gunmetal castings of commercial quality. This may be so, but the fact that such methods do not give satisfactory results with a more difficult alloy suggests scope for improvement and the thought that top pouring methods, as shown at A, would give still better quality gunmetal castings.

It will be found, too, that top pouring methods lessen the sensitivity that different alloys and casting designs exhibit towards feeding head proportions, *i.e.*, the feeding head is generally of a size to compensate for a range of shrinkage wider than that provided for by the more usual methods. This is particularly valuable to-day in view of the variety of alloys being handled in the average brassfoundry.

It might even be suggested that the methods outlined promote a moderate economy in feeding metal and gates and will certainly promote a large economy in the case of certain alloys so far as defective castings are concerned.

Top pouring methods may not be applicable to all types of non-ferrous alloys. Brisbois and Cartright stated that light alloy, aluminium and manganese bronze castings could not be satisfactorily produced due to the tendency to occlude mould gases or entrap dross. On the other hand, Higgins found no difficulty in handling all the normal brasses and bronzes and certainly no difficulties either as regards occluded gas or dross have arisen in connection with nickel, Monel, cupro-nickel, nickel bronze or nickel silver, nor have difficulties been experienced in the work covered by the present Paper. It would therefore seem that the application of top pouring methods to alloys containing appreciable quantities of such elements as aluminium may not be as yet a practical proposition. On the other hand it can be stated that little fear need be anticipated regarding erosion or cutting of the mould surface due to the impact of the metal stream, providing the usual simple precautions are taken.

DISCUSSION

The Chairman read the following written contribution from Mr. N. McManus:—Mr. Hudson is to be congratulated for once again coming forward and adding yet another Paper to the many he has given dealing with non-ferrous foundry practice. Having a special interest in the particular subject, the writer takes pleasure in participating in the discussions, but it is more in the form of a "seconder" or an epilogue with some additional information, confirming much that has been said in the Paper, but it must not be regarded as the only way in producing acceptable valve castings. Coupled with the writer's name must be that of Mr. J. Arnott, well known to most foundrymen, who has materially assisted in the work and whose invaluable aid has made this contribution possible.

It was with extreme interest that the writer read Mr. Hudson's Paper, and noted the

Fig. B.

Fig. C.

Figs. B and C.—Showing Forms and Sizes of Feeding Heads.

methods advocated to produce sound valve castings of the types described, because, quite unknown to him, personal work has been carried out on exactly the same lines with similar valves, but cast with what many consider to be the non-ferrous man's "bogey," namely, "Monel metal." This brings to mind, and it is germane to repeat an excerpt from a Paper given by Mr. J. Dunleavy before the Lancashire Branch of the Institute.*

"In reviewing the complications and the difficulties in making sound castings in Monel metal, the author has reached the conclusion that the foundryman who attempts the problem without metallurgical assistance is worthy of a decoration awarded for conspicuous gallantry in the face of overwhelming odds. Moreover, such a decoration would be awarded posthumously."

There is a good deal of truth in this, but if seriously studied in all its phases—and there are many—much success can be attained. Papers such as Mr. Hudson's go a long way to assist in this direction. From both past and present experience with this method of gating on various castings and valves in particular, the writer unhesitatingly endorses that the methods outlined in the Paper will yield excellent results. Foundrymen are all more or less familiar with the pencil or pop type of gate in one form or another, and much has been published in the technical literature on the subject, but its utility in the non-ferrous foundry is not so well known, more especially when applied to direct riser pouring.

Direct Riser Gates

Fig. A shows three sizes of cores in general use. The 9 in. dia. one, though used as shown, is also in service for other work, in which case it has a core-sand cover attached to the top surface, forming a box with a gate in the centre. Experimenting at first with the small core shown in Fig. A, which then had only two $\frac{3}{8}$ in. dia. holes, the pouring of the moulds was considered too slow and produced an elongated draw in the head of the casting, characteristic of cold metal. The core was then made with three $\frac{3}{8}$ in. dia. holes, which gave a marked improvement in the smaller size of castings.

The medium size core, with four $\frac{3}{8}$ in. dia. holes, proves satisfactory for the general run of work, though at times the holes may have to be slightly increased in diameter. A point may here be made regarding the additional cost of producing the strainer core and the extra moulding entailed, as well as what might be considered the excessive proportion of feeding head when compared with the actual product; nevertheless, the satisfactory outcome more than justified the steps taken to guarantee sound castings for what is considered a very important component.

These runner cores have the following advantages:—

(1) Cleaner metal due to strainer action.

(2) More efficient feeding by having the head filled last with hot metal and the heat retained in the feeding head more effectively, due to being covered by the base of the sand strainer core.

(3) A reasonable economy in metal owing to the absence of any exterior gate, and further the strainer can be practically drained of metal, if care is taken when pouring. Added to this is a marked reduction in the number of rejected castings, when compared with other methods, which also means a reduced melting loss, and, incidentally, a saving in oil fuel.

(4) Monel, as is well known, is one of the difficult metals to cast, owing to its high melting point and very short freezing range, therefore quick and active feeding must take place. The direct riser gating certainly meets these requirements.

However, there is one point to bear in mind. Without good melting practice and control, all the foregoing points are of no avail.

Pintle-Type Valves

A number of valves, mainly the pintle type, had to be made, so the opportunity was taken to make this particular order a trial or test case, and the records of a few of the results have been selected to add to those already shown by Mr. Hudson. The patterns were studied, suitable feeding heads prepared, if not already in stock, and existing runner cores utilised, as shown in Fig. A. All the moulds were dried, so as to introduce one variable at a time. At a later date sand moulds are to be tested under similar conditions.

The form and size of feeding head adopted are clearly shown in Figs. B and C. This type of head, though requiring more metal, is a decided improvement on the more general plain tapered style. Out of 84 castings, eighty were sound and four were rejected on account of shrinkage caused by the feeding head being too small. This pattern is shown in Fig. D (2). Fig. D(3) depicts the same valve cast with the head increased, and defines the depth of shrinkage as being entirely clear of the valve, producing a sound and acceptable product. In passing, and as a matter of interest, this same valve was moulded as if to be made in gunmetal, but poured down the riser with Monel, and is pictured in Fig. D(1). This obviously speaks for itself.

Heavy Valves

Figs. E and F describe a very different form of valve, and one not easy to produce in Monel; in this case it was decided to cast it upside down

*"Foundry Trade Journal," Jan. 9, 1941.

as shown, and provide a feeding head to fit over the domed portion of the base, casting it also by direct riser method; here again the problem was solved.

Fig. G outlines a heavy valve seat which was subjected to similar treatment for casting. In place of the circular runner core, a rectangular basin was formed in the cope mould equal to the width of the risers and extending across them in the form of a bridge. Two ½ in. dia. pop gates were placed over each riser, one of which is seen in the photograph. The response was not a single reject. This method has proved highly successful with various sizes of shallow high nickel bronze rings. Care must be taken in all cases to see that the pop gates do not permit the metal when pouring to impinge on the sides of the mould.

All the valves are cast with 2½ to 3 per cent. silicon Monel, having a Brinell hardness of 180 and a tensile strength of 37 tons with an elongation of 17 per cent. Small quantities of metal are cast in 60-lb. crucible oil-fired furnaces, and larger amounts in 300-lb. crucible oil-fired tilting furnaces. The castings must be poured hot and quickly to fulfil the requirements of (4), consequently all crucibles and ladles must be thoroughly heated; this is done by means of an oil-fired preheater.

In the case of the 300-lb. furnace, the metal for casting valves is deoxidised with magnesium, while still in the furnace, and then poured into small crucibles, if a number of moulds have to be poured and yet kept within the pouring temperature range. The pouring lip being correspondingly small, also lends itself to clean pouring. When the moulds are larger and few in number the furnace is emptied into the ladle, and deoxidised in the usual manner, before pouring.

As previously mentioned, it is not put forward that the treatment of the subject is the last word in this class of work, nor is it a "cure all" remedy for the many "ills" of the foundry, yet it is a useful "stand by" in many cases when other efforts have failed. It has been largely developed to meet purely jobbing work, which varies greatly both in quantity and size from time to time. Naturally, in the case of repetition work, an intensive study would be made in all directions, and in the case of the scheme herein described, the minimum size of head and runner would have to be settled to give a satisfactory output, before being put into production.

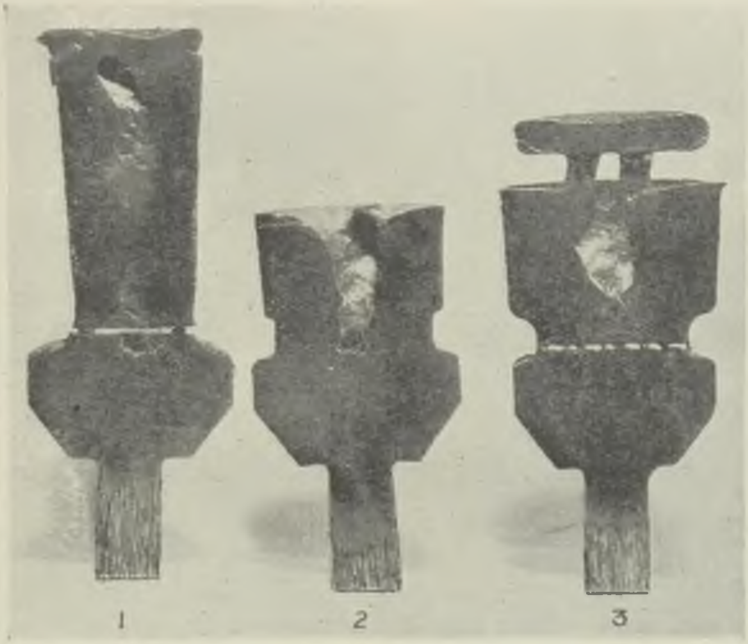


FIG. D.—CASTINGS OBTAINED WITH DIFFERENT FEEDING HEADS.

Sand Conditions

MR. A. HOPWOOD said he had gone pretty thoroughly into the top pouring of all non-ferrous metals, and he agreed with the remarks of Mr. Hudson. With regard to Monel he had had a fair amount of experience of the various methods which had been tried, but the only way in which consistent results could be obtained was either by top running the casting with spray runners, or pouring with a controlled bush. He could bear out the efficiency of that method.

On the question of the erosion of metal dropping on projected portions of sand most foundrymen with a knowledge of sand would

Fig. E.—Valve Cast Upside Down by Direct Riser Method with Feeding Head Over Domed Portion of Base.

quickly overcome that difficulty. Some people did object to metal dropping on the projecting portions of cores and moulds, but with a little care it could easily be avoided.

The Chairman, interposing, asked for more information as to the "little care" stated to be necessary.

Mr. Hopwood observed that it had to be remembered that in the majority of foundries the sand was more or less left to the moulder, and very often, he was sorry to say, the moulds were made from sand which had been used repeatedly. The high temperatures used demanded more refractory sand than was usually to be found in non-ferrous foundries, and an intimate knowledge of mixing was required in order to ensure high permeability and refractoriness.

The Chairman said that meant there must be proper sand control.

Mr. Hopwood replied that the management must establish sand control, and know what sand was being used in the job, otherwise a wrong type of sand was likely to be used and erosion would take place. He had seen that happen through carelessness.

Composition and Casting Temperatures

Mr. E. Longden said the fact that the author had concentrated on a single kind of casting made the Paper more effective in the way of impressing upon the reader the principles involved than would have been the case if a wider range of castings had been dealt with. Could Mr. Hudson tell them what the range of nickel

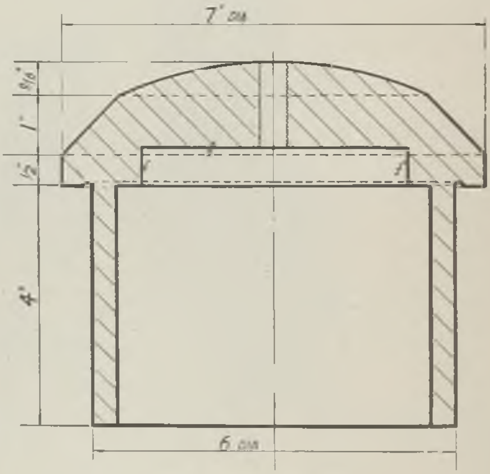


Fig. F.—Reversed Method of Running Valve Casting.

contents was? It was a very wide range that was mentioned, and there might be only 3 per cent. of nickel or as much as 30 or 40 per cent. Some information in that connection would be very useful in correlating the temperatures given in the Paper which were also very wide.

Whilst agreeing with Mr. Hudson that there was not a tremendous amount of published information on the question of the founding of Monel, the Lancashire Branch had had the good fortune to have presented to it a Paper which covered quite a number of ranges of castings of such metal, and they were very grateful to Mr. Phillips for the time he devoted to preparing it. It was very good indeed, and he wished they could get more contributions of that nature.

It was found that a dry sand mould was far superior to the green sand mould for the making of castings of any great importance. For instance with cast iron, and certain non-ferrous alloys, dry sand moulds resisted the movement of the metal after the complete filling of the mould, and if the mould was strong they could get correct filling and a help in securing solidity. He disagreed with the suggestion made by Mr. Hudson in connection with Fig. 8 with regard to the advisability of inserting the Monel in another design of lid, because, as had been pointed out, there should be superheat in the metal to fuse the casting. He would suggest that trouble would be met with gases being occluded or given off from the material if the insert had to be melted. It was not a practical proposition to be safe and to produce a sound casting. One had to remember the presence of studs in all kinds of castings, and if they did not fulfil their functions and fused the cores would move and defective castings would result.

Test-Bars

With regard to test-bars, a number of methods of moulding them were outlined in the final section of the Paper, and a point was made about the stress during shrinkage. The best results would not be obtained if the metal was not allowed to contract freely. There might be stresses set up in the bars due to the resistance of the mould or to the types of heads, and so on. It was possible to produce a test-bar taking the maximum diameter of the grip end as being the same throughout, moulded on end or increasing the diameter of a tapered casting with a head of 50 per cent. It was rather surprising to find, but it was a good fault, such a mass of head metal on these castings. In one case there was nearly 200 per cent. of head metal, and in practice a certain amount of that head metal could be reduced, but not until they were safe and could be assured of it.

Venting to Reduce Head Metal

Mr. A. Phillips remarked that one point on the practical side of the manufacture of Monel metal castings had struck him, and he would like to ask if Mr. Hudson had had a similar experience. Mr. Longden had referred to the large amount of head metal. Monel metal castings were similar to certain types of non-ferrous castings, and he had found that a reduction could be made in the head metal by intensive venting. In fact, some people, who saw some of the moulds at their foundry, would think they had gone absolutely mad on the subject of venting. If a free passage from the face of the mould could be created, more especially if the moulds were dry than with green sand, by the use of a wire from the face, it was an advantage though at times it seemed to be a waste of energy. They had found that sounder castings were obtained by that method and he would like Mr. Hudson's opinion on that point.

The Chairman remarked that he was impressed by what Mr. Phillips had said about venting, which meant an improvement in the permeability. When he had blown smoke through moulds made by the Randupson process he wondered whether that would not be a better solution than intensive venting.

Fig. G.—Heavy Valve Seat Produced Similar to Fig. E.

Mr. Hopwood observed that his experience was that it was essential to use some form of highly permeable sand, coupled with suitable refractoriness, which covered Mr. Phillips' practice as well.

AUTHOR'S REPLY

Mr. Hudson, replying to the discussion, expressed appreciation of the complimentary remarks passed by the various speakers. He would like to endorse Mr. Longden's observations with regard to the presentation of other Papers on the production of individual types of castings, particularly if the writer would select a casting which was giving trouble. A collection of Papers on the production of the more troublesome non-ferrous castings would form a very interesting addition to the Proceedings and a very useful work of reference for every practical foundryman.

He was sorry no mention was made of the type of alloys employed, or of any pertinent information as to the method of melting, but that was more or less intentional. The difficulties to-day in presenting a technical Paper were such that one had to think deeply before it was written, otherwise the censor cut it about. This Paper had to receive the approval of the Admiralty before it was allowed to be presented to the Institute, and it was thought wise that no reference should be made to any particular composition employed on His Majesty's ships or other marine vessels. At the same time he felt that those present making this kind of casting would be aware of the type of alloys hinted at in the Paper. It would, however, be no disclosure of national secrets to say the number of alloys employed was fairly wide, ranging from true nickel bronze, containing about 30 to 40 of nickel up to a higher nickel alloy such as Monel. The methods of moulding described in the Paper were equally suitable to any particular alloy in the wide range of compositions employed.

With regard to Mr. Longden's slight criticism of the casting-in method suggested in Fig. 8, he did not want readers to feel that it was intended the whole end of the pintle should be melted off. The idea was to get fusion of the knife edges on the end of the pintle just the same as they would get fusion of a chaplet. Complete melting was not intended, and he would agree that if complete melting took place trouble might arise from the presence of gas and blows.

In presenting a Paper of this type an effort was made to ensure that the illustrations given were reliable, and therefore perhaps the amount of head in relation to the casting might be larger than was required for production needs. The only point he desired to make in that connection was that the heads shown in the Paper would produce sound castings. He would rather show an excessive head and be sure the foundry got a good casting, leaving any modification of the head to the individual practical man who cared to experiment.

The remarks of Mr. Phillips about venting having an effect on the size of the head had been fairly well covered by Mr. Hopwood. All the methods shown in the Paper were intended to operate on moulds which were extremely well-vented. It was quite possible, of course, where a mould was not well-vented that it might be advisable to use a larger head in order to try to obtain density. At the same time one felt an effort should be made to start correctly by using as permeable a mould as possible.

Mr. Phillips also raised a query in regard to the method of making up the metal. Due to the number of alloys covered by the Paper, it would be difficult to make any definite assertion except to say in a very general way that so far as he could see the best results were obtained in connection with nickel bronzes when foundrymen made the metal up themselves from virgin material. In the case of material like Monel the alloy they generally received was practically virgin material. When they had to add tin, zinc, etc., he preferred to make up the metal from virgin material because by doing so they received the beneficial effects of the oxidation treatment. If one used an alloy containing an appreciable amount of zinc one did not get the full benefits of an oxidising treatment which was an essential feature of good melting technique in the types of alloys under review.

Finally, he would like to say how gratified he felt in connection with Mr. McManus' excellently written contribution in so far as it fully confirmed his own work and how much he appreciated the trouble Mr. McManus had taken in outlining the results he had obtained.

British National Specifications for Cast Iron

By J. G. PEARCE, M.Sc., F.Inst.P., M.I.E.E.

The establishment in 1928 of the first national specification for general grey-iron castings (B.S.S. 321/1928), with which the original Test-Bar Committee of the Institute was actively concerned, was a landmark in the history of cast-iron testing. Among the revolutionary features of this specification were:—

(1) The introduction of the tensile test for use in parallel with the transverse test, previously used almost exclusively.

(2) The adoption of cylindrical test-bars, rendering obsolete the rectangular and square bars previously used, accompanied by the option of machining the transverse bar.

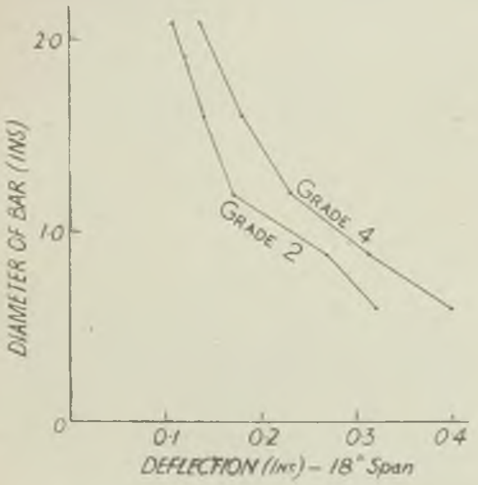


Fig. 1.—Deflection and Diameter of Bar.

(3) The acceptance of the principle of adjusting size of bar to section of casting represented by it.

(4) The adoption of test-bars cast separately from the casting.

In addition, the specification both actively and passively, that is, both by what it said and by what it did not say, powerfully reinforced the principle that for general purposes, iron castings should be specified by their mechanical properties and that composition should be left to the discretion of the founder.

Experience has confirmed the accuracy of the original basis, which has been extended, and in minor degrees modified. To-day there are six grades of iron covered in two specifications, 321 and 786, ranging from 9 to 26 tons per sq. in. in tension, and five test-bar sizes in place of the original three. As was hoped, the basis of testing has been adopted both in new and in revisions of earlier B.S. Specifications. It has had repercussions abroad. A great deal of experience has now been recorded on the round bar, to be found in British, U.S. and Continental

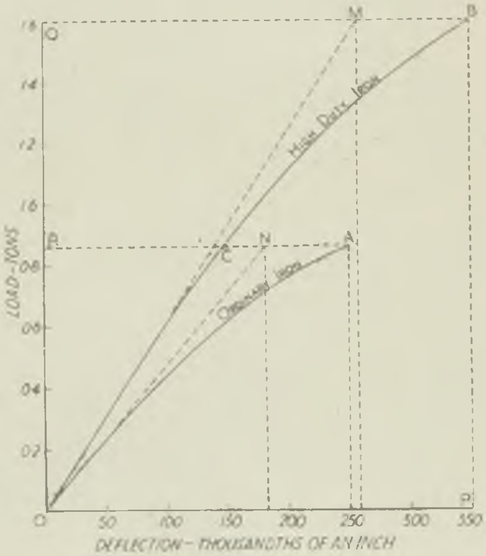


Fig. 2.—Load-Deflection Curve.

sources. The war has given an enormous impetus to the use of these specifications, both for new products and for cast-iron replacements of other materials. Their existence has been a great advantage to the industry.

In some quarters, a demand for revision has been expressed, to take care of the minor inconsistencies arising from the growth of the specification on a basis of experience and the inevitable compromises of committee working. Attention has been drawn, for example, to the gap between the highest grade in 321 and the lowest in 786; to the fact that the transverse strengths do not entirely line up with the tensile strengths, and to the fact that the lowest grade of 786 is not normally accepted as high-duty iron. Such a revision must wait on events, but it may be of interest to foreshadow some directions in which improvement may be made and to furnish a basis for discussion, although pressure of other work under present conditions has prevented this being made as complete as was intended.

The Transverse Test

Skin-machining transverse bars gives a rather better result, and, what is perhaps more important, more consistent results from a series of bars[1 2]. This may be due to the removal of the stressed skin, especially from green sand moulds. The effect is less pronounced in bars from dry sand or core sand moulds. If more than about 0.10 in. on the diameter is removed, the strength may begin to fall.

The conversion of transverse breaking loads to rupture stress, for reasons previously given,[3] is now widely followed. The specifications provide for the conversion of breaking loads obtained on an actual bar, not cast quite to size, to those expected from the corresponding standard bar. The conversion of breaking loads on one standard bar to what might be expected on another standard bar differing in diameter leads, however, to erroneous results, because transverse stress changes with size.

Deflection

The deflection figure gives a valuable indication of toughness, but its value is obscured by diameter and span variations in test-bars and by changes consequent on the change in quality between various grades. At present, deflection is regarded principally as an indication of regularity in manufacture, rather than as of intrinsic value, although it has such a value. If the test-bar be considered as a beam under load, the deflection is directly proportional to the square of the span; if the span is doubled, the deflection is quadrupled. As the diameter of bar increases, the deflection diminishes for a constant span, and in practice the deflection can be taken as inversely proportional to the diameter of the bar, the product of diameter and deflection being approximately constant. Bars can therefore be readily compared with respect to deflection, even if spans and testing diameters differ. To illustrate this point, the deflections are given in Table I for the various sizes of bar in Grade 2 and in the new Grade 4 of B.S.S. 786. The deflection figures are then given for a uniform span of 18 in. on all sizes, and Fig. 1 shows how the diameter changes with deflection for a constant span. Such curves can be constructed for all grades and facilitate the fixing of consistent deflection figures. Table I also gives the product of deflection and diameter. The slight inconsistency in the Grade 2 figures is at once evident from Fig. 1, the deflection being slightly low on the 1.2 in. bar and slightly high on the 0.875 in. bar.

TABLE I.—*Correlation of Deflection Results on Bars of Increasing Diameter and Span for B.S.S.* 786, *Grades* 2 *and* 4.

Dia. In.	Span. In.	Deflection. In.		Deflection on 18-in. span. In.		Deflection times diameter.	
		Grade 2.	Grade 4.	Grade 2.	Grade 4.	Grade 2.	Grade 4.
0.6	9	0.08	0.10	0.32	0.40	0.19	0.24
0.875	12	0.12	0.14	0.27	0.32	0.24	0.28
1.2	18	0.17	0.23	0.17	0.23	0.20	0.28
1.6	18	0.14	0.18	0.14	0.18	0.22	0.29
2.1	24	0.19	0.24	0.11	0.13	0.23	0.27

The statements above relating to the test-bar as a beam are strictly true only if the bar is an ideal beam, which is not the case. Consider loading a transverse bar to a point short of fracture. On removal of the load, the bar appears to return to its original position. If it returned fully, the bar would be wholly elastic and these statements would then apply. It is found, however, that, on removal of the load, there is a small permanent deflection or set. This can be used to estimate the proportion of permanent deflection or set in the total deflection at fracture.[3] The remainder, or part which disappears on removal of the load, is elastic deflection and in ordinary engineering irons about 75 per cent. of the total deflection is elastic and the remainder is permanent set. These two components enable one to distinguish between brittle and tough irons, for rigid or brittle irons have a low permanent set, and tough irons a high permanent set, as do irons having a high resistance to shock. In an open-grained iron, the proportion of elastic to total deflection may fall to 60 per cent. and in a very rigid iron rise to 90 per cent.

The total deflection increases at a greater rate than the load. The elastic deflection increases at the same rate as the load, or at only a very slightly greater rate. Bars capable of withstanding higher loads prior to fracture, the tough irons, therefore have a higher proportion of permanent set in the total deflection.

In considering these components in relation to size of bar, the permanent set varies little from thick to thin bars, and therefore the curve showing changes in elastic deflection with diameter is approximately parallel with those shown, for example, in Fig. 1. In making use of beam formulæ for calculating stresses, elastic moduli, etc., the total deflection is more accurately replaced by elastic deflection. So far as design is concerned, however, at ordinary working loads there is only a very small difference between elastic deflection and total deflection, as the permanent set is, under these conditions, very low, and hence the error in taking total for elastic deflection is small. At fracture, the difference is considerable, and hence elastic moduli calculated from total deflection show large errors.

The difference between an ordinary engineering iron and a high-duty iron under transverse loading is shown in Fig. 2. Increasing loads are measured along OQ, and the resulting increase in deflection is shown along OP. The engineering iron breaks at A under a load OR and with a deflection RA. The high duty iron breaks at B under a load OQ with a deflection QB. It will be observed that at the load R, the high duty iron has a deflection RC, considerably lower than that of the ordinary iron, RA. This is generally true of all close-textured, dense irons as compared with open or coarse-fractured irons. The difference lies almost wholly in the permanent set, and the latter show high permanent set, but early rupture.

The resistance to fracture of high-duty iron results in it breaking not only at a higher load, but also with a higher total deflection. The high-duty iron has a lower deflection per unit of load, but a greater total deflection. The superior properties of the high-duty iron have arisen from reducing the permanent set and thereby enabling greater elastic deflection to take place under load. The total deflection in ordinary comparisons may not appear to be greatly changed, but its character is, in fact, materially altered.

The significant change is the slope of the deflection line, that of the high-duty iron, represented by the tangent OM, being much more nearly vertical than that of the ordinary iron, represented by the tangent ON. Such a tangent drawn from the point O very closely approximates to the line showing elastic deflection, and the area of the rectangle so cut off gives a figure of merit for an iron with respect to this test, the product of load and elastic deflection. In Fig. 2 the high-duty iron is represented by the product OQ × QM and the ordinary iron by the product of OR × RN. The figure of merit clearly increases with the quality of the iron.

Transverse-Tensile Relationship

The fact that a beam breaking in transverse shows a higher specific stress than the same material broken in tension, constitutes the beam paradox, for in a material so much stronger in compression than in tension, transverse failure,

TABLE II.—*Transverse Values for Specified Tensile Values.*

Tensile. Tons per sq. in. From 321 and 786.	Corresponding Transverse. Tons per sq. in. From Fig. 3.	Transverse from B.S. Specifications.
9.0	19.6	17.7, 18.3, 18.9
10.0	20.7	19.6, 19.9
10.5	21.2	21.4
11.0	21.8	23.1
12.0	22.9	24.1
12.5	23.4	25.1, 23.6
13.0	24.0	24
14.0	25.1	25
15.0	26.2	25.9, 26.1
16.0	27.3	27
17.0	28.4	28
18.0	29.5	28.9, 29.1
19.0	30.6	30
20.0	31.7	31
21.0	32.8	33
22.0	34.0	33 35
23.0	35.3	34, 37
25.0	38.3	39
26.0	40.0	41

due to a combination of tensile and compressive stresses, must fundamentally be a tensile failure. There is a reasonably regular relation between tensile and transverse stresses. If the transverse rupture stress is designated R, and the ultimate tensile stress T, both in tons per sq. in., the ratio $\frac{R}{T}$ is not constant. As evidence has been collected, the relation has become more accurately known. It varies between 1.5 to 2.2, being usually 1.8 to 2.0. The author later found that the expression $R = T + 11$ was more satisfactory, and this was used in B.S.S. 786, where the two strengths differ by 11 tons per sq. in. These were evidently only first approximations, for in any equation connecting R and T, when one is zero, the other must also be zero.

The development in recent years of high-duty irons has enabled a much wider range of strengths to be charted from a large number of cases. From the transverse and tensile strengths so obtained, the curve shown in Fig. 3 results, and it will be seen that in the middle range it is substantially straight and slightly curved at the upper and lower ends. This curve enables the transverse strengths to be more accurately estimated with respect to corresponding tensile strengths. The full line covers the range of strengths for which evidence is available. Figures for the tensile strengths given in the two specifications are accompanied by the transverse values deduced from this curve in Table II.

It will be seen that the differences are small, series would enable the present mixed nomenclature of letters and figures to be improved.

The straight portion of the curve, Fig. 3, has an equation of approximately $R = 1.1T + 9.5$, or the transverse rupture stress is 1.1 times the ultimate tensile stress plus 9.5 tons. The curved portions would have equations of such a kind that it is simpler to determine R appropriate to a particular value of T or *vice versa* direct from the curve.

The equation could be altered to give a very different appearance without substantially altering the results. From a much more limited range of values, the author gave in 1930 the equation $T = 0.59\mathbf{R} - 4{,}000$, the stresses here being in lbs. per sq. in.,[4] and the resulting **R** from a given T is not widely different in the two cases.

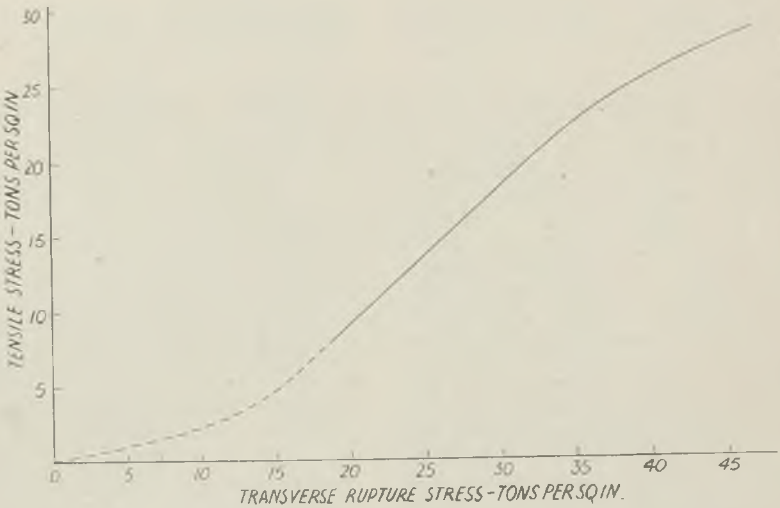


Fig. 3.—Relationship between the Tensile and Transverse Strengths of Cast Iron

but inconsistencies are removed. A series of values which form a continuous range for the 1.2-in. bar of tensiles at intervals of 2 tons, is given in Table III. The odd series includes four already appearing in 321 and 786, and the even series only two, marked with an asterisk. The corresponding deflections can also be accurately estimated, as indicated above. In this way, a regular range of irons could be specified, covering all reasonable requirements, giving eight materials in place of the present six. The effect is to fill the gap between Grade A and Grade 1, retaining Grades A and C. Grades 1 to 4 are virtually retained, with a grade between 3 and 4 to make a consistent series. Such a

One very interesting result follows from the curve, Fig. 3. It has been supposed hitherto that as irons improve, the transverse value does not increase as rapidly as the tensile, and conversely that in the weaker irons the tensile is lowered relatively more than the transverse. Fig. 3 shows through the bending of the high duty iron end to the horizontal axis, that **R** increases relatively more than T. At the other end, the bend in the reverse direction shows that the view with regard to weaker irons was correct.

The author is confident that, while for various reasons freak results may be recorded, as a general rule any combination of tensile and transverse figures obtained from properly tested, sound bars will not lie far off the line in Fig. 3.

Influence of Size of Bar

It is well known that in all cast metals a thick section is weaker per square unit of area than a thin section of the same metal. One of the great advantages of high-duty irons is that they show this change with section much less than commoner irons, and, of course, by appropriate adjustments to composition, the difference in strength between larger and smaller castings is minimised. Even so, however, the founder is not expected to obtain the same strength in a thick as in a thin bar. It may be asked whether there is any logic in providing that the strength of a large casting in, say, Grade 2 iron should be slightly lower than that of a smaller casting in the same iron. It may be argued that if a consumer wants 18 tons per sq. in., he wants it

TABLE III.—*Proposed Series.*

Odd.		Even.	
Tensile. Tons per sq. in.	Transverse. Tons per sq. in. Fig. 3.	Tensile. Tons per sq. in.	Transverse. Tons per sq. in. Fig. 3.
9*	19.6	10	20.7
11*	21.8	12	22.9
13	24.0	14*	25.1
15	26.2	16	27.3
17*	28.4	18	29.5
19	30.6	20*	31.7
21	32.8	22	34.0
23*	35.3	24	36.8

irrespective of section, and that there would be no difficulty in supplying him with the same strength in a heavy section, even if the maker were driven to use a different mixture. This, indeed, is the solution adopted by our American friends, who, incidentally, have adopted British practice of varying test-bar size with section of casting, although they were many years ahead in the use of the round bar and of the tensile test. The quality of the various grades of cast irons specified in the U.S.A. is independent of section, although test-bar and casting are related.

Advantage of British Practice

There is, however, advantage to be gained by following British practice. First of all, it assists the buyer to realise that he cannot expect quite the same properties in a large section as in a smaller section, and in extreme cases he is prevented from asking for heavy castings in strengths appropriate to lighter castings. Secondly, it is the usual practice for a firm to concentrate on the production of a few types of material, and the average founder finds it inconvenient to change his practice and mixtures with each order. There is considerable practical convenience in a recognition of the fact that a foundry making a range of sizes in, for example, Grade 2 iron, will not obtain quite the same strength in the heavier castings.

Taking the present standard bar sizes, it will also be found that the tensile-transverse points in Fig. 3 for the range of diameters will also lie very closely on the curve, and thus a series of values not only for each grade of iron, but also for each size of bar can be evolved, consistent in themselves and to the whole. In practice there will be about 1 ton per sq. in. in tensile difference in strength between each bar and the one next to it in the series. Thus a complete range of strengths and deflections can readily be built up.

Incidentally, in a series of five test bars, the diameters of four of which are expressed in tenths, the diameter of the 0.875 in. bar is unlikely to remain in eighths.

Separately-Cast Test-Bars

Little difficulty has arisen from the use of separately-cast test-bars, the metallurgical desirability of which, compared with the cast-on bar, is now accepted. It is noteworthy that one important authority some years ago expressed its willingness, in case of dispute, to accept the identity of test-bar and casting by an analysis for either silicon or phosphorus. The sensitivity of the analytical method is greater than the difference between the test-bar and casting, unless they were poured from the same metal at the same time. Standard methods of analysis should, of course, be used.[6] As far as the writer is aware, no case has arisen needing to be settled in this way, and the old argument that if the inspector is not present, the bar must be cast-on to ensure identity of bar and casting has lost its force.

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BIBLIOGRAPHY

[1] Pearce, J. G. "Influence of Size of Section on the Strength of Grey Cast Iron." Proceedings of the Institute of British Foundrymen, 1928-29, vol. 22, pp. 535-553.

[2] Pearce, J. G. "The Use and Interpretation of the Transverse Test for Cast Iron." Journal of the Iron and Steel Institute, 1928, No. 2, pp. 73-90.

[3] Pearce, J. G. "The Elasticity, Deflection and Resilience of Cast Iron." Journal of the Iron and Steel Institute, 1934, No. 1, pp. 331-348.

[4] Pearce, J. G. "The Correlation of Mechanical Tests for Cast Iron." Transactions of the American Foundrymen's Association, 1930, vol. 38, pp. 673-711.

[5] British Cast Iron Research Association. "Sampling and Chemical Analysis of Cast Ferrous Metals." 1941. Special Publication No. 7, 148 pp.

DISCUSSION

The Chairman (Mr. V. C. Faulkner) remarked that this was an ideal Paper from a director of research for an industry, because it was what might be termed a liaison Paper in so far as it formed a logical link between the consumer and the manufacturer. It was also very important from the national point of view, because all industrial nations were giving attention to this particular subject. It was pleasing to record that Mr. Pearce's efforts in this particular field were both well recognised and appreciated all over the world, and his work was materially reinforcing the already high opinion of British research activity held in American metallurgical circles of various aspects of testing.

Mr. F. Hudson remarked that, due to his lessened contacts with the cast iron industry, he was not qualified to make any serious contribution to the discussion, but he would like to say that, as foundrymen, they all appreciated the work done on the question of specifications. One felt that the non-ferrous foundrymen could take a lesson from it, particularly in reference to the list of "revolutionary features," with special emphasis on item 4, "The adoption of test-bars cast separately from the casting."

A Standard Test Mould

Mr. E. Longden, A.M.I.Mech.E., observed that through the publication of the Paper the foundrymen in the remote parts of the country who did not come in contact with specifications would be made acquainted with the fact that they did exist, and from that point of view good work would have been accomplished. On the question of the method of casting test-bars, he would ask, when would they have some definite recommendation of a standardised mould into which to cast these bars?

Stress Relieving Necessary

Mr. A. Phillips said it had to be recognised that a great advance had been made in the test-bar demands when one turned back to Specification 321, and remembered that they had got to Grade 4 in the 786 Specification. That gave some idea of the great strides that had been made.

He would like to have Mr. Pearce's opinion on the question of stress relief with these high-duty cast irons. Engineers called them "Grade 3 cast irons." One found that the castings were a little more difficult to produce in the foundry than the ordinary cast irons. When put under pressure tests, certain parts showed failures which, in his opinion, were due to the absence of a stabilising heat-treatment or suitable normalising process. The Cast Iron Sub-Committee, or the I.B.F. Technical Committee, would do a good work for the industry if they would indicate what, in their opinion, was the most difficult box-shaped casting to make; this to be subjected to different types of pressure tests and different stress-relieving treatments. From the information obtained, the industry would be able to obtain a guide as to the most suitable treatment to be applied. He was afraid these castings in the high-duty alloys may get a bad name with some engineers, and a great service would be done if they could either show or give a lead as to whether it was necessary to have a normalising treatment or a change in the mixture of the metal.

It had been suggested that Grade 4 would replace steel castings and the majority of engineers wrongly held the opinion that Grade 4 possessed a modicum of elongation. They included castings in that particular grade on these grounds and they welcomed it because it would be an advantage to have cast iron which had a little elongation. He did not know whether Mr. Pearce had anything up his sleeve which he was going to give them in the near future but if he had it was to be hoped he would do it soon because it would be very much appreciated.

Another point in connection with the high-duty cast irons was that engineers were not sufficiently enlightened in regard to the sections these cast irons could be used in. They had the advantage of the various sizes of bars which were introduced in the 321 Specification, but if the sections on which the various grades of cast iron were based were more stressed to engineers it would assist the foundry considerably.

The Chairman pointed out that elongation could be imparted to cast iron by malleablising, which simple factor often seemed to have been forgotten, and annealing processes were of short duration. People who were manufacturing Grade 4 high-duty irons were buying stress relief furnaces at the present time. Actually the French Admiralty specifications demanded such stress relieving treatment.

More Specifications Needed

Mr. J. Yates, dealing with the general question of specifications, said it had been his experience that co-operation between the designers and the foundrymen themselves, a feature which everybody desired to see, had been rather vague; in fact, it was often impossible to get co-operation wholly between the designer on the one hand and the man who tried to make the material on the other, especially with respect to non-ferrous castings. If a more elaborate range of specifications could be obtained, it would enable the designer to judge his materials more accurately and specify them to the producing foundry. It was possible that the foundry might be faced with the problem of making castings sub-contracted; they would be asked to make a casting to withstand certain tests, although often enough it was not known precisely what the casting had to do. A more elaborate series of specifications, whether from the cast-iron, or non-ferrous point of view, was to be desired mainly to assist not only the designer in getting all he wanted but to assist the foundry in giving to the designer all he needed.

Practical Applicability

Dr. A. B. Everest said they owed a debt of gratitude to Mr. Pearce for an excellent Paper which provided a great deal to think about. Many of the points raised in connection with the position of specifications would be very useful when the question of revision came up after the war. He was particularly interested in Fig. 2 and in the author's method of working out what was suggested as a " Figure of Merit." That rather tied up with the work already done by Hurst and others, but Mr. Pearce had gone a stage further in basing his figure on the true elastic part of the stress-strain curve. He (Dr. Everest) was inclined to think that as a practical works test that was not very suitable, certainly for specification purposes, because it obviously involved fairly accurate drawing of the curve. Although it might be excellent from a research point of view, it would not be of very much practical help, and on that aspect of the matter he would like Mr. Pearce's view.

In regard to the grading of strength in relation to the size of the test-bar the whole question was still very fluid, and much thought had been devoted to considering whether they should adopt the American idea of not mentioning the size of the test-bar but simply asking for iron of a certain strength, and then assuming that strength would appear in the test-bar representing the section of the casting. That was the most logical way to get out a specification. Mr. Pearce advanced many arguments in favour of the British practice, but on the other hand it could be said that the present grading of strength in relation to test-bar size in specifications was really a compromise. An iron which was suitable for a large bar was obviously quite unsuited for a smaller bar, and the figures showing rising strength with decreasing size of the bar bore very little relationship to actual practice. When the question of revision came up it might be considered whether we should not follow the lines of the American specification.

Mr. Pearce had done a very good piece of work in drawing the curve (Fig. 3) from a very large number of results available, but he would suggest that emphasis should be given to the fact that that curve referred only to pearlitic irons. There were other structures to which the curve would not apply at all.

Mr. P. A. Russell wrote the following contribution, saying he had been very interested to read this Paper, and regretted his inability to be present to take part in the discussion:

Mr. J. G. Pearce had been more successful than the writer has ever been in obtaining a curve (Fig. 3) of the relationship between tensile and transverse strengths of cast irons, and personal experience was that enormous variations occurred. He did not believe that there was a constant relationship in view of the wide varieties of irons available. At a transverse rupture stress of 30 tons per sq. in. the variations in tensile will range between 15 and 22 tons per sq. in. The general tendency is for the rigid hard irons to give low transverse strengths and deflections, and the tougher but softer types of high-duty cast iron to give high transverse strengths.

The writer has never appreciated the importance attached to the transverse test, and its main virtue seems to be that it is cheaper to carry out than a tensile test. It is fairly reliable for routine works control of standard mixtures, but very difficult to relate the results obtained over a variety of irons.

He agreed that it will probably be desirable, after the war to abolish the present 321 and 786 specifications, and substitute one specification approximately as given in Table III of Mr. Pearce's Paper. He did not, however, think it necessary to go to quite such small steps as 2 tons.

With regard to the size of bar, he was in agreement with the reduction of requirements on the larger bars, and believed that the British specification had gone rather too far in this respect and that the differences should be reduced.

Finally, he wished to make it clear that these views were personal, and did not necessarily represent the views of the Cast Iron Sub-Committee of the Institute's Technical Committee.

Author's Reply

Mr. Pearce, replying to the discussion, agreed with Mr. Hudson that it was very useful to match experience in the non-ferrous and cast iron fields, and he would like to include the cast steel field as well. He was sure there was a great deal to be learned from each other, and in that way each branch could improve its own particular practice.

There was some force in Mr. Longden's point about the casting of bars. The 321 Specification gained the confidence of the user engineer by specifying that the bar should be cast in the same type of mould as the casting itself, the idea being that, as far as possible, the two metals should be treated on absolutely identical terms. It was the same with the thermal treatment. If one was thermally treated, the other must be dealt with on exactly the same line. He agreed it was a good thing from the point of view of test-bars to standardise the conditions and to pour into a dry-sand mould. For some years past the Research Association made all the standard test-bars for research purposes in baked core sand, and without doubt the results were superior to those obtained with green sand.

Mr. Phillips's point about stress-relief annealing was a very interesting one. Many new components were being made in cast iron, particularly since war broke out. It was the practice previously to soften cast iron for machining purposes by annealing it, but it had the effect of materially reducing the ordinary tensile and transverse strength. An iron that had passed a specification before annealing would not necessarily pass it afterwards. Annealing used to be carried out from above what was known as the critical point, and the temperatures for softening had tended to come down. Conversely through the work of people like Machin and Oldham, Benson and Allison, and from the records of the Proceedings of the Institute and work from America and elsewhere, it would appear that the tendency had been for temperature of stress relief to rise, and there was a certain amount of confusion between the two. If the stress-relief temperature were too high, it tended to bring about the structural change which took place during a deliberate attempt to soften, and therefore there was a risk of getting a lower tensile strength. Ordinary cast iron shrunk on cooling, and, if there were two sections, a thin section adjacent to a thick section, the former cooled more quickly and had gone further at any given moment of cooling towards its final shrinkage than the thicker section. The result was a pull or stress between the two. That, on occasion, might reach such a value that it exceeded the strength of the material at the particular temperature, and the casting broke in the mould. In these high-duty irons a lower carbon content meant that the shrinkage was higher. In common cast iron the natural shrinkage was offset and diminished by the expansion that took place as the graphite was deposited. In higher duty iron the over-all shrinkage was increased so that, as the iron became more and more high-duty iron, stress-relief annealing was necessary.

He would suggest for that a temperature not exceeding 550 deg. C., because above that figure there was a tendency to get a softening—a change of structure from pearlite to ferrite. There might be a tendency to get a slight amount of growth, and it was more important to cool slowly than anything else.

He entirely agreed with the points raised by Mr. Yates, subject to this proviso. If they increased the number of specifications, which he thought did help the designer, they must accompany them by test and control, to be quite sure the specification values were reached, otherwise the designers' work rested on a false foundation.

Dr. Everest had suggested that Fig. 2 could not be used as a routine test. He agreed, and as an alternative test one might take the transverse rupture stress, with the total deflection as an indication. That was subject to some degree of error.

He was grateful to Dr. Everest for pointing out that Fig. 3 was based on pearlitic irons. It was the presumption from the start of the Paper that it applied to B.S.I. specifications 321 and 786 which were predominantly pearlitic, but it was important to state, and he took this opportunity of pointing it out, that it did not apply to austenitic and martensitic or chilled irons.

He did not agree with Mr. Russell's observations about the variations between tensile and transverse strengths. They usually arose from faulty material or faulty testing in one way or another. If they got sound material and tested it properly there was a reasonable concordance between tensile and transverse strengths and in rigid hard irons a low transverse was accompanied by a low tensile and conversely.

Vote of Thanks

Mr. F. J. Cook (Past-President), proposing a vote of thanks to Mr. J. G. Pearce, remarked that the Papers were both interesting and valuable to the industry. With regard to national specifications, sooner or later when the war was over that matter would have to be tackled in a deeper sense than had been the case in the past. There had always been a certain amount of laxity in the testing of metals and Mr. Pearce's contribution would go a long way towards promoting the introduction of proper specifications in the future.

Mr. A. L. Key in seconding said that he

thought great credit was due to the author for the case he had made in support of his theories.

The CHAIRMAN observed that normally they were indebted to those who prepared Papers, but in wartime, with the pressure of business, greater thanks were due to those who gave up their leisure for work in the common cause.

The vote of thanks was carried with acclamation.

PAPERS PRESENTED TO BRANCHES

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Melting and Casting Problems in the Production of High-Strength and Special-Duty Alloy Iron Castings*

By A. E. McRAE SMITH, M.A.

Under the conditions prevailing in wartime, it has been necessary for the ironfoundry industry to undertake the production of high-strength and special-duty cast irons over a considerably wider range of application than previously. This has led to much thought and consideration being given to the choice of raw materials and adaptations of existing melting plant, as well as foundry technique in producing castings to high duty specifications. Of particular importance is the choice of suitable raw materials when producing castings to B.S.S. 786, Grades II and III, and also with physical properties in excess of Grade III. Low- and medium-phosphorus pig-irons of the true Scotch type are no longer being produced in any great quantities for the ironfoundry trade, while hematite pig-iron is in short supply for high-duty and engineering cast iron.

Against this the demand for high-strength cast iron has greatly increased for special applications, in many cases as a supplementary material to replace steel castings and forgings where a non-ductile material is suitable, provided its other physical properties are well suited. Such castings, which are very often massive in section and of the "machined all over" type, call for considerable ingenuity on the part of the foundryman. Not only must he meet physical test requirements with a reasonable margin to spare, but he must also produce castings which are of uniform structure throughout and entirely free from all traces of liquid shrinkage, porosity and similar defects.

In specialised foundries some relief is found in the use of special-process furnaces, such as electric types, rotary furnaces and the like, but in the vast majority of cases the foundryman is still dependent on the cupola. Electric-furnace melting of alloy cast iron is extremely useful, particularly for suitably balanced compositions low in total carbon. However, even to-day, the number of such furnaces is limited, and their individual capacities in iron foundries are comparatively small. Rotary furnaces of all types also have their special field of application, useful in itself, but where selection of raw materials is strictly limited, very often troubles arise which were not evident when adjustments could be readily made by a judicious use of hematite pig-iron rich in carbon. Where only phosphoric pig-irons, scrap iron, refined pig-irons and steel scrap are available, the carbon loss in many types of rotary furnaces is of such an order that it is difficult to produce high-strength cast irons of medium carbon content by this means. Therefore, it is becoming increasingly evident that the cupola still must be regarded as the best general-utility furnace for cast iron.

Advantages of Duplexing

On the other hand, much greater scope is available to the foundryman who can use electric or rotary furnaces for simple duplexing processes using cupola iron as the base material. By this means carbon control can be regulated within much closer limits than is possible in cupola melting. It is also possible to make alloy additions very accurately in the electric furnace and mix the molten and superheated charge with an accurately weighed quantity of cupola metal to obtain any desired result. Nevertheless the cupola can be and is being used very successfully to-day for the manufacture of high-strength alloy cast irons with physical properties very considerably in excess of the minima specified for B.S.S. Grade III.

As will be seen by illustrations to be given later, carbon content is the ruling factor in the attainment of high strengths in ordinary grey cast irons. Other elements, particularly phosphorus, under certain conditions, also have an important effect on this property, but in normal grey cast iron the tensile strength progressively

* The author presented this Paper to both the Lancashire and London Branches. The Paper as presented to the Lancashire Branch is published first, supplementary information given before the London Branch at a later date is appended at the end of the Paper. The author was awarded a Diploma for this Paper.

increases, for any definite section and mass of casting, other conditions being equal, as the total carbon content decreases from, say, 3.8 to 2.4 per cent., which are the limits associated with cupola melting. In practice, highest strengths are associated with the lower end of this carbon range, and when it comes to producing grey cast iron with total carbon contents of 2.0 to 2.4 per cent. within narrow limits, melting processes other than the cupola must be used.

Experience has shown that straight cast irons in the carbon range 2.4 to 2.8 per cent., unless suitably alloyed and treated, because they have short freezing ranges and consequently poor casting properties, even when the composition is adjusted to give a suitable carbon:silicon ratio, have little application in practice. Special-process cast irons within the range 2.6 to 2.9 per cent. total carbon, either alloyed or unalloyed, cover the largest field in the manufacture of high-strength castings. When unalloyed, the carbon:silicon ratio has to be very carefully controlled to get optimum strength coupled with good castability; therefore, the cupola at first sight does not appear to be the best melting unit. In actual practice, however, cupola-melted cast irons in this range of total carbon content, when suitably alloyed and made by a technique which ensures the precipitation of graphite in a random arrangement and free from dendritic patterns, give highly satisfactory casting properties in conjunction with physical characteristics equal to and in excess of the requirements of B.S.S. 786 Grade III. In fact, probably over 80 per cent. of all high-strength cast iron with a tensile strength above the minimum of 22 tons per sq. in. called for in this specification is made in this country in cupola furnaces.

In addition, of course, for special purposes and where it is not desirable or expedient to use a total carbon content under 3.0 per cent., really high-duty cast iron with tensile strengths in the range 25 to 28 tons per sq. in. can be made with total carbon contents of 3.0 to 3.2 per cent. from cupola-melted metal. This usually entails the use of higher alloy contents, and their successful production also requires the correct distribution and arrangement of the graphite flakes in a strong matrix, a subject which will be dealt with at greater length when giving definite examples.

Essential Details in Cupola Practice

At this stage it may be permissible to consider in some detail the more important aspects of cupola melting for the production of high-strength cast irons, although the facts are so well known as to be really unworthy of repetition; yet it is proposed to take this risk of repeating obvious details because of the strongly held opinion that they are vitally important for successful production. It will be assumed that high-strength cast irons with total carbon contents in the range 2.6 to 2.9 per cent. are being produced and that they are of the alloy and special-process types, which (as already stated) combine excellent casting properties with individual strengths related to the actual total carbon content and nature and amount of the alloy in the composition.

In most processes, the use of steel scrap and other graphite-free materials is the fundamental basis of the cupola-melted material. Steel scrap in proportions up to 35 per cent. is commonly used for obtaining metal at the cupola spout containing total carbon in the region of 2.9 to 3.2 per cent., whereas in some of the patented processes where total carbon in the range 2.6 to 2.9 is sought, as much as 80 per cent. steel scrap is used in the cupola burden.

Thus the initial total carbon content charged may vary between less than 1.0 and 2.5 per cent., yet unless a correct technique is employed, the final carbon content may exceed 3.0 per cent., due to carbon pick-up from the fuel and cupola gases. When a final carbon content of 2.6 to 2.9 per cent. is required, it is necessary to control the conditions of operation which affect carbon absorption, such as speeding up the rate of melting and reducing the period of contact with the incandescent coke bed, and at the same time working the cupola in such a way that metal carrying the highest possible temperature is obtained. The main points to be observed are as follow:—

(1) *Selection of Suitable Quality and Type of Steel Scrap.*

The melting of steel scrap at temperatures available in the cupola, which are below the melting point of mild steel, is only made possible by the rapid absorption of carbon by the steel when in contact with the hot coke and carbon containing gases in the cupola. This absorption of carbon causes a considerable reduction in the melting point, and the carburised steel ultimately reaches a condition when it is readily melted in the melting zone of the cupola. Consequently the steel scrap selected (which should be plain carbon steel) must be of moderately thick section, certainly not less than $\frac{1}{2}$ in. For example, thick plate cuttings, railway rail ends, fishplates, bar ends, constructional steel croppings, etc., are all suitable for cupola melting. Very thin sheet scrap, on the other hand, tends to burn and become heavily oxidised before it reaches the melting zone. So, also, large flat surfaces of whatever thickness tend to form a baffle across the cupola and thus hinder the passage of gas in the cupola stack. The general size of steel scrap to be used, independent of thickness, will, of course, depend on the diameter of the cupola. For example, in a cupola lined to 36 in. internal diameter, lumps of steel greater than 15 in. in length should be avoided.

(2) *Attainment of High Tapping Temperatures.*

Although excessive superheating of molten cast iron may have disadvantages, the highest temperatures possible in the cupola will not reach this point. The chief source of failure is due to using metal which is at too low temperatures both as tapped and as poured into moulds. Cast iron with total carbon between the limits 2.6 to 2.9 per cent. has a comparatively short freezing range, particularly when the composition is near the lower carbon limit. Consequently, even with suitably balanced compositions, there is great danger of unsoundness due to trapped air and gas, caused by premature freezing, unless the casting temperature be sufficiently high.

If the following simple precautions are taken, suitably high temperatures can easily be obtained with great regularity in high-strength cast iron melted in most cupolas.

(*a*) It is necessary in order to preheat the first charges and to obtain hot metal in the first taps to use a high coke bed. Depending on the internal diameter of the cupola, this should not be less than 36 in. above the centre line of the tuyeres, and may with advantage be as high as 48 in. in cupolas under 40 in. internal diameter. This is always assuming that the operating conditions are correctly adjusted to the particular diameter of cupola employed.

(*b*) The size of charge should be adjusted to the diameter of the cupola. In order to obtain optimum melting conditions in any cupola a fixed coke charge should be used, based on giving a depth of charge or " split " coke of 6 to 8 in. This is the ideal thickness of the layer of melting coke, and consequently the weight of the metal charge should be adjusted to suit this. For ordinary grey cast iron containing no steel scrap, the weight of the charge should be approximately 12 times the weight of the coke layer, and it should be progressively reduced, probably to eight times, as the amount of steel in the charge varies from zero to 80 per cent. This is to allow for the amount of carbon absorbed by the steel scrap from the fuel. For example, a charge containing 80 per cent. steel scrap may dissolve as much as 2.0 per cent. of its carbon from the fuel, which means about 44 lbs. of carbon for each 1 ton of iron, or approximately 50 lbs. of coke.

From the above it will be seen that in dealing with high steel mixtures the weight of the individual charges will usually be considerably less than normal. The use of comparatively small charges, *e.g.*, 8 cwts. for a cupola lined to 48 in. diameter, when using a particular density of coke has other advantages apart from the promotion of high-temperature metal. It usually allows for the collection of at least two or more charges of metal in any one ladle prior to casting moulds. This ensures regularity of composition by adequate mixing.

It is noticeable that in many foundries it is normal practice to use a low coke bed and an excessive amount of coke for the " split." When the metal is not as hot as desired, additional coke is added between charges. In most cases this does more harm than good because the amount of charge coke is already excessive.

In recommending the above practice, which has been proved effective under widely varying conditions of cupola construction, it is of course obvious that the first one or two charges will show a much higher carbon pick-up than later charges. Thus it is advisable to use the first few charges as compositions with a total carbon content above 2.9 per cent. Alternatively, the first charges may consist of 50 to 80 per cent. steel scrap, the balance being scrap iron or pig-iron which, with suitable additions of ferro-silicon and ferro-manganese, form an ideal type of cupola-melted, refined or " diluted " pig-iron. In fact this method of using up what are to all intents and purposes " wash-out " charges is a very useful one under present conditions.

(*c*) The charges should be preheated in the cupola stack for a reasonable time. Full advantage should be taken of the cupola stack for preheating purposes, by allowing the charges to soak for a period of not less than one hour, after the bed has been well ignited and before the blast is turned on. Unfortunately, in many cupolas, the height from the tuyeres to the charging door is much too short to allow of full advantage being taken of preheating by the hot gases passing up through the cupola shaft. This is particularly noticeable in the case of most cupolas built for the light castings trade accustomed to melting nothing but light scrap and high-phosphorus pig-iron. A suitable height between the top of the tuyeres and the bottom of the charging door would be a minimum of 15 ft., but it can with advantage be greater than this even in comparatively small cupolas.

(3) *Tapping Technique.*

If the total carbon content is to be controlled between 2.6 and 2.9 per cent. with an optimum range of, say, 2.7 to 2.8 per cent., then it is obvious that the time allowed for the metal to be in contact with the coke bed must be controlled. In general terms the longer the metal is in contact with the coke in the cupola well, the higher the carbon pick-up. When the melting rate is fast the carbon pick-up will be lower. The type of coke being used also has a very important bearing on the amount of carbon pick-up. For example, hard, dense cokes, high in ash, are less soluble than open, low-ash cokes with large cellular structure. Therefore, in order to control carbon content, all the above factors must be standardised for each individual cupola before a system of tapping control is decided upon. Then, from experience of the particular group of conditions applying to the production of high-duty cast iron of low total carbon content in an individual cupola, a time interval can be established. This may range from continuous tapping at almost the same rate as the cupola is melting up to tapping intervals corresponding to the time it takes to fill the well completely. Normally, tapping at comparatively short, but precise, intervals gives the required carbon content for any one steel-bearing mixture.

All the above suggestions are based on the assumption that such details as ratio of tuyere area to melting-zone area, blast volume and pressure, distribution of air supply in stack, etc., are reasonably normal.

The New Technique

Now, having established the correct cupola technique to obtain a base composition with controlled carbon content, alloy additions with or without special treatments, such as late silicon additions or so-called inoculation, may be carried out on the metal at the cupola spout. It is impossible in a Paper of this kind to go into the exact details of special-process high-strength cast irons which are the subject of Patents, but in most cases, the broad principles are based on carbon control, with a balanced silicon content and the formation of random graphite patterns.

Some 20 years ago, close silicon control was the pet hobby of most foundrymen, and attempts to make so-called strong cast irons usually depended on obtaining the lowest possible silicon content, consistent with grey machinable structures in the sectional thicknesses being handled. Nowadays, fortunately, with the introduction of inoculated or graphite precipitation types of cast iron, it is possible to have a very wide latitude in silicon content without loss of strength, if the total carbon content be sufficiently low. Cast irons of low total carbon and low silicon have notoriously bad founding and casting properties, due to extremely short freezing ranges. On the other hand, special-process cast irons with total carbon in the range of 2.6 to 2.8 per cent., or even less, provided they have a silicon content well in excess of the minimum required to make them wholly grey, and that silicon has been added in the correct manner to the correct type of initial base charge, are very easily handled in the foundry, and their castability is good.

The Sphere of High-Duty Irons

Much use has been made of high-duty cast iron to meet the requirements of Grades II and III of B.S.S. 786, and particularly of cast iron to have physical properties well in excess of the Grade III minima. These grades of cast iron have found an extremely useful field to replace and be supplementary to steel castings and steel forgings for which a high-strength material of a non-ductile character is suitable. Before giving examples of such uses, it cannot be too strongly stressed that even the strongest grades, with tensile strengths of 30 to 35 tons per sq. in. on the 1.2-in. dia. bar in the as-cast condition, are to all intents and purposes non-ductile materials. It is true that certain types have a high resistance to shock as measured by various forms of single-blow impact tests —in fact, this may reach a figure three or four times that obtained from an ordinary engineering grade of phosphoric cast iron—but, even so, this impact value is in no way comparable with that of steel or malleable castings. In the same way, the degree of ductility exhibited is scarcely measurable. Nevertheless, they do fill a very important role, particularly under present conditions.

Available Materials

It may be worth while for a moment to consider the various grades and types of cast iron which are available, confining attention to those possessing physical properties to meet the requirements of 786 Grade II and upwards. It is not intended to give exact compositions and processes, but to give indications of the most suitable, and at the same time most economical, grade to meet various applications and degrees of strength, etc.

Table I gives a brief summary of some types of cast iron available as everyday production according to the present state of knowledge. All the tensile strength figures quoted are for the 0.875-in. dia. bar, but in the higher grades the decrease due to sectional gradient is not nearly so great as in ordinary cast irons. Therefore almost identical figures would be expected for the 1.2-in. dia. bar and there should be little drop even on the 1.6-in. and 2.1-in. dia. bars.

The cast irons suggested can all be made in the cupola, although the same and similar materials can be made in rotary and electric furnaces and by duplexing processes.

With regard to actual applications, cast irons to meet 786 Grade II are being used generally for medium-duty applications, such as machine tool castings, pressure-tight castings and castings for the electrical trade where something better than high-phosphorus cast iron is necessary.

General Utility High Strength Irons

Amongst Grade III materials, Ni-Tensyl iron in particular is being very extensively used where tensile strengths in the order of 22 to 25 tons per sq. in. are required with some increase in shock-resistance over good-class engineering cast irons. As a material to replace and supplement steel castings and forgings it has been used for some very interesting applications. When alloyed with a small percentage of molybdenum in the range 0.4 to 0.6 per cent., its strength and shock resistance can be considerably increased. These grades with tensile strength in the range 22 to 26 tons may be described as general-utility high-strength cast irons. Standard compositions may be modified to meet special requirements, *e.g.*, for highly-stressed gears, nickel-chromium-molybdenum Ni-Tensyl irons are in many cases very suitable. Their wear resistance is excellent and machinability good. Their range of application is too wide to give in detail, but it will be sufficient to indicate that they are being regularly used for motor-vehicle castings, diesel engines, high-pressure castings, pumps, machine-tool castings, dies, gears and all forms of highly-stressed components where, from experience, it is found that some type of cast iron is the most suitable material. One great advantage to the engineering trade is the ease with which Ni-Tensyl iron and similar irons may be cast into complicated designs, without after-treatment, thus ensuring speedy deliveries. Their production can be carried out in any reasonably equipped foundry possessing a cupola which is capable of giving high temperature metal. They may, of course, be heat-treated to give higher hardness and greater strength. In most types of castings beneficial results are obtained by giving a stress-relief low-temperature or artificial ageing treatment.

TABLE I.—*Types of Cupola-Melted Cast Irons of High Tensile Strength.*

B.S. Specification.	Tensile strength. Tons per sq. in. on 0.875-in. bar as cast.	Approximate range of composition and process.	Remarks.
786 Grade II— For medium and heavy sections	18 (min.)	T.C. 2.9 to 3.2; Si. 1.2 to 1.6; Mn. 0.7 to 1.0; P. 0.3 to 0.6; Ni. 1.4 to 1.8	Typical low-alloy cast iron. In order to obtain this T.C. range, steel scrap is normally used in base charge.
For light sections	18 (min.)	As above but increase Si to 2.0 to 2.4 per cent.	As above, but best to use some form of late silicon addition.
786 Grade III .	22 (min.)	(1) Special-process cast irons such as Ni-Tensyl iron and Grade A Meehanite, etc.	Alloy cast irons made by inoculation processes.
		(2) Low Ni-Mo cast iron to following range of composition: T.C. 3.0 to 3.2; Si. 1.2 to 2.0; Mn. 0.7 to 1.2; P. 0.30 (max.); Ni. 1.5 to 2.0; Mo. 0.4 to 0.5	Cupola melted cast iron, which may be produced without addition of steel scrap and without inoculation.
In excess of 786 Grade III	25 to 28	Special-process cast irons with addition of molybdenum, *e.g.*, standard Ni-Tensyl iron with 0.5 per cent. Mo.	These irons will normally have pearlitic or mixed pearlitic and acicular structures.
	28 to 35	Nickel-molybdenum cast irons made by special process or otherwise, but with T.C in range 2.7 to 3.0 per cent. with 2.0 to 2.5 per cent. Ni and 0.8 to 1.5 per cent. molybdenum. Phosphorus not over 0.2 per cent.	Special-process and other cast irons with acicular or pseudo-martensitic structures. Possess high impact values.

Acicular or Pseudo-Martensitic Structures

In the range of really high-strength cast irons, the most recent development has been the production and application of nickel, molybdenum and nickel-chromium-molybdenum cast irons with acicular or pseudo-martensitic structures.

Cast irons of this type can be produced in routine practice with tensile strengths of 26 to 35 tons per sq. in. in the total carbon range of 2.6 to 3.0 per cent. Much lower total carbon contents were at one time considered to be essential to obtain castings with physical properties considerably less than this, and electric-furnace irons held the field as being the ultra-strong cast irons, sometimes with a total carbon content as low as 1.8 per cent. and bordering on the steel castings range. Here the author is dealing with high-strength cast irons with a minimum carbon content of, say, 2.5 per cent. and capable of being produced in the average cupola.

Latest developments reveal the fact that cast irons of this type depend on the formation of an acicular or pseudo-martensitic structure for their high strength and also for their remarkable resistance to shock, although they must still be classified as non-ductile materials.

How Molybdenum Functions

This development has been due in great part to the use of small amounts of molybdenum in cast iron, but unfortunately the effect of molybdenum as an alloy addition to cast iron has sometimes been misunderstood in British foundries. Molybdenum is neither a graphitiser nor a strong carbide former, but by reason of its matrix-improving qualities, it greatly increases the tensile strength of any grade of cast iron. The effects produced by molybdenum alone, although very striking, are rather drastic, and it has been found from practical experience that combinations of nickel and molybdenum produce the maximum beneficial effect on the physical properties of grey cast iron.

In correctly-balanced proportions, added to a suitable base composition, nickel and molybdenum impart to cast iron the maximum tensile and transverse strengths and deflection so far achieved in any material which is a true grey cast iron. Probably more important is the fact that this type of high-duty cast iron, when possessing an acicular structure, has a very high degree of shock resistance as measured by single-blow impact tests.

It will appeal to the practical foundryman, the metallurgist and foundry executive (who, after all, are the people responsible for production, if the engineering trade is to obtain its supplies of high-duty cast iron easily and economically) that this type of top-grade high-strength cast iron can be produced in any standard cupola, as installed in 95 per cent. of the foundries in this country.

Acicular structures are a function of molybdenum as an alloy constituent of cast iron, yet straight molybdenum cast irons have been found to be somewhat difficult to handle in the foundry when produced from cupola-melted metal. So far as present personal knowledge goes when dealing with cupola-melted irons, 1.0 per cent. molybdenum and upwards is necessary to produce an acicular structure in cast iron with a carbon content of 2.6 to 2.9 per cent., silicon being adjusted to suit the mass and sectional thickness of any particular type of casting. Phosphorus has a very definite influence, and may cause the formation of laminated pearlite, instead of acicular pearlite if over 0.15 per cent. in straight molybdenum irons. It is known, however, that with the normal carbon contents obtainable from cupola-melted metal, the molybdenum content may be reduced to 0.7 per cent.

FIG. 1.—NI-MO CAST IRON NO. 14. UNETCHED. × 50 (APPROX.). RANDOM GRAPHITE.

when 1.5 per cent. nickel is present, the phosphorus content being still about the 0.15 per cent. level. Such compositions ensure the formation of the acicular structure without risk of the formation of sorbite when higher percentages of molybdenum are used alone.

Thus a typical composition for cupola-melted metal would be:—T.C, 2.7 to 2.9 per cent.; Si, 1.8 to 2.5 per cent. (according to section thickness); Mn, 0.8 to 1.2 per cent.; S, 0.12 per cent. (max.); P, 0.15 per cent. (max.); Ni, 1.5 to 2.0 per cent., and Mo, 0.7 to 0.8 per cent.

Graphite Distribution

It will be noted that the phosphorus content is given as very low, and this will be discussed later when dealing with the general effect of phosphorus in high-strength cast irons. Reverting to the question of graphite distribution and so-called graphite patterns in high-strength cast irons, it is sometimes observed that almost identical compositions can give a great diversity in physical properties. Whichever grade of high-strength cast iron is being produced, whether it be to meet 786 Grades II or III with pearlitic structures or for the routine production of higher strength grades of the acicular type, foundrymen fully experienced in the production of these classes of cast iron may encounter a cast which is very disappointing in its physical properties, although the composition is as expected and the processing is thought to be correct.

Almost invariably this will be found to be due to failure to get a random graphite arrangement, no matter what the matrix condition happens to be or even the size of the individual graphite flake. In other words, whether aiming at minimum tensile strengths of 18, 22, 25 and 30 tons per sq. in., if a dendritic graphite pattern is produced, no matter what the matrix structure is, the physical properties will decline very steeply.

It will be remembered that the first attempt to make high-strength cast iron of low carbon content (say 2.5 to 2.8 per cent.) in cupolas with comparatively high silicon contents was by the Emmel process. In this process little attempt was made to get random graphite structures. This led to many failures or discrepancies which can now be recognised as weak structures due to dendritic graphite patterns. Even in the Lanz hot-mould process, where the aim was to have a low-silicon cast iron with total carbon of 3.0 to 3.2 per cent. and a grey pearlitic structure, it was often noticed that, although the individual graphite flakes were much larger than in typical Emmel cast iron, the tensile strengths were often comparable.

Thus, in all types of high-strength cast irons, whether developed by special processing or pro-

FIG. 2.—NI-MO CAST IRON NO. 14. ETCHED NITAL. × 500 (APPROX.). ACICULAR STRUCTURE.

FIG. 3.—NI-MO CAST IRON NO. 20. UNETCHED. × 50 (APPROX.). DENDRITIC PATTERN GRAPHITE.

TABLE II.—*Nickel-Molybdenum High-Strength Cast Irons (Electric Furnace) with Normal and Abnormal Graphite Structures.*

(By courtesy of the Climax Molybdenum Company.)

No.	Composition. Per cent.							Test-bar size. In.	Tensile strength. Tons per sq. in.	B.H.N.	Graphite.	Matrix.
	T.C.	C.C.	S.C.	Si.	Mn.	Ni.	Mo.					
14	2.50	0.61	1.89	2.73	0.98	1.02	1.03	1.2	36.7	321	Normal (random)	Acicular.
								2.0	34.2	302	Normal (random)	Acicular.
20	2.62	0.60	2.02	2.50	1.11	1.05	1.00	1.2	23.4	325	Abnormal (dendritic)	Acicular.
								2.0	26.5	293	Abnormal (dendritic)	Acicular.

duced by means of suitable alloy combinations, or both, it is essential to have random pattern graphite. In most cases this is ensured by correct processing, such as correctly applied late silicon or other forms of graphitising additions. This is given as a word of warning to the foundry metallurgist, and does not in any way affect the designer or user. If the latter calls for high-duty cast iron to any definite B.S. specification or any high specification he may care to designate, he will be amply covered by normal physical tests. The foundry metallurgist, on the other hand, can immediately check any tendency in this direction by taking simple micrographs, without waiting for physical test results.

FIG. 4.—NI-MO CAST IRON NO. 20. ETCHED NITAL. × 500 (APPROX.). ACICULAR STRUCTURE.

Microstructure of the New Irons

As illustrating this phenomenon, Table II gives typical examples from an electric-furnace cast iron of the nickel-molybdenum acicular type.* The compositions of these two irons are almost identical, yet the physical properties show very great differences. It is only by examining the microstructure that these differences can be explained. Fig. 1 shows the unetched structure of the 1.2-in. dia. test-bar from melt No. 14, a typical example of random graphite. The etched structure of the same bar shows an acicular matrix (Fig. 2).

Figs. 3 and 4 are taken from a 1.2-in. dia. test-bar from melt No. 20. The acicular matrix as shown in Fig. 4 is exactly similar to Fig. 2, but Fig. 3 shows that the graphite in this melt exhibits dendritic pattern. Hence the much lower tensile strength. These are only given as examples, and it must be emphasised that exactly the same thing will occur in cupola-melted high-strength cast iron of pearlitic and acicular structure.

Figs. 5 and 6 show the graphite arrangement and acicular matrix of a cupola-melted nickel-chromium-molybdenum cast iron containing 3.05 per cent. total carbon. Although the total carbon content is high, yet a tensile strength of 28.5 tons per sq. in. was obtained on a 1.6-in. dia. test-bar as cast (machined to 0.798 in.) This micrograph was taken from a series of nickel-chromium-molybdenum acicular cast irons in

FIG. 5.—ACICULAR STRUCTURE OF NI-MO CAST IRON, SHOWING RANDOM GRAPHITE, AND CONTAINING T.C. 3.05; SI 1.86; MN 0.86; S 0.109; P 0.11; NI 2.17; CR 0.55; AND MO 0.65 PER CENT. MAX STRESS (ON 1.6 IN. DIA. BAR) 28.5 TONS PER SQ. IN. UNETCHED. × 60.

daily production for hot heading dies, where structure, wear resistance and heat resistance are more important than strength. The small percentage of chromium is to help to stabilise the carbides under heat, and is not added to gain strength. In fact, it may detract from actual tensile figures. The microstructure shows rather large graphite of random arrangement, yet the tensile strength is much in excess of the highest B.S. specification. Over a recent period some 20 casts have given tensile strengths of 20.5 to 32.0 tons per sq. in. on the 1.6-in. dia. bar.

This shows that high-duty cast iron of this order is a thoroughly reliable commercial material and that its production does not re-

* Quoted from "Molybdenum in Grey Iron" Section V, published by Climax Molybdenum Company.

quire the installation of special plant. It can be produced in any ordinary cupola, provided the essential details are carefully observed and that contamination from other metal, as, for example, from premelting of later charges, is strictly prevented. This is a point about which some foundrymen are very careless, particularly where they imagine that a few extra pounds of coke after the last charge of special metal will be sufficient to avoid this ever-present risk. Where the amount of special metal being melted does not warrant a special " blow," then the cupola should be drained, the coke bed re-established and the cupola recharged. In addition, of course, the first one or two charges prior to the high-duty metal should be dealt with in the manner already described.

Of current importance to the foundry trade is the question of obtaining adequate supplies of low-phosphorus material for the production of high-strength cast iron. Normally, steel scrap, hematite pig-irons, Scotch pig-irons, refined pig-irons, together with ferro-silicon, ferro-manganese, etc., have been abundantly available and have satisfied all requirements when used in conjunction with normal alloying elements.

Influence of Phosphorus on High-Duty Irons

In the abnormal circumstances at present prevailing, with hematite and low-phosphorus pig-irons in short supply, research workers have turned their attention to the influence of phosphorus on the physical properties of high-duty cast irons. The question is how far use can be made of high-phosphorus pig-irons of the Derbyshire and Northamptonshire types with phosphorus contents ranging from 1.2 to 1.6 per cent. Since each 10 per cent. added to any mixing will give a phosphorus increment of 0.12 to 0.16 per cent., it is obvious that only a very small proportion could be used if the usually accepted low-phosphorus levels are to be adhered to.

The graphs illustrated in Figs. 7 and 8 give the results of work not previously published concerning a series of experimental casts which have recently been examined with a view to establishing the effect of phosphorus on tensile strength and shock resistance as measured by modified Izod single-blow impact tests.

The first series consisted of B.S.S. 786, Grade II type cast iron containing about 3.2 per cent. total carbon, 1.8 per cent. silicon and 1.5 per cent. nickel, with phosphorus contents of 0.03, 0.18, 0.23, 0.42, 0.55, 0.65 and 0.75 per cent. Fig. 8 shows the effect of increasing phosphorus on the mechanical properties. The tensile tests have been carried out on 0.875-in. and 1.2-in. dia. test-bars (as cast) and machined to 0.564 in. and 0.798 in. dia. respectively. The modified Izod single-blow impact test pieces were machined from the 1.2 in. dia. tensile bars to the dimensions given in Fig. 9.

The conclusion which may be deduced from these tests is that the effect of total carbon content is more important than the effect of phosphorus in the lower phosphorus ranges. Thus the points for the iron with 0.23 per cent. phosphorus fall below the curves for tensile strength and above for impact value, whereas the points for the iron with 0.42 per cent. phosphorus fall above the tensile strength curves

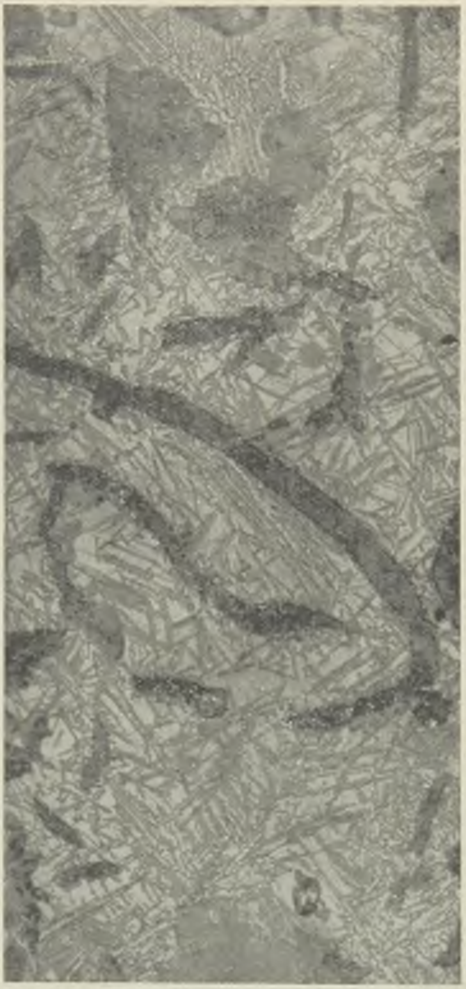


FIG. 6.—AS FIG. 5 BUT ETCHED WITH 4 PER CENT. PICRIC ACID IN ALCOHOL, × 500, SHOWING ACICULAR STRUCTURE WITH MEDIUM GRAPHITE IN RANDOM ARRANGEMENT.

and below the impact value curve. This is because, at 0.23 per cent. phosphorus, the total carbon content of the sample was too high (3.37 per cent.), and at 0.426 per cent. phosphorus was too low (2.96 per cent.). The general tendency is a slight increase in tensile strength initially, say up to 0.35 per cent., and a steady decrease after that. The impact value, on the other hand, shows a steady decline as phosphorus is increased.

The general conclusion may be deducted that up to 0.6 per cent. phosphorus, in this type of Grade II iron, there is little loss in tensile strength but a considerable reduction in impact value.

Fig. 8 gives graphs for a similar series of tests on a Grade III cast iron, having the general composition as follows: Total carbon, 2.9; silicon, 2.2; nickel, 1.5; and molybdenum, 0.5 per cent., with phosphorus 0.03, 0.03, 0.09, 0.20, 0.42, 0.63 per cent.

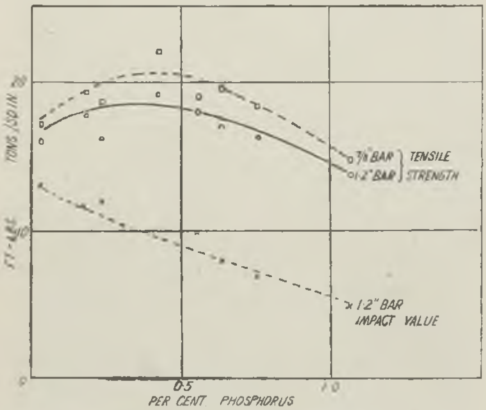


FIG. 7.—EFFECT OF PHOSPHORUS ON THE MECHANICAL PROPERTIES OF GRADE 2 (B.S.S.786) CAST IRON.

In a similar manner to the Grade II series, unintentional variations in the total carbon content have a greater effect on the tensile strength than phosphorus. If all the irons in the series had been at exactly the same total carbon level, the tensile strength curves would have been flatter, since at 0.2 per cent. phosphorus the total carbon content was low (2.8 per cent.), whereas the two higher phosphorus irons were rather high in total carbon (3.02 and 3.06 per cent.).

The tensile strength curve shows the same general tendency as in Grade II but the strength definitely falls away more rapidly, showing that a maximum phosphorus content of 0.4 per cent. is the most that could be tolerated in this grade of cast iron.

The sharp drop in impact value on passing from 0.1 to 0.2 per cent. phosphorus in nickel-molybdenum Grade III iron is almost certainly due to the substitution of pearlite for shock-resisting acicular structure. In the case of pearlitic Grade III irons (without molybdenum) there is no reason to suppose that such a sharp change in impact strength would occur, though the shock resistance of the low-phosphorus pearlitic iron would no doubt be considerably below that of the acicular nickel-molybdenum type. The best phosphorus content for the acicular type would appear to be 0.1 per cent., giving a satisfactory compromise between tensile strength and impact value.

This work is still in progress and from a

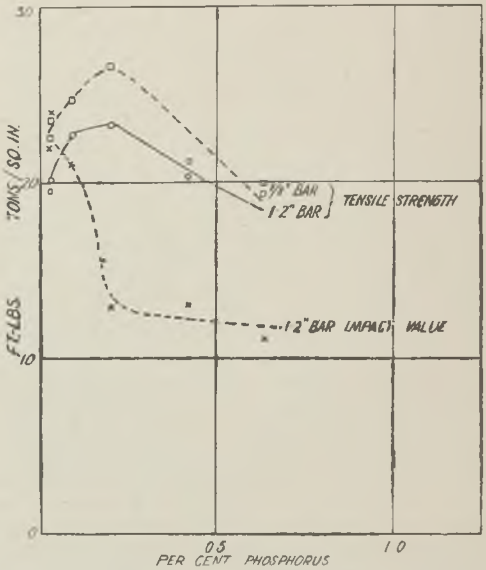


FIG. 8.—EFFECT OF PHOSPHORUS ON THE MECHANICAL PROPERTIES OF GRADE 3 (B.S.S.786) CAST IRON.

recent study of commercially-produced cupola cast irons of acicular structure this low phosphorus limit may be increased if the nickel and molybdenum contents are also increased.

Probably owing to the method of manufacture and raw materials being used to get the range of phosphorus contents without having recourse to ferro-phosphorus additions, the general tensile strength level is low in both series, but this does not detract from their value in showing the effect of phosphorus on the physical properties, provided due allowance is made for unintentional total carbon variations.

From the above it can be deduced that for Grade II iron, up to 30 or even 40 per cent. high-phosphorus pig-iron may be used in conjunction with steel scrap and/or refined pig-iron with very low phosphorus content.

Overcoming the Difficulty

For Grade III irons this would have to be limited to about 20 per cent. of the charge, but in the acicular-structure cast irons, the state of present knowledge indicates an upper limit of about 10 per cent. However, if ample supplies of steel scrap are available, synthetic pig-iron could be produced first and remelted as part of high steel-mix charges, so that each ton of phosphoric pig-iron when melted with steel scrap and ferro-alloys might produce 5 to 20 times its own weight of high-strength cast iron by this means.

From the practical point of view, the above requires some qualifications. Even in Grade II irons it may be advantageous to limit the phosphorus content to perhaps 0.3 to 0.4 per cent. in complicated castings liable to exhibit liquid shrinkage porosity troubles.

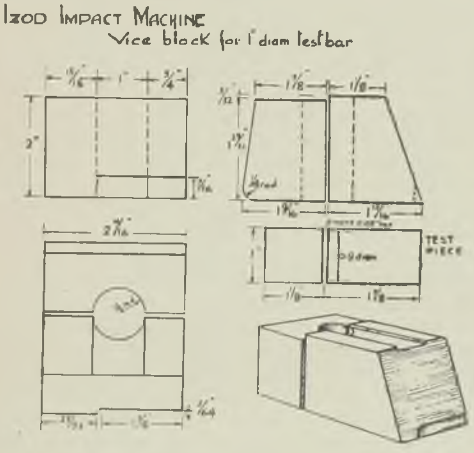


Fig. 9.—Design of Impact Testing Machine Used.

In conclusion, this Paper has been intended primarily to show that really high-strength alloy cast irons can be produced regularly and successfully using the cupola as the melting unit. This, of course, is coupled closely with good foundry practice, and much could be said about branches of this technique, such as the study of self-feeding methods, methods of running castings, and use of denseners to control solidification, etc.; but that is beyond the scope of the present Paper. It will suffice to draw attention to the fact that high-duty cast irons are usually associated with applications which call for high perfection of finish and complete soundness of the metal structure throughout. In a great many cases the application will be for "machined all over" castings and castings which require to be completely pressure-tight under exacting conditions. Thus the foundry technique, although not calling for anything very different from that required in the production of good-class engineering castings, must be of an order that will take care of the above conditions.

ADDITIONAL INFORMATION GIVEN TO THE LONDON BRANCH

B.S.I. Specification for Cast Iron

The iron foundry trade has made great efforts during the last few years to bring about improvements in the properties of grey cast iron, and more especially to produce a series of products of consistent quality. Every possible means of improvement has been studied, but special attention has been paid to obtaining higher strengths, coupled with greater uniformity of structure in castings of complicated design and where widely divergent sectional thicknesses are exhibited in one and the same casting.

The B.S.S. for general iron castings No. 321 drawn up in 1928 enumerated two grades, the highest minimum tensile strength being that called for in Grade C, namely, 12 tons per sq. in. on 0.785 in. dia. test bars as cast, the corresponding figures for 1.2 in. and 2.2 in. dia. test bars being 11 and 10 tons respectively.

During 1938 a new British Standard Specification 786 was issued to cover high-duty cast irons. This specification detailed three grades of high-duty cast iron, the highest grade, number III, calling for a minimum tensile strength of 22 tons per sq. in. on 0.785 in. dia. test bars, with corresponding values of 18 and 15 tons from Grades II and I.

Although for several years previously alloyed and special process cast irons had been used to meet specifications calling for over 22 tons per sq. in. tensile strength, the issue of this new B.S.S. specification did much to bring high-strength cast iron to the notice of engineers. It is interesting to note that 786, Grade III, calls for nearly double the highest strength called for only 10 years previously. Of course, this does not mean that cast irons of higher tensile strength were not being made in 1928, but until 1938 there was no British Standard Specification which could be quoted. A still higher strength grade has recently been added, namely Grade IV, with a minimum tensile strength of 25 tons per sq. in. on the 0.875 in. dia. bar.

The question immediately arises in any gathering of foundrymen, what is the best, easiest, and most economical method of meeting these specifications for any particular application, and what are likely to be the founding difficulties. During more normal times when choice of raw materials is almost unlimited there are, comparatively speaking, very few real difficulties, but at present choice of raw materials tends to be somewhat limited.

Broadly speaking, the easiest and most reliable method to produce castings to meet B.S.S. 786, Grades II and III and IV, is by the use of alloy additions to base compositions, in which the various elements are suitably controlled and for the two higher grades it is usual to make use of processed cast irons. By that it is meant processed in the liquid condition and not by after treatments, such as quench and temper methods. For the high strength cast irons this usually entails the use of comparatively low phosphorus materials and, in the case of Grade IV, probably quite low phosphorus contents.

Hematite and other low phosphorus pig-irons, and even medium phosphorus pig-irons of the true Scotch type, together with refined irons, are in short supply, as far as the ironfoundry trade is concerned, therefore this has led to much consideration being given to choice of basic raw materials for all iron castings being made to comply with the requirements of the higher specifications.

Simultaneously with this, there has been a greatly increased demand for high strength iron castings for special applications, in many cases as a supplementary material to replace steel castings and forgings where a non-ductile material is suitable, provided its other physical properties such as resistance to impact, toughness, etc., are satisfactory.

Meeting Modern Requirements

In order to meet B.S.S. 786, Grade II, consistently the use of alloy cast irons of suitably controlled composition has been widely accepted. In the same way it has been found necessary to make use of special process and alloy cast iron to obtain a tensile strength of 22 to 24 tons per sq. in. to meet the requirements of Grade III. As already indicated, foundrymen now have to be prepared to meet a still higher grade with a minimum tensile strength of 25 tons per sq. in. on the 0.875-in. dia. test-bar as cast. In practice this means that average figures of 26 to 28 tons per sq. in. must regularly be obtainable in order to allow for a reasonable margin of strength above the absolute minimum. To-day alloy cast iron with a tensile strength of 28 to 32 tons per sq. in. in the as-cast condition, *i.e.*, without any after process such as heat-treatment can be regularly produced in any foundry possessing a reasonably modern cupola furnace if full use is taken of the alloys available.

Before dealing with types of cast iron and ranges of composition in alloy and special process cast irons in detail, it may be worth while to consider for a moment the main reasons for adding alloying elements to cast iron and consider the broad tendencies exhibited by various commonly recognised elements either used singly or in a variety of combinations. The main alloying elements used are nickel, copper, chromium, molybdenum and less frequently vanadium, titanium, aluminium, boron, etc., together with silicon and manganese when used in amounts considerably greater than normally found in cast iron. Nickel, copper, chromium and molybdenum are the elements most frequently used to give increased strength to the matrix of cast iron used either singly or in various combinations.

Use of Alloy Additions

Better to appreciate the influence of alloy additions to cast iron it may be useful to consider very briefly the structure and constitution of cast iron. Cast iron is essentially an alloy of iron and carbon in which the greater part of the carbon separates in the form of graphite and a smaller proportion, generally ranging from 0.3 to 0.85 per cent., remains combined with the iron in the form of iron carbide. If the graphite flakes were absent, the strength of any cast iron would be equivalent to the strength of the matrix and alloy additions would bring about changes in physical properties such as tensile strength, very similar to that ruling in alloy steels. This, of course, is not true since all types of grey cast iron, whether alloyed or not, contain free graphite and it is obvious that the graphite particles possess practically no tensile or shear strength. Therefore the ultimate physical properties exhibited by a cast iron having any particular type of matrix structure will depend on the amount, size and distribution of the graphite flakes, since cast iron acts in many respects as though the graphite flakes were a series of voids in the metal.

Alloy additions produce two distinct effects in grey cast iron. In the first place they will act in such a way as to accelerate or retard the graphitisation process and to vary the size and shape and distribution of the graphite. In the second place alloying elements when added to cast iron may also produce a beneficial effect on the matrix by alloying directly with the iron constituent. Speaking very broadly, most of the alloy additions, all other conditions, such as base composition, rate of cooling, etc., being equal, tend to yield stronger, harder and more dense matrix structures.

Both the above tendencies produce changes in the physical properties, and much research work has been done in recent years to make the greatest use of this in order to obtain easily controlled methods of greatly enhancing the quality of grey cast iron.

Briefly, the alloying elements may be classified into two main groups, namely, chill or carbide inducing elements and graphitising or chill restraining elements. The chief chill-inducing elements are chromium, vanadium and boron. These elements, by reason of being very powerful carbide formers, increase chill, stabilise carbides and refine and harden the matrix in pearlitic cast irons.

Chill-Restraining Additions

The chill-restraining elements most commonly used, apart from carbon and silicon, are nickel and copper, the latter only within the limits of its solubility. These two elements also refine and strengthen the pearlitic matrix. Other graphitising or chill restraining elements are aluminium, titanium and zirconium. Of these, aluminium acts like carbon and silicon, in that it produces ferrite and softens the matrix and also coarsens the graphite structure.

On the other hand, titanium, although producing ferrite with its softening effect on the matrix, when used in small quantities, particularly when oxide is present, strongly refines the graphite structure. Like aluminium, this element is also used on account of its deoxidising properties, and is very useful for that purpose, but both must be used with great discretion and normally only in small quantities, since bad effects are brought about by their indiscriminate use. In passing, it may be mentioned that titanium additions, while certainly refining graphite structures, may under certain circumstances lead to the formation of so-called "sooty" fractures, with weak dendritic graphite patterns, a subject which will be dealt with later in connection with the production of the highest strength grey cast irons.

Special Rôle of Molybdenum

In addition to the above, there is one other extremely important alloying element, namely, molybdenum, which has been described as neither a graphitiser nor a strong carbide former. Molybdenum is mainly used to increase the strength and shock resistance of cast iron, since its addition exercises a direct solid solution effect in the ferrite, a refining action in the matrix and an improvement in the size and distribution of the graphite.

The most striking improvements in the production of high-strength tough cast irons have been brought about by taking full advantage of the beneficial effects of combinations of nickel and molybdenum on the physical properties of grey iron.

In order to meet the requirements of engineers, foundry metallurgists have made use of the tendencies indicated above to promote the following properties in cast iron, *viz.*:—

(1) Uniformity of structure, particularly in castings of widely varying sectional thickness.

(2) Better physical properties, including higher tensile and transverse and compression strength and resistance to shock, etc.

(3) Improved wear resistance.

(4) Improved heat resistance.

(5) Improved corrosion resistance.

(6) Improved machinability when correlated with any or all of the above improvements.

(7) Reliability and uniformity of output, etc.

Cast irons of higher strength and shock resistance, being of most general interest to foundrymen and engineers, will be discussed in detail, but special-purpose alloy cast irons prepared particularly for their wear, heat and corrosion resisting properties, will be excluded.

Current Practice for Meeting B.S.S. 786

The usual method adopted by foundrymen to meet B.S.S. 786, Grade II, is to use a base cast iron of suitably controlled composition, with the addition of nickel and/or copper in quantities varying between 1 and 2 per cent. Nickel is normally preferred to copper since the solubility of copper in cast iron is strictly limited and in practice is often erratic. Provided the total carbon content of the base iron does not exceed 3.2 per cent., there is little difficulty in meeting the specification of 18 tons per sq. in. minimum tensile strength. Such cast irons may have a phosphorus content of up to about 0.6 per cent. without experiencing any considerable loss in tensile strength, but their shock resistance as measured by single blow impact tests will gradually decrease as the phosphorus content is increased.

Although the middle grades of processed cast iron such as Meehanite cast iron, Grade C, mostly without alloy additions have mechanical properties sufficiently high to meet this grade, low nickel cast irons in this category exhibit extremely good machining qualities, take a high quality finish and are generally foolproof. Furthermore, they can be produced in any foundry without special equipment and with very little metallurgical control. Their wear resistance is also good, but this can be further improved by the addition of chromium in the ratio of 0.5 per cent. chromium to 1.5 per cent. nickel, but usually at the sacrifice of some degree of machinability.

With regard to actual uses, cast irons to meet B.S.S. 786, Grade II, are being used generally for medium duty applications, such as machine tool castings of the highest quality, pressure-tight castings, automobile and diesel engine castings, and a host of other castings where uniformity of structure, moderate strength, machinability and wear resistance are required coupled with reliability and ease of production in any foundry.

In order to meet the requirements of Grade III, 22 tons per sq. in. minimum tensile strength, the same type of cast iron, *i.e.*, with 1 to 2 per cent. nickel, with the addition of 0.3 to 0.5 per cent. molybdenum, is useful, particularly where comparatively small tonnages are required in foundries lacking the necessary metallurgical control for the production of the processed types of high-strength alloy cast iron.

The production of these special process cast irons such as Ni-Tensyl iron and the highest grades of Meehanite are governed by British patents and therefore it is impossible to give exact details of foundry methods. It will be sufficient to indicate that the processes are based on the use of high steel charges followed by late applications of graphitising agents such as ferro-silicon, calcium silicide and other graphitising agents.

In cupola practice, the amount of steel scrap used—usually upwards of 50 per cent.—together with the technique of melting, controls the amount of total carbon in the resulting cast iron, the amount usually being in the range 2.6 to 2.9 per cent. The late addition of suitable graphitising agents also controls the size, arrangement and distribution of the graphite flakes.

Meeting Grade IV with Pseudo Austenitic Irons

Amongst Grade III materials Ni-Tensyl iron in particular is being very extensively used where tensile strengths in the order of 22 to 26 tons per sq. in. are required with some increase in shock resistance over good class engineering cast irons. As a material to replace and supplement steel castings and forgings it has been used for some very interesting applications. When alloyed with a small percentage of molybdenum in the range 0.3 to 0.5 per cent., its strength and shock resistance can be considerably increased and will achieve the mechanical properties appertaining to Grade IV with a minimum tensile strength of 25 tons per sq. in. These grades with a tensile strength in the range 22 to 26 tons per sq. in. may be described as the general utility high-strength cast irons. The matrix in the as-cast condition usually consists of very fine pearlite. Although it is not uncommon for such materials to exhibit Brinell hardnesses up to 300, they are quite readily machinable and their wear resistance is good.

Standard compositions may be modified to meet special requirements; for example, for highly stressed gears required to have both strength and wear resistance. Nickel-chromium-molybdenum Ni-Tensyl irons are in many cases very suitable.

The range of application of Grade III and Grade IV alloy cast irons, particularly Ni-Tensyl iron, is too wide to give in detail, but it will be sufficient to indicate that they are being regularly used for motor vehicle castings, diesel engine castings, etc. Nickel-molybdenum Ni-Tensyl iron is particularly suitable for pistons, cylinder heads and cylinder blocks in high-speed supercharged types of diesel engines. Often strength and wear resistance have to be coupled with freedom from any risk of picking up or galling under very severe conditions and with extremely limited clearance tolerances under high-speed lubricated rubbing conditions. Other important fields of application are for dies, gears, hydraulic castings, air and gas compressors, highly stressed components of special process plant such as mechanical, hydraulic and pneumatic presses, frames of tools such as steam and compressed-air hammers, stone crushers, etc. One great advantage to the engineering trade is the comparative ease with which Ni-Tensyl iron and similar irons may be cast into complicated designs without after-treatment, thus ensuring speedy deliveries.

They do not exhibit the same degree of liquid shrinkage porosity difficulties in unequal sections as is experienced in the production of steel castings. Hence their immense value to the engineering industry under present conditions.

Industrial Applications

Recent evidence of their usefulness to replace steel castings and forgings where a non-ductile material is suitable, is forthcoming from a section of the machine tool industry handling special purpose lathes. Ni-Tensyl irons, particularly those with small molybdenum additions and meeting the requirements of Grades III and IV, are being used extensively for such components as headstock spindles, helical tooth driving gears, sliding gears, tool holders, spindle couplings, forming and profiling cams as well as horizontal tailstock and collet cylinders in hydraulically operated lathes. These components would normally be made from steel forgings or in the case of the hydraulic cylinders from gunmetal and similar copper alloys.

The new Grade IV specification has recently stimulated much additional interest in the use of high-strength cast iron, particularly when a grade can be obtained which has normal properties well in excess of the minima called for, and also has greatly increased shock resisting qualities. The Grade IV specification was suggested primarily at the instigation of engineers who require a still higher strength cast iron, mainly for applications where a non-ductile material will replace or at least supplement the use of steel components.

Suggested Methods

When contemplating the best method to be adopted to meet this highest cast iron specification, it must be remembered that, when dealing with the range over, say, 24 tons per sq. in. tensile strength, each additional ton of strength specified is more difficult to achieve than when dealing with the range 12 to 20 tons per sq. in. One method is to apply normal quench and temper heat-treatments to Grade II and Grade III cast iron, but this process is outside the scope of the large majority of foundries, particularly even the best jobbing foundries. It is not readily applicable to any but relatively simple designs of castings, such as bushes, liners, gear blanks, etc. One would not willingly attempt to heat-treat by quenching methods complicated castings such as automobile and diesel engine cylinder blocks and cylinder heads for obvious reasons. All high strength castings benefit, of course, from low temperature stress-relief heat-treatment.

Although molybdenum bearing Ni-Tensyl iron will meet the minimum requirements of the new specification, nickel-molybdenum cast irons of somewhat higher alloy contents should prove very attractive to the iron foundry and engineering trade as a reliable method for obtaining really high strength cast iron capable of being produced from cupola melted metal.

An Ultra-Strong Iron

When discussing the individual influences of alloying elements on cast iron, it was observed that molybdenum is neither a graphitiser nor a strong carbide former, yet it exercises a profound influence on the shape and distribution of the graphite flakes as well as refining and strengthening the matrix to a marked degree. Additions of molybdenum up to about 1.5 per cent. bring about a very substantial increase in the tensile strengths of cast irons of suitable base composition. Advantage of this property has been taken for a number of years, but recently more attention has been paid to nickel-molybdenum cast irons, with alloy contents of 1.5 to 3.0 per cent. nickel and 0.7 to 1.0 per cent. molybdenum. In fact, various authorities have shown that suitable combinations of nickel and molybdenum produce the maximum beneficial effect on the properties of true grey cast iron so far observed.

This effect combines high tensile strength, transverse strength, and deflection with intermediate hardness values (up to 350 B.H.N.) and outstanding machinability in relation to strength. Their resistance to shock is much in advance of anything previously achieved for grey cast irons with normal carbon contents. This type of cast iron depends for its properties on the formation of partially or wholly acicular or pseudo martensitic structures. They can be produced in routine practice with tensile strengths of 26 to 35 tons per sq. in. in the total carbon range 2.8 to 3.0 per cent., and are therefore readily produced from cupola melted metal.

Much lower total carbon contents were at one time considered to be essential to obtain castings with tensile strengths considerably less than this, and electric furnace irons held the field as being the ultra-strong cast irons with total carbon sometimes as low as 1.8 per cent. and bordering on the steel castings range. Here one is dealing with high-strength cast irons with a minimum carbon content of, say, 2.6 per cent., and in most cases not under 2.8 per cent.

The Acicular Structure

Acicular structures are a function of molybdenum, yet straight molybdenum cast irons have not been very popular. So far as present knowledge goes when dealing with cupola melted irons 1.0 to 1.5 per cent. molybdenum is necessary to produce an acicular structure in cast iron with a carbon content of 2.8 to 3.0 per cent., silicon being adjusted to suit the mass and sectional thickness of any particular type of casting. When 1.5 per cent. nickel is present the molybdenum content may be reduced to 0.7 per cent. for normal section castings up to, say, 1½ in. thick. Above that the nickel must be increased as the sectional thickness increases, but care must be taken not to over-alloy the material with the formation of true unmachinable martensite.

Practical Applications

So far most of the practical applications of acicular-structured nickel-molybdenum cast iron has been confined to rather lumpy thick section castings, particularly in connection with a variety of types of hot heading and forging dies and sleeves for specialised work. In these castings the alloy content, always assuming the carbon content is in the range of 2.8 to 3.0 per cent., must be regulated to the cooling rate and mass of the casting and not to test bars being cast with the job. For example, test bars of the 2.1 in. dia. or 1.6 in. dia. sizes may be martensitic, with a given alloy content, yet solid castings of 5 to 10 in. diameter can be fully acicular and machinable when poured from the same ladle of metal if the alloy content has been adjusted to the mass of the castings, and consequently is too high for the test bars.

A typical composition for castings over 1½ in. sectional thickness would be as follows:—T.C, 2.8 to 3.0 per cent.; Si, 1.8 to 2.8 per cent., according to mass of casting; Mn, 0.8 to 1.2 per cent.; S, 0.12 per cent. max.; P, 0.20 per cent. max.; Ni, 1.5 to 3.0 per cent., according to mass of casting; Mo, 0.7 to 0.9 per cent.

It will be noted that the phosphorus content is given as very low. This type of cast iron on account of its high strength and extreme toughness has been found extremely useful for hot pressing and forging dies, highly stressed sliding gears, crankshafts, camshafts, levers and numerous heavily stressed components. Even when the carbon content is increased to 3.3 per cent., as may happen under certain cupola operating conditions, tensile strengths over 28 tons per sq. in. will be maintained, provided the alloy content is adjusted to the mass of the casting. Its wear resistance is extremely good, and these properties appear to be retained up to quite heavy sections.

Limits of the Phosphorus Content

It has already been strongly emphasised that increase of phosphorus from, say, 0.3 to 0.7 per cent., or even 1 per cent., does not greatly reduce tensile strength in pearlitic cast irons (other considerations being equal), but this increased phosphorus does increase or widen the freezing range, at the same time lowering the temperature at which solidification commences. This extension of the freezing range does make such irons more difficult to handle in the foundry, for the production of complicated castings. A useful analogy may be taken from the founding of phosphor bronze. An alloy containing 10.0 per cent. tin and the balance copper has been stated to have a freezing range of approximately 140 deg. C. (1,000 to 860 deg. C. for complete solidification), whereas the same alloy with 0.5 per cent. phosphorus will have a freezing range of approximately 340 deg. C. (980 to 640 deg. C. for complete solidification). It is well known how difficult it is to produce sound castings of heavy section in this type of alloy in sand moulds. This is due to the long solidification period or wide freezing range, and to produce sound castings in this alloy it is essential to obtain rapid freezing by the use of chill or centrifugal casting methods.

Although the changes which have taken place in cast iron during the solidification are somewhat different and are also dependent on the carbon and silicon contents, it does show that the same main principles apply. With high-phosphorus cast irons, different methods have to be adopted to reduce porosity troubles compared with low phosphorus cast iron. These include extensive use of denseners, but far too often a passable looking casting is produced by means of puddle or rod feeding. This method naturally fails where pressure-tight castings of complicated design are being produced. High phosphorus, of course, is not detrimental to attainment of solidity if adequate feeding facilities can be provided, such as by means of self-feeding heads, progressive solidification, etc.

Unfortunately, the degree of liquid shrinkage tendency produced by phosphorus increments so far cannot be estimated accurately. Most of the various tests, such as the K-test piece and the dumbbell test piece, although useful in their own sphere, have not proved of great value to the practical foundryman. One design of test block which has not received sufficient attention is that suggested by Mr. P. A. Russell. It consists of a solid block, 4 in. by $3\frac{1}{2}$ in. by 3 in. deep, and presumably cast with a standardised runner and without any form of riser. Two holes are drilled $2\frac{1}{2}$ in. deep by $1\frac{1}{4}$ in. dia., leaving a wall of metal $\frac{5}{16}$ in. deep at the nearest point. One hole is drilled and tapped to take an adaptor for the application of a pressure test to the internal wall.

High Phosphorus and Moulding Technique

Moulding and core making practice for the production of high-strength alloy cast iron varies little for that adopted for ordinary grey iron being used for similar applications. Far too often the extra cost of feeding heads, moulding methods, fettling costs, etc., are cited. This is not strictly true since a very high percentage of all castings made in high-strength cast iron are of the machined all-over type, and in a great many cases require to possess a high degree of pressure tightness. Again, many such castings are heavy and massive, for instance, to take a very simple example, all types of dies. If these castings were made in common grades of phosphoric cast iron, to ensure complete freedom from liquid shrinkage defects, the same precautions would have to be taken, and even then the result would be hopeless because they would not be suitable for deep machining in heavy sections and would vary in structure from the skin so rapidly as to be useless. This is apart from all considerations of lack of strength.

Definite Recommendations

Consequently in producing castings in high-strength cast irons attention must be given to achieving complete soundness in all parts of every casting. Many methods and combinations of methods are used to obtain this, but they must all have as their primary object the equalisation of cooling rates in parts of varied thickness, or, in other words, they must aim at progressive solidification. The commonest methods employed are:

(1) Suitable distribution of runners to superheat the thin sections and so retard the cooling rates, and also keep the hottest metal away from the heavy sections. Moulds should also be filled uniformly, so that there is no tendency to create a hot and a cold side to the casting during cooling. For example, flat circular castings should always be run with ring type runners with ingates equally distributed round the castings, or in other cases be run from a central point. Long cylindrical castings should invariably be

run from the top, with the addition, when absolutely necessary, of auxiliary or rather initial bottom running to provide a cushion or buffer for the stream of metal from the main hot runners. It is very bad practice to run such castings from the bottom only because the bottom of the castings and mould surface thereat is being superheated. Instead, top runners should be used to promote progressive solidification from the bottom upwards.

(2) Progressive solidification may also be encouraged by the use of suitable external denseners.

(3) In lumpy, heavy section castings, self-feeding heads of correct design and bulk are very effective, although they may entail extra cost in removal and remelting of surplus metal. This feature of increased cost has unfortunately been grossly over-stated by engineers and machine shop executives. After all, it does not cost any less to part off a short straight feeder than it does to remove a correctly proportioned feeder.

(4) Precautions should be taken to ensure ample rigidity of the mould and core structure in such a way that resistance is offered to the expansion which takes place prior to solidification due to graphite formation. This, of course, must be tempered with discretion to avoid hot tears and cracks.

(5) In many cases so-called steam-feeding may be used with advantage.

(6) Small parallel risers should be rigidly avoided. By all means use pressure relieving poppers or whistlers on the highest points, but do not use other types of risers which will solidify long before the portion of the casting directly beneath has set. How often in all kinds of grey iron castings does one find liquid shrinkage porosity immediately beneath risers. On no account should rod or puddle feeding be employed unless solely for the purpose of preventing the top of a self-feeder from freezing too early or used with " off the casting " feeders.

(7) Slow running methods may sometimes be used with advantage, taking care that the rate of pouring is really slow and the metal used is at a sufficiently high temperature.

Since all high-duty cast iron must be poured at a high temperature other difficulties may arise, such as distortion of cores, where large masses of metal surround comparatively small and fragile cores, but with sufficient ingenuity these factors can easily be overcome.

LANCASHIRE BRANCH DISCUSSION

Melting Losses

Mr. C. R. van der Ben congratulated Mr. McRae Smith on the way in which he had dealt with the subject of high-duty cast irons, and the development of the acicular or pseudo-martensitic structures, which, besides being one of the latest phases in the production of cast irons, was of extreme importance. Mr. McRae Smith knew that the company with which he (the speaker) was associated, was probably one of the first in the country to undertake the manufacture of such high-duty cast irons. Their extraordinary toughness was undoubtedly a particularly outstanding feature.

Mention had been made of the loss of carbon on melting in rotary furnaces. Personally, he had not had that experience. He was operating a rotary furnace and the loss of total carbon involved was negligible. The question of adjusting total carbon in such an iron was a different matter. This was found to be a difficulty, but the actual loss of carbon itself was not a serious factor.

Stress had been laid on the fact that high-duty cast irons could be produced of the order of 3 per cent. total carbon or even more. This, apparently, was extremely important, for every point below 3 per cent. doubled the founder's difficulties. He thought that was the general opinion nowadays.

Cupola Operation

A serious practical point to be noted in connection with the production of high-strength irons in the cupola had reference to the operating conditions necessary to be developed in the cupola. If a cupola were run entirely for such irons, then everyone in the foundry could be happy, but if about two tons of high-duty iron were required, and then only common irons in the afternoon, the foundryman was faced with a difficulty. The normal operating conditions of the cupola would not meet the case for a 2.9 per cent. carbon iron. If any attempt were made to modify the cupola conditions in the middle of a blow, the desired iron would not be obtainable, and there could be no casting from the cupola for the rest of the day. In many cases the difficulty was solved by the use of a small separately-melted charge of very low-carbon material, which could be added to the normal cupola 3.3 per cent. carbon iron. This was a very convenient way of obtaining 3 per cent. carbon iron from a cupola.

Mention had been made of the standard size of the metal charge in relation to a depth of coke of about 6 to 8 in., and the loading of 8-cwt. metal charges with a 48-in. cupola. He feared that Mr. McRae Smith would not get 6 to 8 in. of coke in such a case.

The development of the acicular structure had been made possible through the use of molybdenum in irons. He had personally spent a considerable amount of time developing molybdenum irons, and then with the usual human perversity had tried to eliminate them. He believed it was possible to produce a pseudo-martensitic structure without the use of any alloy.

Properties of the New Irons

Mr. McRae Smith said that Mr. van der Ben was one of the pioneers in this country who had dealt with the acicular structure of cast iron. There had been quite a considerable amount of work done in America, though it was not done in exactly the same way that Mr. van der Ben had been doing his. This work was now being developed in this country for what might be termed war-time uses. He would like definitely to stress the fact that it was the toughest form of high-strength true cast iron obtainable, and its properties were rather amazing.

Carbon Losses in Rotary Furnaces

With regard to loss of carbon in rotary furnaces, he noted that Mr. van der Ben had not experienced any excessive loss. Perhaps his own remarks had not been sufficiently clear concerning this point. What he really meant was that, in order to obtain in a rotary furnace a cast iron of about 3 per cent. total carbon content, much steel scrap could not be used, because there was extreme difficulty in recarbonising a charge in a rotary furnace. He had to deal with such cases from time to time, and he was aware of instances where foundries had tried to recarbonise with hard gas carbon, but attempts were never very successful. It should be borne in mind, however, that he was not seeking to criticise the uses of the rotary furnace, although they had heard a great deal in the earlier days of rotary furnaces that it would be possible to melt 100 per cent. borings and all the " muck " left over in foundry yards and still obtain good castings; yet in certain furnaces in the country the carbon loss was very considerable. He was aware of other cases, in addition to that of Mr. van der Ben, where this was not so. At the same time, one could not run a 60 to 70 per cent. steel charge in a rotary furnace and get 2.5 to 2.8 per cent. total carbon.

He agreed that when really high-strength irons with 3.1 per cent. total carbon could be obtained it was very desirable, because their castability was very good. If one carried inoculation or late silicon addition or addition of other graphitisers to a degree greater than that which was originally intended, instead of adding 0.3 to 0.5 per cent. silicon, when thinking of irons of 2.6 to 2.8 per cent. total carbon range, this enabled one to get a balance up to about 3 per cent. silicon. If up to 1 per cent. of the silicon was added in the form of late silicon addition, then the castability was really good; otherwise he agreed with Mr. van der Ben that for every 0.1 per cent. of carbon reduction, foundry troubles were greatly increased. Carbon-silicon balance must be maintained if good castability was also to be retained.

Meeting Variable Demands

Actually he intended to speak about the question of making small quantities, say 2 tons, of high-duty cast irons along with other work, but he had had to curtail his Paper somewhat. Nevertheless, it did present a great difficulty. In the case where, with a 4 tons per hr. cupola. only 2 tons of metal were required, if high-duty iron was to be produced, it was very handy to be able to make a little synthetic pig-iron with the first ton of material. After that it was not difficult. and the required number of charges were put on in order to get the 2 tons of iron. There was great difficulty, however, if the 2 tons of special iron were charged during the middle of a blow.

A great many foundrymen were still of the opinion that if about 50 lbs. of coke were put on as an extra split, then the trouble was over. It would be found, however, after running on a high-phosphorus iron after a low one. that the phosphoric iron had crept down the cupola, and there would be about 0.6 or 0.8 per cent. of phosphorus in the high-duty iron. There were two practical methods of dealing with it. One was simply to blow down, re establish the bed, and charge again. The other way was to have a low-phosphorus iron or type of iron as near as possible in base composition to the high-duty cast iron to follow, and then go over to the common, higher phosphorus grade.

With regard to duplexing, a small electric or even an oil-fired crucible furnace might be very useful in order to make a really low-carbon material of 1.0 to 1.5 per cent. total carbon, preferably if using alloys, and mixing the correct proportion of this with a cupola metal of about 3.2 to 3.3 per cent. total carbon.

He might have been somewhat mistaken in mentioning 8 cwts. He forgot whence he obtained the actual figure. As a matter of fact, he thought it was a mistake for a 48-in. cupola, and he would check the figure. It should be borne in mind that he was speaking of an 80 per cent. steel-mix charge and the coke ratio would be high.

Stress Relieving

In regard to Mr. van der Ben's statement concerning the development of acicular structures without alloys, he was aware that there might be important possibilities in that line before very long. Perhaps suitable heat-treatments might give acicular structures. His own idea was to produce the high qualities in cast iron " as cast." By all means give stress-relief annealing at a temperature of 400 to 450 deg.

C., and on soaking eliminate internal stress, which was an artificial way of doing what engineers used to do by weathering castings for long periods.

The Rôle of Phosphorus

Mr. E. Longden said that the strength of cast iron depended upon the constituents present, particularly carbon. The lower the percentage of phosphorus the stronger the iron would be, other factors being equal. The useful upper phosphorus limit shown on the graph was around 0.3 per cent. Was it possible to understand the mechanism of this beneficial effect of something like 0.3 per cent. of phosphorus? Was it because the metal had better feeding properties? It was known that short freezing ranges caused a closer grain. This part of the action of phosphorus was not quite clear to him, and he would be grateful for any information which could be imparted.

It was noted that Mr. McRae Smith was not demanding the operation of cupolas on economical lines. The coke consumption to the author was not a matter of any great importance, and it was to be agreed that the first and most important matter for consideration was the best quality of iron. It was noticeable, however, that while using quite considerable quantities of coke, Mr. McRae Smith obtained low-carbon irons. This was due to the rapid rate of melting. Mr. Longden assumed that the blast was increased over normal theoretical ratios, etc.

The Newer Range of Irons

There were many types of high-duty irons on the market, but the latest development was something of an eye-opener with regard to strength. Having referred to Ni-Tensyl iron, Mr. Longden then mentioned that Meehanite would give a tensile strength of 20 to 28 tons.

Hot Mould Irons

Reference had been made to hot-mould irons which were really not very high-tensile irons, but which gave a tensile strength of something like 18 to 20 tons and were remarkably resistant to impact. Hot-mould iron was definitely of a very high order and standard so far as impact values were concerned. One could suggest anything between 10 or 1,000 per cent. more in yield. They were remarkable irons for withstanding impact values, and he could say that from experience. Another iron which was definitely a low-carbon iron should be really beyond the definition of cast iron, *i.e.*, Corsalli iron, for which 60 tons per sq. in. was claimed. It was to be presumed that that figure would relate to heat-treated iron, where the greater strengths were obtained with pearlitic structures.

There was a special high-duty iron which had a high silicon content of 3 per cent. and a high carbon content of 3.5 per cent. There was no pearlite, and yet there was a high-strength material of up to 28 to 30 tons. Thus high-duty cast irons were being very much developed, and great credit was due to those who had brought about this latest form of high-duty cast iron.

Phosphorus Content and Physical Properties

Mr. McRae Smith was pleased that Mr. Longden had mentioned the 0.3 per cent. phosphorus content, but it was something about which he could not give a definite answer. He did know that it was a fact and the graphs incidentally had shown this rather well. It was a point upon which work was being done at the present time in connection with high-duty irons. He was inclined to agree that the difference between 0.1 per cent. and 0.3 per cent. phosphorus might extend the freezing range in the same way as different amounts of phosphorus in a phosphor bronze extended it. It might give some degree of extra feeding quality and thus produce a sounder structure of greater strength. This referred only to pearlitic cast irons and not to the acicular structure irons.

The strength of the cast iron mentioned was dependent upon the strength of the matrix, and this was broken up by graphite. The breaking up by graphite did not necessarily mean that it had to be small and fine graphite, as everyone was inclined to think at one time. It must be a random, ragged structure which permitted the matrix to do its work and withstand stresses.

Coke Consumption

With regard to coke consumption, he had mentioned a 36-in. to 48-in. coke bed. This was essential as a pre-heating device. It was not for melting the metal, and the bed reached its own level. The split coke should not be much greater than that required for ordinary phosphoric cast iron, except that allowance must be made for the absorption of carbon into the steel.

Regarding impact tests on a hot-mould iron, he knew Mr. Laing would agree with him that the single-blow Izod impact type of bar shown was really developed in connection with Lanz-Perlit iron. Although some extremely high figures had been obtained by the Lanz process, particularly with Izod bars taken out of billets 8 or 10 in. in diameter, unfortunately the results were very erratic. Lanz Perlit iron was never meant to be used as a high-strength iron, but its shock resistance was good.

Border-Line Processes

He was not particularly familiar with the Corsalli process, but as far as he knew it aimed at producing in the cupola a cast iron with low total carbon in the range of 1.0 to 1.4 per cent. The material is not really a true cast iron, but rather a border-line material, more related to cast steel. In the as-cast condition an average tensile strength had been quoted of 33 tons per sq. in. A much higher-strength low-carbon cast material was the Ford alloy cast crankshaft, but this also should not be classed as a cast iron. It was a cast crankshaft as opposed to a forged crankshaft.

He had heard of the Schüz process, but did not know very much concerning it. In addition to some of the irons he had already mentioned, 30 or 33 per cent. chromium irons were interesting. They were not used for their strength, but for their corrosion-resisting and wear-resisting properties.

Composition and All-Pearlitic Structure

MR. VAN DER BEN said that, when viewing cast iron under the microscope, it was possible to obtain a pearlitic structure with combined carbon of roughly anything from 0.65 per cent. minimum. The effect of the phosphorus might have some bearing upon this. The effect of the addition of phosphorus to a pearlitic iron containing 0.65 per cent. of combined carbon would probably tend to throw the true structure of the iron more towards the higher combined carbon content. In other words, the addition of phosphorus might perhaps in some respects be similar to that obtained by a reduction of silicon, and in consequence the strength increased.

Lately his thoughts had been rather running in that channel; namely that the increase in phosphorus was really doing much the same thing as if an increase of strength was obtained by a reduction in silicon. In other words, phosphorus tended to annul the slight excess of pearlite which was obviously present, and yet did not show in the microstructure as free pearlite.

MR. MCRAE SMITH said this point had always puzzled investigators in the field of cast iron. As Mr. van der Ben had stated, it was possible to obtain a fully pearlitic cast iron with only about 0.65 per cent. combined carbon, while another one would approximate to saturation point.

MR. LAING said that the lecturer had referred to the height of the cupola as being from the top of the tuyeres to the charging door with 15 ft. maximum. He would suggest 18 ft. might be desirable in any size of cupola. There seemed to be a tendency to scaffolding with cupolas when taken beyond those heights. During the past week or two he had noticed an article in "The Foundry Trade Journal" recommending a lower height.

Shape of Cupolas

MR. MCRAE SMITH said that perhaps he was somewhat of a faddist concerning high cupola stacks and with regard to obtaining all the advantages of pre-heating. By small cupolas he was speaking of 30 in., and then probably 12 ft. would be a better height than 15 ft. As far as scaffolding was concerned, he had not spent a great deal of time in considering the matter. If a furnace lining was kept definitely parallel and the charges were not too large, there should not be much trouble with scaffolding.

MR. LONGDEN inquired as to the incidence of blast pressure.

MR. MCRAE SMITH said that if there was to be a long pre-heating zone, or the length between the top of the tuyeres and the bottom of the cupola charging door was greater than normal, the fan would have to be satisfactory. A correct volume was maintained, and the blast pressure was suitably adjusted, because very well distributed blast pressure was necessary. There should be air distribution right into the centre, and yet there should not be such a low pressure that the air was only creeping round the walls.

He had not seen the report Mr. Laing mentioned concerning short cupolas, but he had often found in the light-castings trade in particular that cupolas which were installed perhaps a couple of years previously were very short. He thought it was a question of saving steel and bricks.

MR. J. JACKSON referred to the statement about keeping a cupola perfectly straight. Many cupolas were made perfectly parallel every day, the very large bellied portion in the melting zone being carefully patched. Yet by making such a curved section in the melting zone the cupola patching had been reduced very materially.

Patching Problems

MR. MCRAE SMITH said the irons he had been speaking about were definitely high-strength irons, and for a few trades, particularly textile engineering, they were rarely necessary. What many people required was an accurately shaped casting, true to pattern, and of moderate strength. He disagreed with the idea that in making such high-strength irons an attempt was being made to turn out a poor substitute for steel. The irons had certain properties which were entirely different from those of steel.

In regard to the question of the patching and the keeping of the cupola lining parallel he was really thinking, when replying to Mr. Laing, of the old type of boshed cupola, which he did not like. Particularly when wishing to obtain accurate mixings, or even carefully controlled cast iron, there was likely to be trouble with this design of cupola shaft. As far as much patching was concerned, he would be rather inclined to think that the cupola was being severely over-blown. He appreciated the fact that the cupola was blown twice daily. A cupola should never be allowed to get into such a state. If it was necessary to put barrow-load after barrow-load of patching material into the cupola each morning, then there was something wrong with the cupola practice. It was not necessarily a question of eroding the lining; probably due to difficulties in drying and venting the large quantity of patching material, the lining would come down in any case. The patching in a cupola should be restricted and the blast conditions should be such that if a cupola was worn back 5 to 6 in. then it should be regarded as time to reline that part of the melting zone.

Liquid Shrinkage

Mr. H. Haynes was particularly interested in the comments regarding feeding and running and getting equal thickness of metal in order to avoid porosity due to liquid shrinkage. Would Mr. McRae Smith make a statement regarding the porosity due to liquid shrinkage in an 8-ton casting varying in thickness between $\frac{7}{8}$ and 3 in., if made in high-duty iron?

Mr. McRae Smith said that actually the freezing range of these high-strength irons was shorter than that of higher carbon irons, and shrinkage troubles were slightly increased in that respect. Correct carbon-silicon balance, however, allowed of good castability coupled with high strength. They were mostly low-phosphorus cast irons, however, and therefore there was not the shrinkage-porosity trouble experienced from a high phosphorus content. When lumpy castings were being produced it was necessary to have some sort of feeding head, of the correct shape and design. Mr. McRae Smith further illustrated the point by means of diagrammatic sketches on the blackboard with regard to shrinkage in Diesel liner practice and with regard to a plated flywheel made without rod feeding.

Continuing, Mr. McRae Smith thought that much might be done by a process of what he would term progressive solidification. This entailed much thought being given to design and distribution of runners, use of denseners, etc., with a view to superheating the mould faces in thin parts and selectively cooling others quickly.

Mr. A. Hopwood inquired what would be the effect on the structure of a quick cooling of any section in relation to the rest of the casting owing to the use of any material which would act as a densener or hasten the transmission of heat from one part to another. Was the acicular structure destroyed by the use of denseners?

Mr. McRae Smith was unable to say; he had not densened any casting with acicular structure. Nevertheless he did not think it would be destroyed unless the densener was too heavy. The real answer to the question was that denseners must be very carefully designed. The dimensions and mass of the densener must be such that there was no possibility of experiencing more than an equalisation of cooling. After all, it was simply a method of quick conduction of heat, which would give the same cooling rate on a heavy section compared with the lighter sections, which cooled off and consequently solidified more quickly.

Vote of Thanks

Mr. E. Longden, in proposing a hearty vote of thanks to Mr. McRae Smith for his extremely interesting and instructive Paper, said that an enormous amount of material had been dealt with, the implications of which could not be fully absorbed during the hearing of the lecture. Mr. McRae Smith was certainly doing much excellent work during the war period.

Mr. J. Laing (who has since died) seconded the vote of thanks, saying that he had been associated with Mr. McRae Smith many years ago, and therefore had some first-hand knowledge of his capabilities. The author had delivered a very practical, though somewhat academic Paper, and no doubt the skilled moulder would now better appreciate the metallurgical side of the high-strength irons.

The vote of thanks was carried unanimously.

Mr. McRae Smith, responding, said that the provision of steel scrap presented a certain difficulty, and he quite appreciated how foundrymen would feel about it. Actually, as he was going about the country on his particular present-day job, he found that as far as some localities were concerned the foundries had plenty of suitable steel scrap on hand, while others had difficulty in obtaining supplies.

LONDON BRANCH DISCUSSION

Mr. P. D. Pincott, who, after congratulating the author upon his Paper, said he had gained his first knowledge of acicular cast iron at the time when experiments on cast crankshafts were being carried out by a Northern metallurgist, who had obtained some rather staggering figures; having since been able to make a number of experimental casts, Mr. Pincott said he had to agree that results such as those referred to were obtainable.

Spanners Made in the New Iron

Describing a rather amusing and interesting experiment with which he had been concerned, he recalled that, in connection with the supply of refrigerating machines, together with their tool kits and spare parts, he had experienced great difficulty in obtaining supplies of forged steel spanners. Until that time he had visualised cast iron spanners only of the type used for assembling beds and probably clothes wringers, and so on. However, some spanners of the standard type were made in the new iron, the sizes being $\frac{1}{4}$ in. to $\frac{5}{16}$ in., $\frac{3}{8}$ in. to $\frac{1}{2}$ in., $\frac{5}{8}$ in. to $\frac{3}{4}$ in., $\frac{7}{8}$ in. to 1 in., and some 1.2 in. dia. test-bars were also cast. The tensile strength of that particular cast—it was not the first cast, incidentally—in the as-cast condition was 27 tons per sq. in.; the modulus of rupture was 47 tons, and the Brinell hardness was, roughly, 340. After heat-treatment at 350 deg. C., holding that temperature for 1 hr. and cooling in the furnace, the tensile strength of the spanners was $32\frac{1}{2}$ tons per sq. in., the modulus of rupture was 57 tons and, strangely enough, the Brinell hardness number was reduced to 300. In view of that experience, he asked for further information on the mechanics of the heat-treatment and its effect on the structure.

The tool-room foreman and his assistants had commenced their tests of the spanners by dropping them on the floor and subsequently by throwing them down, but they did not break. Then they had extended the tests, using a bolt, 2 or 3 in. long, held in a vice, and pulling the nut tight by means of the spanners. Finally, a 2-ft. length of tubing was placed on the end of the spanners, and the nut was pulled up tight, but the bolt had sheared and the spanners had not broken. They could be broken only by severe hammering, and all who were concerned with the experiments had been amazed by the results; even so, the spanners broke only through the jaws at the corners, where the section was relatively shallow. He confessed that in the course of those experiments he had found the iron particularly easy to handle and to work in the foundry. During the last four or five years he had been concerned with the making of cast iron crankshafts and, in view of the difficulty of obtaining steel forgings, the acicular iron was being used for extending the range of cast crankshafts. Everyone concerned seemed entirely satisfied.

With regard to the heat-treatment of relatively large castings in acicular iron, he asked if it were possible to use for that purpose a mould-drying stove, provided it was of fairly modern design, based on the forced-draft principle.

Stress-Relieving Heat-Treatment

Mr. McRae Smith, replying to the question concerning the heat-treatment of the acicular type of iron, said it would appear, from his own personal experience—and he believed that the work by the authority quoted by Mr. Pincott confirmed it—it was not amenable to the ordinary pearlitic cast iron treatment. However, with stress-relief annealing at about 350 deg. C., one obtained increased tensile strength, probably with some modification of structure, because there might be some austenite present in the as-cast condition as well as the pseudo-martensite. It was rather surprising that the Brinell hardness figure of the material mentioned by Mr. Pincott was reduced as the result of heat-treatment. He had not expected to hear that. Perhaps the temperature was slightly higher than 350 deg. C., or perhaps even a temperature of 350 deg. C. was a little too high for the composition of the metal dealt with. Bearing in mind that the tensile strength was increased, he said that perhaps there was a little pearlite in the structure which had resulted in the reduction of the Brinell figure to about 300.

The heat-treatment of such irons at relatively low temperatures was visualised; therefore, the ordinary foundry stove capable of giving even only 250 deg. C. would probably be quite suitable for giving that treatment.

Completing American Research Work

Mr. V. C. Faulkner asked, on behalf of Mr. G. R. Webster, whether the author favoured the use of receivers for dealing with the type of iron discussed in the Paper. Recalling that 0.4 per cent. was regarded by Americans as a high phosphorus content in cast iron, whereas in this country percentages up to 1.7 were being used, Mr. Faulkner suggested that the enormous amount of American research work which had been devoted to cast irons had had a profound effect upon our views concerning phosphorus content. It was up to the British, he said, to go further and to complete a good deal of the work which had been carried out by the Americans. Apparently in America there were but few irons containing more than 0.4 per cent. of phosphorus, and the Americans were amazed when they heard that we were using as much as 1.6 per cent. Finally, he mentioned that, in his experience, the melting of cast iron in the ordinary electric arc furnace was difficult, and he suggested that infinitely better results were obtained by duplexing from the cupola.

The Question of Receivers

Mr. McRae Smith replied that he did not favour the use of receivers for dealing with high-duty cast iron. Indeed, he personally did not like using ordinary receivers at all for cast iron, and contended that, using a cupola having a well of reasonable size, *i.e.*, a well capable of taking care of two charges at a time, one secured far better control than when using receivers. Most of the receivers installed in this country were for cupolas rated at, say, 4 tons per hr. and over, and the cupolas would have receivers with capacities ranging from 4 to 10 tons, or something of that order. The ordinary iron foundries of this country did not make use of individual receiver ladles of the American barrel type, which could be externally heated and used for superheating or for retaining the temperature of the metal at a definite level. These were excellent, and their use should be greatly extended in this country, but he did not like ordinary receivers.

The fact that in America the maximum phosphorus content was rarely over 0.4 per cent. in cast iron, and that 0.4 per cent. was regarded as a high phosphorus content, was due to the limitations of the types of iron ore available and pig-iron produced there. In the southern foundries of U.S.A. a small amount of pig-iron having a phosphorus content of approximately 0.7 per cent. was obtainable, but normally the phosphorus content was less than 0.4 per cent. The machine tool industry in this country provided a very good example of what could be done. The ordinary machine tool castings trade made extremely good castings with high-phosphorus iron, but for very complicated castings the material used should be comparable with the American iron. After all, a great many of the machine tool designs were of American origin, and such castings had been made in America in low-phosphorus iron. Naturally, therefore, makers of such castings in this country also preferred low-phosphorus iron. In view of the exigencies of the present time an endeavour had to be made to use high-phosphorus iron for additional types of castings, but it was extremely difficult, and it was necessary to modify foundry practice very much to ensure complete freedom from liquid shrinkage defects in complicated castings of diverse thicknesses.

For specialised products, such as automobile cylinder liners, piston rings, and so forth, fairly large tonnages of high-duty cast iron were being melted in electric furnaces, but he did not think that much was being converted from borings. The electric furnace was also being used for duplexing.

Mr. W. F. Rowden said he also would like to congratulate Mr. McRae Smith on his very valuable Paper. High-strength irons of the type that had been described were very extensively used in the United States for many applications, the total carbon and silicon contents being generally on the upper limits of the specifications given. The lecturer had rightly stressed the fact that high strengths were obtainable in the "as-cast" condition. An increase in tensile could be obtained by oil quenching and tempering; thus an iron having an "as-cast" tensile of approximately 30 tons could be increased to 40 tons by oil quenching, following by tempering between 350 and 400 deg. C., but it was impracticable to oil-harden certain complicated sections and, in addition, the necessary equipment was not always readily available.

He asked for Mr. McRae Smith's opinions on the desirability or otherwise of the inclusion of an impact test in the high strength specifications, also what minimum impact value he would advocate.

A recent interesting application demonstrating the utility of these high strength irons was instanced in their use as shanks for carbide cutting tools, to replace steel.

Molybdenum Cast Iron

With regard to Mr. McRae Smith's remarks, also those of a previous speaker, on the importance of phosphorus, especially at the present time, some experimental work in this connection had been carried out by the Climax Molybdenum Company using 30-lb. laboratory high-frequency melts having a base composition of: T.C, 3.14; C.C, 0.66; Gr, 2.48; Si, 1.95; Mn, 0.75: S, 0.080; P, 0.015; and Mo, 0.03 per cent.

To this iron was added 0.5 phosphorus, 0.5 phosphorus and 0.5 molybdenum, and 0.5 phosphorus and 1.0 per cent. molybdenum. Analyses and mechanical properties are shown in Table A.

It will be seen that, whilst there is a fall in impact values with the addition of phosphorus, with molybdenum additions impact is maintained, and of interest is the fact that the structure of the iron (D) was found to be somewhat acicular in nature. The graphite distribution was practically acicular in nature, and was nearly the same for all four melts.

Further laboratory melts produced in a Detroit Electric Rocking furnace have also been made using a somewhat different base iron as below, to which varying increments of phosphorus were added up to about 1 per cent. Complete analyses and mechanical properties are given in Table B.

Variation of the total carbon content will be noted, which will undoubtedly account in some measure for the variation in the mechanical properties. These data may provide a useful basis for further experimental work.

Impact Tests for Cast Iron

Mr. McRae Smith replied that, unfortunately, there was no standard impact test for cast iron, and he felt it was time that the evolution of a standard test was considered. However, there had been grave difficulty in evolving a simple test. His method was to machine a 1.2 in. dia. test-bar down to 1 in. dia. and to make a 0.05 in. semi-circular groove—not a notch—so that the diameter in the groove was reduced to 0.9 in. On this test-bar the high-duty cast irons should give minimum impact values in the region of 24 to 30 ft.-lbs., whereas in the pearlitic irons the maximum obtained in the same manner was about 16 ft.-lbs. In the case of the high-phosphorus irons, the figure was about 5 to 7 ft.-lbs. However, one could not think of putting that forward for specification purposes until the authorities had decided a standard design of test-bar and conditions of testing.

With regard to tool holders, he said he had heard recently of some small complicated holders which had to be made urgently for small automatic lathes. Those components were not designed for production in cast iron, and normally one would use 0.35 or 0.4 per cent. carbon steel; but nickel-molybdenum Ni-tensyl iron had been used, and the castings had proved to be very successful. Again, he had heard recently of the application of that type of cast iron to the making of tool shanks for tipped tools. There it was a question of practical economics. If one could obtain steel more easily and more cheaply, one should use it, but it was nice to know that a substitute material was easily available in the event of a temporary scarcity of steel shanks.

Mr. Faulkner suggested that one should not visualise shock tests for cast iron until the steel foundry industry had adopted such tests for their specifications.

Tool Holders to Eliminate Chattering

Mr. R. B. Templeton (Branch-President-Elect) said he had found that, where high-duty cast iron was used for making tool holders, its high damping capacity was very valuable, for it prevented a good deal of the chipping of the tool.

Mr. McRae Smith was particularly interested in Mr. Templeton's experience, because it was a fact that, if one used a heavy tool of about 2 in. by 2 in. section made in 18 per cent. tungsten steel, with a long shank, on a heavy face plate lathe, there was often a tremendous amount of chatter, no matter how much care was exercised in securing the tool. He felt that the founders might be able to help the engineering trade a great deal by looking much further into the problem of tool shanks. The capacity for absorption of vibrations, exhibited by most types of cast iron might prove very valuable when coupled with materials having tensile strengths equal to or in excess of that specified in B.S.S. 876, Grade 4. In the present state of knowledge, cast iron shanks would probably have to be confined to the larger sizes, say 1 in. by 1 in. section and upwards.

The Field for C.I. Tool Holders

Dr. A. B. Everest (Past-Branch-President) stated he had been considering the problem of tool shanks in conjunction with one or two of the big machine tool firms in this country. He said the decision at the moment seemed to be that a high duty cast iron shank had advantages for large tools, but that it was not suitable for tools less than about 1 or ¾ in. square. One of the principal difficulties was that most of the tools had to work in conditions in which there was a fair degree of "overhang," and it was then not considered safe to use cast iron except in the heaviest tools.

Table A.—*Mechanical Properties of Mo Cast Irons.*

	A. Base iron.	B. 0.473 P.	C. 0.470 P. 0.49 Mo.	D. 0.468 P. 0.99 Mo.
*Transverse, lbs.	2,600	2,830	3,060	3,020
Deflection. Ins.	0.291	0.268	0.234	0.205
Modulus of rupture. Tons per sq. in.	30.7	33.9	36.1	35.6
B.H.N. (1.2 in. dia.)	215.0	245.0	262.0	277.0
†Tensile. Tons per sq. in.	19.4	21.6	24.1	24.9
Impact. Ft./lbs.	43.0	26.0	31.0	31.0

* 1.2 in. dia. × 18 in. centres. † 0.8 in. dia.

After commenting that a committee was being formed to try to arrive at a standard impact test for cast iron, Dr. Everest emphasised the point made by Mr. McRae Smith with regard to uniformity of the structures of castings. It was of no use, he said, producing high-duty irons unless the castings were sound; it was useless having a mass of 32-ton tensile iron around a blowhole. Two vital features of the nickel-molybdenum irons were that they had remarkably uniform structures and had very good casting properties, so that difficulties with unsoundness could readily be overcome.

Substitution of Steel

One firm within his knowledge was using the new nickel-molybdenum type of iron for handles and levers on machine tools; and he emphasised that if cast iron could be used widely for making such parts, in substitution for steel, there were very great possibilities. He had in mind the use of such material for making many details, and even such common parts as cheap scissors, and so on.

New Iron has Good Casting Properties

Mr. McRae Smith confirmed Dr. Everest's remarks concerning the ease of casting the nickel-molybdenum cast irons, even in the case of castings of fairly complicated sections. Unless such castings were sound throughout, he said, they were useless for their purpose, and he would prefer to use iron of lower tensile strength rather than sacrifice soundness. It was often suggested to the industry that, if common high-phosphorus iron of comparatively low strength were used, one had not to sacrifice strength for soundness. His answer was that the high-duty cast iron specifications usually covered very complicated or lumpy castings, and the castings had to withstand very high stresses and be pressure tight, etc. He did not think that satisfactory castings for that purpose could be made in soft high-phosphorus high-silicon cast iron. If deep machining were necessary they would be hopeless. Unfortunately, the advocates of the phosphoric irons had in mind only the castings for which those irons were suitable, and not castings of the kind for which the high-duty irons were used.

Some time ago some levers for auxiliary control work in diesel engines had been made in high strength nickel-molybdenum cast iron. Previously the levers had been made in steel. Forgings and stampings could not be obtained economically or sufficiently quickly in small quantities, and it was decided to use a high-duty cast iron, involving a cost of about £12 per ton for alloy content. Thus, the same service results were obtained at much lower cost than formerly, in spite of the higher initial cost per lb. of material used, because the high strength cast iron could be cast accurately to shape.

Alloy Additions plus Technique

Mr. C. H. Kain (past-Branch President), speaking as a maker of both steel and iron, said he was delighted that levers and some other things which the steel foundries had been asked to make in the past were now being made in iron. Expressing his strong objection to the use of the phrase "*rough* castings and forgings," he remarked jocularly that, whilst he knew that forgings were not very good—he did not make them—he must challenge the idea, which seemed to be generally accepted, that steel castings were necessarily rough. As proof of his contention, he pointed to the modern fighting machines, and said that steel castings were being made to limits of accuracy at least comparable with those of the average grey iron casting. Steel foundry technique had greatly improved during the past ten years, and many sound castings were produced in steel, whereas their soundness would be very doubtful if they were produced in high-duty irons.

Asking for more information of the technique of production of the high-duty irons, he said that whilst engineers were interested in the properties of those irons, the founders were interested particularly in their production; and he believed it would be found that a very great deal of the improvement of the properties of those irons reresulted from improved technique of production, as distinct from alloying additions. It should be clearly impressed upon foundrymen that mere alloying additions would not necessarily improve the quality of the irons; unless it was emphasised that improved technique was necessary, there was danger of the foundrymen being led astray. An outstanding instance of that fact was to be found in the statements and figures published by Piwowarski concerning superheating; he believed that many foundrymen had got into difficulties as the result of those statements and figures. Finally, he expressed thanks to Mr. McRae Smith for having devoted his afternoon to the meeting.

Table B.—*Composition and Properties of Mo Cast Irons.*

Analyses (base iron)	1.	2.	3.	4.	5.	6.	7.	8.
T.C	3.46	3.36	3.27	3.11	3.27	3.14	3.14	3.08
C.C	0.87	0.76	0.63	0.66	0.75	0.72	0.77	0.67
Gr.	2.59	2.60	2.64	2.45	2.52	2.42	2.37	2.41
Si	1.44	1.41	1.45	1.45	1.45	1.43	1.45	1.40
Mn	0.62	—	—	—	—	—	—	—
S	0.097	—	—	—	—	—	—	—
P	0.019	0.175	0.321	0.471	0.585	0.664	0.872	1.01
Mo	0.56	0.56	0.56	0.56	0.5[illegible]	0.56	0.56	0.56
Mechanical properties.								
Transverse. Load, lbs. (1.2 × 18 in.)	2,990	3,120	3,120	2,925	2,970	2,660	2,550	2,330
Transverse rupture. Tons per sq. in.	35.2	36.8	36.8	34.5	35.0	31.4	30.1	27.5
Deflection. Ins.	0.374	0.355	0.306	0.272	0.253	0.208	0.189	0.165
B.H.N. 1.2 in. dia.	223.0	228.0	228.0	241.0	241.0	241.0	255.0	255.0
Tensile. Tons per sq. in. (0.8 in. dia.)	22.8	23.0	25.0	23.5	24.4	21.1	22.4	20.6
B.H.N. (0.8 in. dia.)	217.0	228.0	228.0	235.0	241.0	241.0	241.0	241.0

Higher Carbon Aids Ease of Casting

Mr. McRae Smith, replying, remarked that perhaps Mr. Kain was under some misapprehension. It had been emphasised a number of times in the Paper that the material discussed therein was a supplementary material to steel castings and forgings, and he had never suggested for a moment that if a casting could be produced more cheaply in steel than in the high-duty irons he had been discussing, one should not use steel. He could not remember having used the term "rough steel castings." While he had referred to "rough" forgings from the point of view that they were not forged to close limits, and entailed high machining costs, he said he admired very much the steel castings trade of the present day for the fine steel castings it produced to very close limits. The work that was being done for some types of production reflected very high credit on the steel castings trade.

With regard to the castability of the high-strength nickel-molybdenum cast irons, his contention was that they could be produced with carbon contents in the region of, say, 3 per cent. Therefore, the difficulties associated with low-carbon cast irons did not arise. The cast irons described were much more readily castable than were the cast irons in the 2.4 and 2.7 per cent. carbon range. Such castings were extremely good, and Mr. Kain would have to look to his laurels when producing competitive steel castings.

All with whom he had discussed the matter knew that he held strong views concerning alloy additions, and he did not wish anyone to think that merely by adding any alloying element to any type of cast iron one could produce a good job. One must work upon definitely controlled base compositions. With the high-strength nickel-molybdenum irons the carbon limits were fairly wide and, therefore, they were much easier to handle. It was only necessary in the production of alloy cast irons of this type for the foundryman who possessed a satisfactory cupola, which could deliver really hot metal, to add a carefully weighed and pre-determined proportion of alloy or alloys to a carefully weighed proportion of correct type base metal. With that reservation, he believed that the production of those irons would be open to 60 or 70 per cent. of the foundries of this country, if they cared to go into the matter.

The Nickel-Silicon Balance

Mr. Fred Gentles, referring to the height of the cupola stack, said he gathered that the 15 ft. mentioned in the Paper was intended to be a minimum. In some places it was the practice, he continued, to melt steel and hematite iron as a first charge, and then to run that as a steel mix instead of charging steel direct into the cupola. He asked whether Mr. McRae Smith knew of many places where that practice was followed.

Although references were made in the Paper to cupola melting temperatures, no figures had been given, and Mr. Gentles asked what Mr. McRae Smith would regard as a minimum temperature. Finally, referring to the production of cylinders of sectional thickness varying from 1 in. to 1½ in., in metal having a carbon content of, say, 3.2 to 3.4 per cent., silicon 1.6 per cent., manganese 0.8 to 1 per cent., and phosphorus 0.2 per cent., he asked what Mr. McRae Smith would regard as the minimum addition of nickel to suit the requirements of machinability and freedom from porosity on test pressure, after machining.

Tall Cupolas and Melting Technique

Mr. McRae Smith replied that the height of 15 ft. between the centre or top of the tuyeres and the centre of the charging door, mentioned in the Paper, was definitely a minimum; a height of from 20 to 22 ft. would be better. He liked a height of from 18 to 20 ft. in cupolas of between 24-in. and 50-in. internal lining diameter. The melting of steel scrap and hematite to give a so-called steel mix pig was quite a good practice. He had mentioned that as being a suitable method of producing refined or diluted low-phosphorus pig-iron, and particularly as a method of getting rid of the first one or two charges of cupola melted metal which usually had a rather high total carbon content, no matter how much steel scrap was used in the mixture. But it would be wasteful to use hematite with the steel. Why use another low-phosphorus material with it? Under present conditions hematite pig-iron would not be available for ironfounders for melting in that way. Instead he would suggest 60 to 80 per cent. of steel scrap and 20 to 40 per cent. common pig-iron scrap, which would give 0.25 to 0.45 per cent. phosphorus in the final product.

Mr. Gentles commented that there might be carbon pick-up.

Mr. McRae Smith replied that one could not carburise above a certain point. The second pick-up of carbon on remelting would be negligible in most cases. As to cupola melting temperatures, he expressed the opinion that there was no cupola anywhere which could give too high a temperature. There was a danger of obtaining weak dendritic patterns by superheating too much in electric furnaces. However, he was of the opinion that one should not tap any metal from the cupola at a lower temperature than about 1,350 to 1,380 deg. C., if possible. One should not worry about too high temperatures, but should ensure that the temperature was never below a certain minimum.

In cylinders having a metal thickness of from 1 to 1½ in. he would be inclined to restrict the maximum carbon content to 3.2 per cent. He would not increase it to 3.4 per cent., from the point of view of reduction in wear resistance. The silicon content he would keep to 1.2 to 1.3 per cent., when alloy additions were not used. If one were going to add part of the silicon in the ladle, one could have 1.2 per cent. silicon in the charge, and could add about 0.4 to 0.5 per cent. silicon as a late addition, making the final silicon content about 1.5 to 1.7 per cent. When alloys were added silicon adjustments would be necessary.

A High Impact Test Result

Mr. Pincott, referring to the standardising of test bars for the Izod impact test, said that, in addition to the bar of 1 in. dia., having a groove of 0.05 in., reducing the effective diameter of the bar to 0.9 in., there was also the British Cast Iron Research Association's test piece, having a diameter of 0.798 in., un-notched. He had not tested the acicular irons in the 1-in diameter grooved bar, but he had tested them in the B.C.I.R.A. test bar, and had secured results as high as 44 ft.-lbs. In view of the fact that the average figure mentioned by Mr. McRae Smith was in the region of 24 ft.-lbs., obtained with the 0.9-in. bar, he was beginning to doubt the accuracy of his own figure of 44 ft.-lbs. In that connection, he asked what was the effect of a notch or groove, for that must be an important consideration in deciding upon a standard Izod bar for cast iron.

Mr. McRae Smith said he was aware that two modified test bars were being used, and the 0.798-in. B.C.I.R.A. bar would give a lower value than the 0.9-in. effective diameter bar. But there was little information available yet on cast irons with acicular structure. Owing to the limited number of tests having been made so far in this country on acicular irons using the 0.9-in. test bar, he had put forward his figures on a very conservative basis. He was not at all surprised that Mr. Pincott had obtained impact values of more than 40 ft.-lbs.

At the conclusion of the discussion, a very hearty vote of thanks was accorded Mr. McRae Smith for his very interesting and important Paper. The vote of thanks was proposed by Mr. V. Delport (past-Branch-President), who commented on the wide interest of the subject, and seconded by Mr. B. B. Kent; and Mr. C. Cleaver took the opportunity to add his meed of praise of the Paper and of the work of the metallurgists who were developing the special irons.

Rope Pulleys*

By JOHN R. WEBSTER

Since electric power transmission came into common use and motors became more reliable, the rope drive is not so commonly used as it once was, but there are still fair quantities of them in use, and as power transmission engineers, it is very seldom indeed that the author's firm is without rope pulleys of some sort in the foundry. Although the shape of the groove has changed considerably, yet, on the whole, sizes are smaller than they used to be. There are few castings currently made which involve so many different designs or lend themselves to so many different methods of moulding as the rope pulley. The reasons are possibly as varied as the designs themselves. It might be profitable, therefore, to consider what factors most profoundly influence design. As there is seldom more than one-off each pulley—unless in exceptional cases, where the pulley is part of a standard machine—a whole pattern is too expensive, and for large sizes, practically impossible. Therefore, the designer has usually considered the method most suitable for his foundry to produce. This feature probably explains how the many different types of arms, the varied methods of moulding grooves, and similar divergencies came into existence. The author's firm, after trying different designs, finally standardised on the design shown in Fig. 1. This particular pulley is 9 ft. 10 in. dia. over the rope pitch line; it has 17 grooves, and weighs 11,500 lbs. It was run with four $1\frac{3}{4}$ in. down-gates on the nave and the pouring time was 1.5 min. This pulley is a good example, though six arms per set are usually considered ample. In adopting this design, consideration was given first to appearance, aiming to produce a pulley as artistic as possible, whilst taking cognisance of the cost of production, including patternmaking. The latter cost is reduced to the minimum, by having the pattern parts, core boxes, sweeps and groove plates made to serve for a wide range of sizes. Moreover, due consideration was given to moulding, dressing and particularly machining costs, and the management was prepared to pay a little more in the foundry, if such costs could be recovered in machining.

* The Author was awarded a Diploma for this Paper.

Working System

With this end in view, Mr. Hendry Fraser produced the system now in use in the foundry, and which has proved most satisfactory. Under the system all grooves are swept in loam, and necessarily stove dried. This reduces dressing costs, as there are no fins all over the face as there often is when the grooves are cored. It also reduces the machining allowance to a minimum, as there is no "siding" through cores

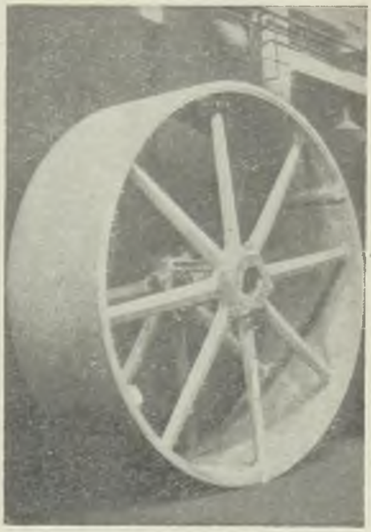


FIG. 1.—DESIGN OF PULLEY DISCUSSED.

being distorted by handling or core box rapping. Pulleys with a 12 in. face or less have the inside swept in green sand. Above this dimension, the inside or core is built and swept in loam. Small diameters up to about 4 ft. are built on a bottom-plate and stoved. Larger sizes are built in a pit and dried on the site.

Tackle Used

Fig. 2 shows all the tackle set up ready to build the grooves. The spindle is 3 in. dia.

and has a long taper in the footstep to ensure rigidity. The usual split collar is provided, on which rests an eccentric block with 1 in. eccentricity. The block is held in position with a pinching screw fronted with a gunmetal pad to keep the pressure from pitting the spindle. It has also a centre line on the top, through the eccentric. Over this, the sweep-arm works. The sweep for the grooves is cast iron, $\frac{1}{2}$ in. in thickness. Down the length of the spindle is a line or member clearly defined approximately $\frac{1}{32}$ in. wide and at least the same in depth. On the floor is a straight edge with a notch cut out to accommodate the spindle, and on the left can be seen a stake driven into the floor and properly plumbed to the vertical. A small straight edge is fixed to the bottom of the will come in line with the bottom of the groove. The cakes are 9 in. square, and the holes in the plate are for riveting on the loam. The labourer, when the cakes are dry, lifts them out of the stove, gives them a light rub with a card cloth, and sets them ready for the moulder who builds them as shown in Fig. 2, setting each cake with the sweep as he proceeds. After the moulder has completely built the half pulley, he then loams up and sweeps the grooves; loams up the ends and strikes them off with the straight edge, having a bearing on the spindle and also on the post already mentioned.

This only leaves the ends of the grooves to square off. For this purpose two short pieces of groove are provided. This half is now lifted away and placed on the stove carriage, and the

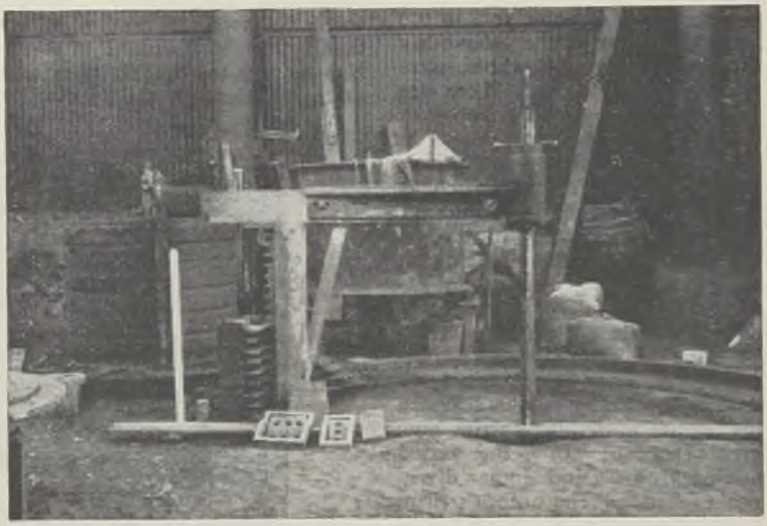


FIG. 2.—TACKLE FOR BUILDING THE GROOVES.

sweep with which the bed is swept, and after the usual preparation the cope ring is placed in position as shown in the illustration. These plates are necessarily thin, being only $\frac{1}{2}$ in. thick at the edge tapering back to about $\frac{7}{8}$ in. to enable the moulder to get in the first groove. This carries all the building.

The back flange which is 5 in. by 3 in. is required to keep the mould rigid when stoving. In the foreground i the cake box. There are different thicknesses of these for the different sizes of ropes or pitch. Inside the box is a mild steel plate, with six holes punched out. Previous to starting a pulley, a labourer goes into the stove, the floor of which is plated, and makes as many cakes off this box as the moulder will require for building the pulley. Each cake has one of these plates bedded-in, so that the edge other half plate is put down on the bed and the same process is repeated. Half-plates are only used for the larger sizes, as they can be more easily stoved. The moulder has now swept a half pulley, but he has done more than this, for he has swept a half pulley, plus $\frac{3}{8}$ in. at each end to allow for machining and camber This $\frac{3}{8}$ in. is controlled by the straight edge—the straight edge being $\frac{3}{8}$ in. back from the centre line of the pulley.

If this pulley had been about 7 ft. or less in diameter the plate would have been whole instead of in halves. The procedure then would have been different after building the first half. Two print blocks for splitting cores $1\frac{1}{4}$ in. thick would have been provided, and would be placed against the struck face of the building. The eccentric block would have been turned over.

and the building proceeded with as before. As there is one inch eccentricity on the block, the moulder is always sweeping 1 in. off the centre. This gives a 2 in. gap between the two halves of the mould, and is used for $\frac{1}{4}$ in. machining each side on this size of pulley and $\frac{1}{8}$ in. for camber, which is insufficient. This finishes the building of the grooves, and as they are now stoved it seems worth while to examine the building of the inside or core.

Core Making

It is regretted that Fig. 3 does not show more of the operation. It would have been better if it could have shown the inside or core of the pulley half built with the arm cores set in position, but an attempt at rectification will be made by description. There can be seen at the back of the spindle (Fig. 3) the arm core box. It has a metal head, machined at the joints at the correct angle and flanged at the bottom to allow of the bolting on of a wood bottom. This is a standard depth, but the depth or thickness of the core is controlled by the length of nave required. It should be noted that this box has a second bottom to make it of the necessary depth. The arm is loose, and in the centre of the bed, the section of the nave where it fits into the mitre end, and the end is held in position by the blocks fixed to the side. The arm is tapered and dowelled into the fillet on the back. After the arm is rammed up in dry sand and turned over on a plate, the back, with the fillet, comes away. The arm is then drawn out, and the core is ready for stoving.

After drying, it is blackened and is then ready for building in. The other box shown is for making the distance piece between the naves of the two sets of arms. This carries a print for the core through the nave, and also a tee-section-piece, about 2 in. by 2 in. by 1 in., which joins the two naves together. This keeps "spring" from affecting the arms, and as the pulleys are run off the nave the iron flows through these and fills the bottom part of the mould. The two long pieces shown in Fig. 3 are the patterns for the bolt lugs carrying a print for the splitting core. The sweep for the inside of pulley is in position, and from this view can be seen the arrangement for setting.

The arm is machined at the neck to a given size from the spindle centre. It is really machined all along the face and the top edge. On this edge, a plate is fixed projecting about $\frac{1}{4}$ in. over the face, and thus making a flange. To set the sweep, it is put in the arm, close up to the shoulder and against the flange along the top and bolted up; a little "plumbing" to guard against any droop is all that is required. The patternshop foreman is responsible for sizes, and there are no size sticks used. The crosspiece, on the bottom of the sweep, is for sweeping the bearing for the first set of arm cores. There is a permanent plate in the bottom of the pit. This is cleared and the sweep set for height. A single-brick bearing is built round the spindle wide enough to support the tapered end of the arm core, and another at the centre of the arm and at the rim. On these, when laid down, a facing of loam is swept.

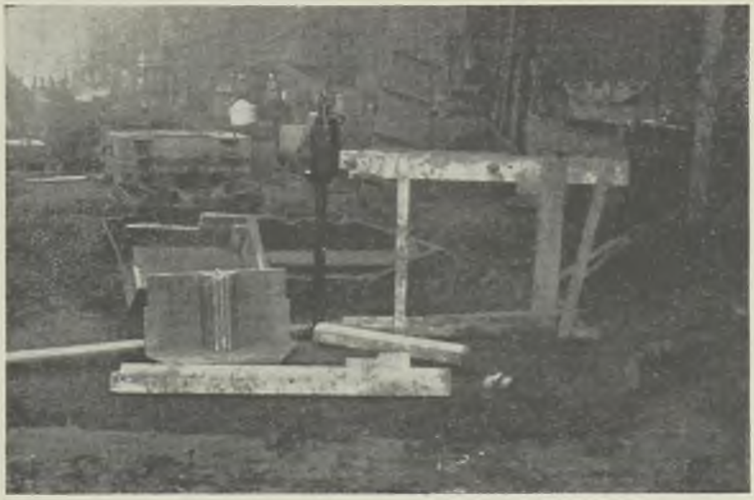


Fig. 3.—Some of the Core-making Tackle Used.

Ascertaining that the eccentric is sound, the process is repeated for the other half, whilst leaving gaps at the sides to accommodate the bolt lugs.

The mould is now ready to receive the arm cores. The straight edge is again placed in position, using the centre line connecting with the line on the spindle, and weighted down. A templet, the size of the half nave, with a gap to fit the spindle, is placed against the straight edge. The cores are set to this, first the outside ones, the straight edge and templet giving the angle for the arm. Then the other cores are fitted in and equally spaced. When this is done, the straight edge is lifted away and the arms on the other half are set. The only difference here is that, instead of the straight edge, there is a $1\frac{1}{2}$ in. block to place against the arm already set. The next arm core is placed against this, the nave templet getting the proper angle as before. The block is then withdrawn, and leaves the print for the nave splitting-core.

The crosspiece on the bottom is unscrewed and lifted to the next position, forming the bearing for the next set of arm cores, and the bottom nave is now properly finished. The two distance-piece cores being set, they form a cover core for the bottom nave, and the bottom of the top one. The first one is set with the straight edge and a templet for the core print; for the other side, the $1\frac{1}{2}$ in. block or print is again used. The moulder now builds in between the arm cores with brick to form the inside of the pulley. Sometimes he builds brick round the outside of the distance-piece, depending upon how much bearing is available. These have to be well secured, as this is the only possible place for iron to escape from the mould. When the building comes up to the crosspiece, a single brick bearing is brought up from the centre of the arm core, carrying the exact width of the core, and supporting the centre of the core on top. This bearing is then loamed and swept, and the crosspiece is taken off. The next set of cores is then placed in the same manner as before, and the building is carried to the top. Then the bolt lugs are set in position, again using the straight edge and a plumb-bob. These are built in. The bearing for the cope is then set, after which the face is loamed up and swept. The edge at the top is sharpened up and the bolt lugs drawn out, and the job is ready for drying. To effect this, it is covered with plates, and fires are lit at four or more places according to the size of the pulley. The fire travels round slowly, and is so stoked that it is just burned out by morning. The heat is never allowed to be too strong, and the mould is dry and in a suitable condition for blacking. After blacking and finishing it is given another light firing, and the mould is as shown in the background of Fig. 3. During this time, the grooves have been finished, stoved, blackened, and are ready for assembly, as are also a cover plate for the rim; a dry-sand top-part to cover the nave, with the necessary runners, and the cores for the split and bore.

Fig. 4.—Showing Provision made for Splitting Cores.

In Fig. 4 is shown the space in the grooves for the splitting core. The part shown is lowered into the inner part of the mould, set properly, and gauged all round for metal thickness. The splitting cores for the bolt lugs are put in from the outside and the back is rubbed up with good stiff loam. The cover plate is placed on the rim; the splitting cores through the nave slipped in and the ends secured; the parts of the core placed in position; the dry sand cover or sometimes a loam plate put in place over the nave, and the assembly is complete.

"Cribs" put round the outside are shown at the back of the mould in Fig. 5; actually they are not deep enough for the pulley illustrated. A mild steel ring is placed round the bottom and rammed. The crib plates are then put in position and well rammed to the top of the mould. The inside, which is open between the arm cores, is filled in with sand, which is merely tamped in with a touch round the sides or under the cores with a shovel shank. The head box is put on and the head made up carefully with a skimmer core bedded in about 8 in. or 9 in. from the downgates. The whole is then weighed down, using weights in preference to binders.

The foregoing is a description of a system of moulding rope pulleys, and if one considers that all the pattern tackle is adaptable for many other sizes; that the machining is cut down to a minimum as the grooves are clean and true; that the dressing costs are negligible, it is obviously a worth while process. Though the moulding operations may seem rather involved, they are not really so, and it is surprising how expert and fast a good moulder soon becomes on this job.

Inherent Difficulties

There are obviously some difficulties in the moulding of rope pulleys. The usual practice until some years ago was to mould the pulley as near the size as possible. It was marked off and machined to the given size, due regard being given to strength or rather metal thickness at the bottom of the grooves, for $\frac{1}{4}$ in. or $\frac{3}{8}$ths of an inch on the diameter of a 10-ft. pulley was not considered a fault.

New conditions arose when an order for a range of pulleys showed sizes given to two places of decimal such as 59.58 in., 118.38 in., and 63.36 in. over the rope pitch dia. These are three of the actual sizes, and the inspection was to be very exacting. The first pulley of this series, shown in Fig. 1, sent to the machine shop brought back a report that it would not machine up to size. The desired size was 59.58 in. dia. and was to be over size in inside diameter by $\frac{3}{8}$ in., but after marking off it was machined to the specified dimensions. The sweeps were checked and found to be correct to contraction rule of $\frac{1}{10}$ in. per ft. Test bars showed that the iron had contracted normally. It is thus apparent that the main difficulty to be overcome in pulley manufacture is that of contraction.

FIG. 5.—MOULD READY FOR PLATES.

FIG. 6.—SHOWING FINISHING OPERATIONS.

Contraction Problems

The conclusion reached was that the casting did not contract according to rule, and as the foundry was then making another pulley exactly the same size, it was decided to take $\frac{1}{8}$ in. off the sweeps, which would involve $\frac{1}{4}$ in. off the diameters, thus reducing the contraction allowance by 50 per cent. The inspector's report stated pulley was concentric internally but still $\frac{1}{8}$ in. too large. It was too early at this stage to have a definite opinion, but one could assume that pulleys of this type cast in loam contracted less than half the normal allowance of $\frac{1}{20}$ in. per ft. The next pulley, 118.38 in. R.P. dia. by 12 grooves, was very close to the size of the one illustrated in Fig. 1. This was the second one cast, and was being moulded at the same time as the first. Therefore no change had been made, and it was produced under normal practice, with the usual contraction allowance. The sizes required were 119.63 in. dia. over the flanges, and 114.214 in. inside diameter. The casting measured inside the rim from the centre of the nave through the centre arm 114.75 in., that is 0.536 in. too large. Across the split it measured 115 in.—an error of 0.786 in. The author has found an error of 0.536 in. in actual diameters, but a greater difference through split. There the error is 0.786 in., which would mean that if this pulley was machined to the sizes demanded, the metal at the bottom of the grooves would be too thin by $\frac{3}{8}$ in. at the split to $\frac{1}{4}$ in. at the centre arm. This pulley was not accepted by the machine shop, and the sizes again show that pulleys cast with a loam centre contract only by half the usual allowance.

The difference in size through the split was a graver problem. Here the contraction had been only about 20 per cent. of the normal allowance. This condition, it was judged, arose through the contraction operating along the periphery until it was stopped by the strain on the side arms. This was a known but only dimly recognised fault in pulley manufacture, and had been until now counteracted only by bringing out the rim beyond the centre line of the nave, to allow for what was loosely termed "camber," but something more was now called for.

On the next pulley of this same size but carrying 14 grooves, which it was anticipated would contract along the same lines as the last one, it was determined to sweep $\frac{1}{2}$ in. smaller in diameter through the lugs than through the centre rim of the arm. This was the only alteration made, and though it left room for a fault it was such that there would be material enough for correction in the machining. The sizes required were 119.6 in. outside diameter and 114.214 in. inside The inspector's report stated that the outside diameter was 120 in. and the inside 114.214 in. This was correct, but as the contraction allowance had not been altered, the centre had to be put forward, leaving too much to machine off the joint and the slight thinning of the bolt lugs. The next step was to reduce the contraction allowance and to reduce slightly the amount taken off the diameter. Careful records were kept over a long range of pulleys until the management was able to gather sufficient data to enable them to issue an instruction sheet stating the contraction allowance and the amount the sweep was to be drawn in for different sizes of pulleys. This has now become a matter of routine. The contraction allowance for pulleys made in loam is $\frac{1}{10}$ **in. per ft.** Pulleys with the inside of green sand the usual $\frac{1}{10}$ in. per ft. From 5 ft. to 7 ft. dia. inclusive, the amount taken off the diameter through the split $\frac{1}{4}$ in., which means the sweep is drawn in $\frac{1}{8}$ in. (see Fig. 2). From 8 ft. to 10 ft. the sweep is drawn in $\frac{1}{4}$ in., making $\frac{1}{2}$ in. difference in the second diameter. To draw in the sweep, the eccentric block is turned off the centre line and the sweep worked from the outside to the centre. The action is then reversed, and the other side swept from outside to centre. Thus $\frac{3}{8}$ in. off the centre line draws in the sweep $\frac{1}{4}$ in. As the top of the block is lined off in eighths on each side of the centre line, the moulder has no difficulty in bringing the sweep to any desired position. These corrections only apply to pulleys with six arms per set.

On the range of pulleys that have been cited, the analysis throughout was: T.C, 3.3; Si, 2.0; Mn, 0.7, and P, 0.54 per cent., yielding tensile tests of the order of 12 tons per sq. in. The one shown in Fig. 1 gave T.C, 3.26; Si, 1.85; Mn, 0.72, and P, 0.45 per cent., but the test bar gave a tensile of 15.5 tons. This would be an argument in favour of making these pulleys of still lighter section. The author gratefully acknowledges the help given by his directors and colleagues in the preparation of this Paper.

Some Notes on Bell Founding*

By J. M. STONES

In the construction of large bells, it is of great importance to know the proportions between the dimensions which are most advantageous for the production of sound. The principal conditions for a good bell are:—

(1) The greatest diameter of the bell must be at the mouth, and the greatest thickness of metal must be at the sound-bow.

(2) A bell should at the utmost measure in width fifteen times, and in height (measured obliquely on the outside) twelve times the thickness of the sound-bow.

(3) The thickness of the bell decreases from the sound-bow up to half its height, and from there on should amount only to one-third of the thickness of the sound-bow. From the sound-bow to the circumference of the mouth, the thickness also decreases.

(4) The diameter of the mouth of the bell should be twice as large as that of the uppermost part of the crown.

(5) The weight of the clapper should be about 1-40th that of the bell. For very large bells a weight of 5 to 10 lbs. may be added to the clapper.

(6) The ball of the clapper, *i.e.*, its round or pear-shaped end, should be thicker in the proportion of 5:3 than the thickness of the metal on the sound-bow. However, this applies chiefly to bells weighing over 120 lbs.

Tracing the Profile

The correct profile of a bell of given diameter is traced in the following manner; small variations being, however, customary in many foundries. Suppose the horizontal line *a b* in Fig. 1 is the prescribed width of the bell at its mouth—divide this line into 15 equal parts, which are called "Prims," because one such part represents the thickness of the bell on the prim or sound-bow. The diameter of the bell thus divided serves as a measuring scale in the following operations:

First divide *a b* by the lines *c f*, *d g*, and *e h* into equal parts; *f h* now gives the diameter of the cap, which is one-half the diameter of the mouth. Now measure off, with the compasses, twelve prims, and with the distance thus obtained intersect from the point *e* the line *e h* in *i*, then draw the line *b i* and divide it into twelve equal parts; with the radius *b k* which is equal to $1\frac{1}{2}$ prims, describe an arc from *b*.

By now cutting off a prim from *k* to *l*, the thickness of the bell on the sound-bow is obtained. After drawing the line *l b* erect upon *m*, as the centre of *b i*, a perpendicular, and set off upon it a piece, *m n* = $1\frac{1}{2}$ prims. The point *n* determinates how far the curve of the bell recedes in the centre of the height.

The curve itself consists of two parts, *n k* and *n i*, of different curvatures. To trace it, find with a distance of 30 prims from *n i* an intersecting point *o*, and from there describe with the radius *o n*, the arc *i n*. Further, set off upon the line *m n* from *n* to *p* 1-3rd prim, and describe from *o* with the radius *o p* the arc *p q* for the interior curve of the upper half of the bell.

The interior curve of the lower half has to be drawn from another centre. For this purpose one finds with a distance of 12 prims from points *p* and *l* a centre *r*. Describe from it the arc *p l*; then from the points *n* and *k* find, with a distance of 8 prims, a point *e* which gives the centre for describing the arc *n k*.

Finally, with a distance of 8 prims intersect from the terminal points *a* and *b* of the line *a b*, the axis *d g* of the bell in *t*, and from the latter point, describe with the radius *t i* the arc *i* for the curvature of the cap. The cap receives a thickness of 1-3rd prim, and hence its internal curvature is described from the centre *t* with a radius which is 1-3rd prim smaller than *t i*. For the better securing of the crown upon the bell, the thickness of the centre cap is increased by 1-3rd prim, which is designated *w x*.

Exterior Tracing

The exterior shape of the bell traced according to the rules given is frequently subject to small variations—for instance, by rounding off *i* and *u* on the edge of the cap, as well as *k*, and by hoops and rods arranged in different parts on the surface, partly for the sake of increasing the strength, and partly for ornamentation.

Thus it is seen how difficult the construction of bells is, and that every part must be strictly

* The Author was awarded a Diploma for this Paper.

cast in accordance with its proportions. If bells of a fixed weight are to be cast, a normal bell of known tone, dimensions and weight is used for calculation. However, such calculation is not applicable to very large bells, and, hence, must be constructed to a given formula.

Though the moulding of large bells may be considered a good job of work, the casting requires the same attention and equal skill, in order to obtain a pure, harmonious tone; the slightest inaccuracy or defect in casting destroys the harmony, and spoils the bell.

The exact tune of a set of bells, as they come out of the moulds, is a secondary consideration, because the notes can be altered a little either way by cutting, but the quality of the tone will remain the same for ever, except that it gets louder for the first two or three years that the bell is used, probably from the particles arranging themselves more completely in a crystalline order under the hammering.

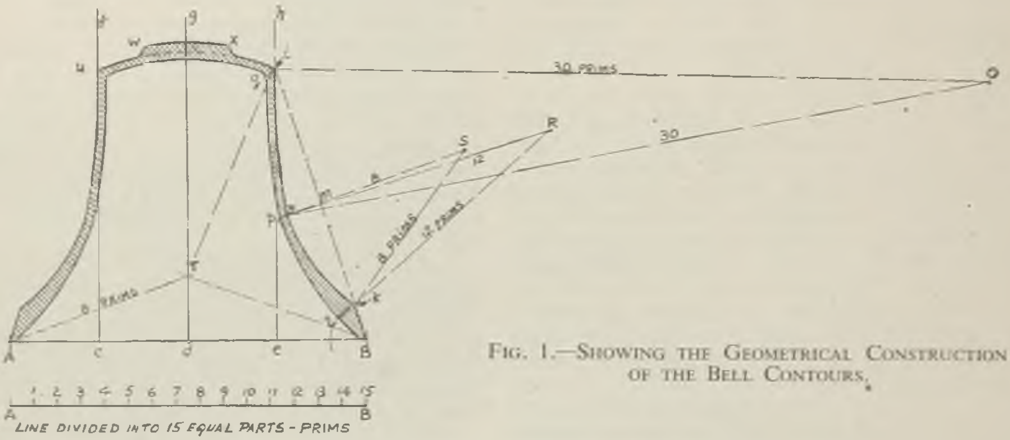


Fig. 1.—Showing the Geometrical Construction of the Bell Contours.

Hanging of Bells

The usual method of hanging bells is to cast six ears or loops on the top of the crown of the bell; these are called canons, through which iron hooks and straps are put in, to fasten the bell to the stock. This method of hanging by canons is, no doubt, objectionable, as they must always be the weakest part of the casting, from being nearest the top, and in practice it is found that they frequently break off, and have to be replaced by iron bolts put through holes drilled in the crown. It is also difficult to turn the bell, in the stock, to present a new surface to the clapper, when it is worn thin in one place.

In some bells these disadvantages are avoided by casting a very short, thick, hollow neck with a strong flange round the top, which can be fastened to the stock by hooked bolts. By this arrangement the bell is held by a large section of its own metal, and can at any time be shifted round by slackening the bolts. If a clapper is to be used, it can be hung upon a separate bolt, passing through the hole in the neck, and through the stock, and secured above.

When only clock hammers are employed to strike on bells, the wear is so small that the facility of turning the bells is of secondary importance. This plan has the recommendation of great strength, and would probably have been used to a larger extent but for the loss of the canons, which are regarded by the founders as an ornamental finish to bells, upon which they rather pride themselves.

In calculating the sizes of bells to produce particular notes, and assuming eight bells are made of similar material and their sections are exactly similar figures in the mathematical sense, they will sound the eight notes of the diatonic scale, if all their dimensions are in the proportions, 60, 53⅓, 48, 45, 40, 36, 32, 30, which are merely convenient figures for representing the inverse proportions of the times of vibration belonging to the eight notes of the scale, so that if it is required to make a bell a fifth above a given one, it must be two-thirds of the size in every dimension, unless it is intended to vary the proportion of thickness to diameter, for the same rule then no longer holds good, as a thinner bell will give the same note with a less diameter.

Moulding Large Bells

These are moulded in loam, which should be sifted very finely. In the centre of the pit a post is driven into the ground—around this a wide platform of bricks is built upon which the core is erected in brick. This core is hollow, and, to enable the moulder to make a fire in it, is provided with flues for the necessary draft. About half the height of the core a spindle base is laid upon the post, and bricked in the wall of the core; the spindle is then set up, and moulding continues in the ordinary way. The core is first built up, and then the thickness put on, and the outside built up.

In casting bells, it is a rule to melt the metal as rapidly as possible, keeping the surface covered with charcoal; when the metal is melted, a sample is taken out with a ladle, cast in sand, and examined as to grain and fracture, before casting.

Bell metal is best composed of 80 parts copper and 20 parts tin, or 78 parts copper and 22 tin. There are, however, variations from these proportions, and small accidental or intentional admixtures of zinc and lead, for instance, 71 parts copper, 26 tin, 1.8 zinc and 1.2 iron—or 80 parts copper, 10.1 tin, 5.6 zinc and 4.3 lead.

For house bells the following proportions may be recommended:—Copper, 4 parts, tin, 1 part. For tower bells, copper 32 parts, tin 9; and for very large tower bells, copper 16 and tin 5.

DISCUSSION

In thanking Mr. Stones for his very interesting Paper on methods of designing bells, Dr. H. J. Van Eck said he had not previously given very much thought to the subject, and much of what Mr. Stones said was new to him. The Paper showed what care was necessary to obtain good notes. He could think of several famous bells—in particular, the bell in the Kremlin at Moscow, which weighed 250 tons and was the biggest in the world. Unfortunately, this was one of the bells which was not successful, for it broke after casting. What he particularly wanted to find out from Mr. Stones was how the dimensions were originally obtained. Were they worked out mathematically, or did they develop by experience and trial and error? Mr. Stones had mentioned that in order to change the tone metal could be removed from bells. This was another interesting point. With these observations Dr. Van Eck declared the Paper open for discussion.

Mr. Stones said that bell founding was probably one of the oldest arts in the world. He imagined the different sounds had been obtained by practice, not calculation. If the sound was not correct, the tone could be altered by chipping a certain amount of metal from the curve. The sound could be changed either by chipping grooves or by cutting a groove just inside the sound-bow. In the establishment where he used to work, men spent weeks in chipping out 1-8th in. grooves which they thickened gradually until the correct sound was obtained.

In reply to the chairman's remarks on the subject of famous bells, Mr. Stones said that the bells of Westminster were cast in 1856. One of these bells, which weighed 15 tons 8½ cwts. and was 9 ft. 5½ in. in dia., had to be hoisted to 200 ft. The clapper alone weighed 12 cwts. A bell which was cast in Vienna in 1511 weighed 17 tons 14 cwts. and had a diameter at the mouth of 9 ft. 10 in. In regard to the bell at Moscow, the author informed the meeting that another bell was subsequently made which weighed 110 tons and had a diameter of 18 ft. The date of casting was unknown.

Dr. Van Eck inquired whether the bells of Moscow conformed to the formula of dimensions referred to in the Paper. Mr. Stones replied in the affirmative, and added that at most works the same formula is worked to and holds good for bells from 100 lbs. to 100 tons in weight. A considerable amount of thought must have been required to work out this formula in such a way that it would be applicable to bells of all sizes.

Mr. D. Lion-Cachet completely agreed with Mr. Stones that there are a great many people who do not know how to make bells. He recalled how he had once found a bell in a scrap-heap, and was thereby inspired to make a pattern and cast a small bell for summoning his children to dinner. He gave instructions for phosphor bronze to be used. Ultimately he decided to use the old bell because it sounded better. Mr. Lion-Cachet then asked Mr. Stones how bells were run and the risers attached.

Running Methods

Mr. Stones said that bells were run from the top. In the case of an ordinary house bell which had a lug on top to which a hook was attached, a riser was put on the top and cut off. Most big bells were run from the top, pouring being carried out downwards with a series of gates round the mould cavity.

In connection with heavy bells, Mr Lion-Cachet recalled a mechanical contrivance which he had seen. In the old days the mechanical operation of running gear was not satisfactory, and the difficulty of swinging a bell weighing several tons had to be overcome. This was done to some extent by using balance weights, but the trunnions increased the friction and the only lubricant available was animal fat. A special trunnion was therefore evolved. Mr. Lion-Cachet described one of these special trunnions, which consisted of an arrangement of plates giving a rolling friction at every point. Apparently this appliance had been running for a few hundred years but it was still quite satisfactory when he saw it.

In reply to Mr. Lion-Cachet, who asked whether many bells had been cast in South Africa and what were the results, Mr. Stones said that he knew of one bell only, which had been cast in his works to the design he had outlined, and was quite satisfactory. He was of opinion, however, that there might be a time when they might have to cast bells, and there were no bell founders in South Africa.

A MEMBER asked whether the composition of the bell metal had any effect on the sounds. MR. STONES in reply stated that eight bells of different sizes could be made with the same metal to give different sounds. By taking a chip out of the side a louder tone was imparted. The heavier the bell the lower the tone obtained.

What particularly impressed MR. HOLDSWORTH were the tremendous weights which had been cast, and he wondered how such weights of metal could have been poured. He presumed that all the metal had to be poured at once.

MR. STONES said that all bells over 15 tons in weight were cast from metal melted in a reverberatory furnace, the metal being led direct from the furnace into the mould.

Permanent Moulds and their Application to the Production of Non-Ferrous Castings

By FRANK HUDSON

It is interesting to try to visualise exactly what constitutes a permanent mould. In the true sense of the word there is, of course, no such thing. The designation "long-life mould" is obviously more appropriate, but by virtue of common usage the term "permanent" has been applied to any type of mould from which a number of castings may be produced. Probably the most obvious application of this type of mould to the production of non-ferrous alloys is the ordinary ingot mould, made of cast iron or copper, used for the casting of sometimes large but relatively simple shapes. Another familiar example which readily comes to mind is the manufacture of die-castings where the mass of the casting is relatively small but often intricate. In both these examples mass production is a common entity, but whereas in the first case casting composition, and consequently melting point, play a minor part, in the second case these factors at present largely determine whether manufacture is a practical proposition or not.

In between these two extremes, ingot production on the one hand, and the manufacture of die-castings on the other, falls the bulk of ordinary non-ferrous foundry requirements in which the use of long-life moulds has, in this country at any rate, received relatively little application. What possibilities exist in this direction? The answer to this question might conceivably be assisted, first of all, by briefly reviewing the developments which have already taken place here and in other parts of the world.

Development of Long-Life Moulds

In the first place it is of interest to note that in all probability long-life moulds pre-date sand moulds by several thousand years. The progression appears to have been: Stone, hard-burned clay and bronze moulds for the casting of spear heads and kindred articles from copper and its alloys. Naturally, cast-iron moulds are of much later date and their use, principally for ingoting purposes, can probably be traced to about the middle of the 14th century. It was not, however, until the close of the 19th century when die-castings were first developed that any real impetus was given to the question of long-life moulds for casting purposes.

The production of light alloy articles such as pistons, cylinder heads and covers, etc., for the automobile industry, from cast-iron moulds is an outstanding example of the progress made in this direction. At this juncture, it should be pointed out that there is a distinct tendency in some circles to class the method of production just mentioned as gravity die-casting. From the foundry point of view this is not strictly correct, and it is difficult to visualise, say, a large diesel-engine piston about 3 ft. high and 18 in. in diameter as a die-casting even although it is made in a cast-iron or steel mould. These are essentially permanent or long-life mould castings and as such are distinct from die-castings. This point is not sufficiently well appreciated by foundrymen and engineers, and it is worth noting the published remarks of American experience[1] in this direction:—

> "In the first place the cast-iron moulds can be made from wooden patterns and the finishing cost therefore is low. They need not be made from the highest-grade die steels and machined from the solid blank, as is necessary for die-casting dies. The principal advantage of the long-life mould technique, however, is not the lessened die cost, but the fact that no air bubbles or gases are entrapped. Hence the chilling effect of the metal mould produces a dense homogeneous metal that is at least 20 per cent. stronger than a die-casting."

According to the same source of information, the American writer further states that, because of their superior qualities, permanent-mould castings are usurping the field of aluminium die-castings and are being increasingly employed for such articles as washing machine agitators, vacuum cleaners, automatic vending machines, electric ironers, typewriters, aircraft parts and many other machine elements.

Following the production of light alloy articles in permanent moulds, further developments have taken place in an attempt to obtain castings of greater strength, and a considerable measure of success has arisen in this direction by the use of aluminium bronze. Gearbox selector-forks, roller-bearing cages, nuts and bolts and small gear wheels are only a few of the many articles made to-day in this way.

Mention should also be made of the now long-established practice of casting phosphor bronze in stationary permanent moulds, resulting in the production of chill-cast solid and cored sticks so widely used for bearing purposes, valve guides, etc., and by the more modern centrifugal methods developed for liners and gear blanks.

It will be noted that up to this point the production of non-ferrous castings in permanent moulds has been successfully accomplished with certain types of alloys which seem to lend themselves to service with metallic moulds. Surprisingly little work has been done relative to the production of castings in refractory or refractory-lined moulds or in the use of the more common copper-base non-ferrous alloys, so widely employed in the average brass foundry. It may be that there is a production field open in this direction, and a useful purpose may be served by examining the latter problem in some detail. Such is the aim of this Paper.

Mould and Metal Relations

In the manufacture of castings from permanent or long-life moulds there are two broad factors which must be taken into account, apart from the very obvious initial question of design. Consideration might be given in the first place to the effect of the mould upon the metal and, secondly, to the converse—the effect of the metal on the mould.

Effect of the Mould upon the Metal

This aspect has considerably more bearing on the subject than first thoughts indicate, and its importance may be more clearly gauged by recounting a recent experience of some interest. At the present time the demand for rolled phosphor-bronze bars up to 2 in. dia. to B.S. Specification 369/1940, calling for a maximum strength of between 30 and 40 tons per sq. in., with not less than 15 per cent. elongation, exceeds the sources of supply, and a useful purpose would be served if some cast substitute could be developed of similar type and properties. The material possessing the most likely commercial possibilities in this direction appeared to be one of the more recently developed age-hardening bronzes, namely, that containing 88 copper, 5 nickel, 5 tin and 2 per cent. zinc.

This cast alloy, after suitable heat-treatment, compares most favourably with rolled phosphor bronze so far as mechanical properties are concerned, as will be observed from Table I, and it has also a similar structure. Furthermore, no undue difficulty had been previously experienced in the production of sound sand castings, and little initial apprehension existed relative to the scheme finally devised to utilise cast-iron permanent moulds as being the most economical foundry method for the manufacture of 28-in. bars in diameters varying from about $\frac{5}{8}$ in. up to 3 in.

Centre Porosity Defect

Preliminary trials, however, proved disappointing, as bars of the alloy in question cast in this way suffered from slight centre porosity practically along their entire length. Now porosity, however slight, inhibits age-hardening and prevents the necessary mechanical properties being obtained following heat-treatment. The cause of this porosity seemed to be due to the rapid cooling effect of the mould, in conjunction with lack of fluidity in the metal which prevented the necessary degree of feeding taking place. Similar trouble can be experienced in the chill casting of 88:10:2 gunmetal bars to B.S. Specification 382-3/1940 when the presence of centre porosity causes the founder some difficulty in meeting test requirements. Parenthetically, it may be observed that, partially due to this, founders who chill test-bars will find the mechanical properties as specified for 88:10:2 chill-cast bars are actually less than for sand castings. This difficulty is minimised by pouring the moulds through a jet runner between $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter, according to the size of sticks being produced, in an endeavour to obtain instantaneous solidification throughout the section. The adoption of this method did not, however, eliminate the centre porosity in the 88:5:5:2 nickel bronze. Other expedients were tried without any real measure of success. For example, it is known that bronzes containing over 1 per cent. phosphorus are free from centre porosity when chill cast, due to their extreme fluidity and wide freezing range. Accordingly, steps were taken to increase the fluidity of the nickel bronze by the use of hot moulds, by the use of higher pouring temperatures and even by altering composition so far as this permitted without completely upsetting the final mechanical properties obtained on age-hardening. None of these modifications eliminated the trouble, and satisfactory results were only positively obtained after the adoption of centrifugal casting methods.

This incident clearly indicates that the material used for the permanent mould plays an important part in the production of sound castings. Moulds which cool the casting rapidly (*e.g.*, cast iron, silicon carbide, etc.) are likely to produce better castings both as regards density and mechanical properties when used with alloys having the common entity of adequate fluidity, and in addition a very wide low-temperature freezing range, or in the absence of this, a low order of liquid shrinkage. A wide freezing range will obviously assist feeding under conditions of rapid chilling, whilst there will be no need for feeding in the absence of liquid shrinkage. Very few of the copper-base alloys used in the non-ferrous foundry have these properties.

cent. tin leads to the formation of excessive delta constituent, which further reduces strength and ductility. This can, however, be corrected by annealing.

Some idea of alloys in the other category, those possessing a low order of liquid shrinkage, can be obtained from Table II. It will be observed that aluminium bronze and manganese bronze are possibles in this direction, which tends to bear out practical experience, as both these materials are not readily affected by fairly wide variation in cooling rates. It should also

TABLE I.—*Effect of Mould upon Mechanical Properties of Some Cast Non-Ferrous Alloys.*

Alloy.	Chill cast.		Sand cast.		Remarks.
	M.S. Tons per sq. in.	E. Per cent.	M.S. Tons per sq. in.	E. Per cent.	
Phosphor bronze (10.5 per cent. Sn, 1.0 per cent. P)	20.7	1.5	15.0	4.5	It is essential to cool this alloy rapidly if satisfactory results are to be obtained. Slow cooling is detrimental.
Gear bronze (11.5 per cent. Sn, 1.5 per cent. Ni, 0.05 per cent. P)	14.0	1.5	24.6	19.8	Rapid cooling is detrimental unless assisted by centrifugal action. Slower cooling as obtained from sand or partially-chilled moulds is to be preferred.
Gunmetal (88:10:2)	15.0	6.5	19.0	25.0	
Nickel bronze (5 per cent. Ni, 5 per cent. Sn, 2 per cent. Zn)—heat-treated	23.4	5.0	34.2	18.0	
Heat-treated (centrifugally cast)	31.6	17.0	—	—	
Brass (44 per cent. Zn, 1 per cent. Sn)	21.0	25.0	16.0	25.0	Rapid cooling gives best results.
Aluminium bronze—					
8 per cent. Al	26.2	48.0	24.9	48.5	Cooling rate within wide limits has little effect on properties.
9.3 per cent. Al	27.8	21.0	30.2	31.0	
Manganese bronze—					
Ordinary	30.0	28.0	28.0	25.0	
High tensile	44.0	25.0	42.8	23.5	

NOTE.—Chill-cast test-bars machined from vertical cast sticks 1 to 2 in. dia. with exception of centrifugally cast nickel bronze.

Cast Phosphor-Bronze Sticks

Phosphor bronze containing 10 per cent. tin and between 0.5 and 1.0 per cent. phosphorus has a wide freezing range, and will produce chill-cast sticks entirely free from porosity. Furthermore, as will be observed from Table I, rapid chilling promotes maximum mechanical properties. If the freezing range be reduced by decreasing the phosphorus content, centre porosity on rapidly cooled bars becomes evident by the decrease in strength, and slower cooling methods must accordingly be adopted. In addition to the presence of centre porosity, rapid cooling of bronzes containing around 10 per

be clearly understood at this point that the remarks just made apply to castings of even section made *entirely* in a permanent mould having pronounced chilling effect. They do not necessarily apply to castings which are only partially chilled or of variable section.

Under conditions of slowest cooling, such as would arise when using the ordinary refractory type of permanent mould, alloys having a very wide freezing range such as the bronze containing 1 per cent. phosphorus should be avoided for obvious reasons. Apart from this exception all the more common copper-base materials can probably be safely employed providing the usual precautions are taken in regard to contraction and the provision of adequate runners and risers. In fact, conditions are similar to dry-sand practice, with the exception that the mould is designed to produce several castings instead of one.

Design of Mould

In between these two extremes a good deal of ingenuity can be displayed in designing the best type of permanent mould to regulate cooling conditions best suited for any particular casting or alloy. For example, the chilling effect of a cast-iron mould could be reduced to promote better feeding of the casting made in it by decreasing the thickness of the mould wall or by the use of a refractory coating, such as is employed in the Holley permanent-mould process for the production of grey iron castings. Very often, too, the application of refractory inserts or cores to a metal mould, or alternatively the inclusion of a chilling insert to a refractory mould, is all that is required to obtain satisfactory results. These modifications obviously depend to a great extent on the design of casting being made, and in view of the variety in this direction it is impossible to do justice to this aspect in the space available on this occasion. It might, however, be mentioned that according to the experience gained in the light castings industry, where sections tend to be light, there is something to be said for the employment of the thinnest possible metal mould section for the majority of alloys in order to prevent excessive chilling which, of course, makes the molten metal sluggish. Frequently in the production of light aluminium castings, an auxiliary heating agent has to be employed on the mould, generally in the form of gas jets, in order to assist fluidity. Furthermore, by proper design of the mould, it is nearly always possible to obtain progressive solidification of the casting being made, which is a distinct asset in many cases.

TABLE II.—*Liquid and Solid Contraction of Some Non-Ferrous Alloys.*

Alloy.	Shrinkage (volume per cent.). Liquid.	Solid.
Aluminium alloy (11.0–13.0 per cent. silicon)	3.5	—
Copper (deoxidised)	3.8	6.9
Aluminium bronze (90 per cent. copper, 10 per cent. aluminium) ..	4.1	7.1
Manganese bronze (40 per cent. zinc, 1.25 per cent. iron, 1 per cent. aluminium, 0.5 per cent. manganese, 0.5 per cent. tin)	4.6	6.9
Nickel silver (20 per cent. nickel, 15 per cent. zinc, 65 per cent. copper)	5.5	6.6
Nickel (98 per cent. nickel, 1.5 per cent. silicon, 0.1 per cent. carbon)	6.1	8.1
Monel (1 per cent. silicon)	6.3	7.6
Gunmetal (5 per cent. tin, 5 per cent. zinc, 5 per cent. lead)	6.3	4.3
Yellow brass (27 per cent. zinc, 2 per cent. lead, 1 per cent. tin) ..	6.4	6.0
Nickel silver (20 per cent. nickel, 15 per cent. zinc, 4 per cent. tin, 5 per cent. lead)	6.5	5.6
Aluminium-rich alloys not containing silicon	6.5–8.0	—
Bearing bronze (10 per cent. tin, 10 per cent. lead)	7.3	3.9

Effect of the Metal on the Mould

Coming now to the second factor—effect of the metal on the mould—it can be assumed that cast iron and various kinds of refractories are the principal materials of interest. Owing to the relatively high temperatures involved, the casting of copper-base alloys ultimately causes failure of cast-iron permanent moulds through cracking or surface "crazing," so the life of these is limited. The composition of the iron used for the mould, together with the composition and design of the casting being made, has an important effect on the life obtainable. For general purposes a low-phosphorus cast iron having a composition as shown at A in Table III is usually employed. For very massive methods it is desirable to use a hematite-type base iron, high in total carbon in order to get some degree of resilience as shown at B. In this latter type, freedom from premature cracking and crazing may be obtained by adding 1.5 to 1.7 per cent. nickel with 0.4 to 0.6 per cent. chromium. For special work, *i.e.*, moulds for centrifugal casting machines, requiring high strength combined with good thermal shock and heat-resistance, the use of composition C, which contains molybdenum as well as nickel and chromium, is to be preferred.

TABLE III.—*Composition Employed for Cast-Iron Permanent Moulds.*

Element. Per cent.	A.	B.	C.
T.C ..	3.0–3.3	3.5–3.7	2.8–3.0
Si	1.2–1.6*	1.2–1.6*	1.6–2.0*
Mn	0.8–1.2	0.8–1.2	0.8–1.2
P	0.30 max.	0.30 max.	0.20 max.
S	0.12 max.	0.12 max.	0.12 max.
Ni	—	1.5–1.7	2.5–3.0
Cr	—	0.4–0.0	0.5–0.7
Mo	—	—	0.6–0.8

* According to sectional thickness.

In addition to thermal stress and high temperatures, the cast iron used for moulds has also to withstand attack by molten metal, the extent of which is determined by the alloy used. The aluminium oxide film, for example, so readily formed on the surface of molten aluminium bronze affords a large measure of protection to the cast-iron mould, a fact which is mainly responsible for the high position which this alloy occupies in connection with permanent-mould castings. Accordingly, the life of moulds when casting aluminium bronze is greater than that obtained with straight manganese bronze and brasses. It might be presumed that the use of a heat- and corrosion-resisting cast iron, such as Ni-Resist, would have possibilities for permanent-mould work. Whilst such material is probably more resistant to crazing, as shown by Fig. 1, it must not be forgotten that austenitic cast iron has a very high coefficient of expansion which is liable to lead to the development of excessive thermal stresses in many instances and consequent liability to cracking

Mould Dressings

The use of a suitable dressing also materially assists in protecting the mould face. For simple castings made in open moulds such as ingots, sticks, etc., a paste made from rape or lard oil with finely ground plumbago has reliable qualities, and ordinary blacklead grate polish makes a good substitute. For more intricate work in closed or centrifugal moulds very great care must be taken to see that the dressing is not too "gassy," and a plain rub with plumbago is to be preferred. In practice an attempt is made to keep the mould at a temperature usually between 200 and 250 deg. C.

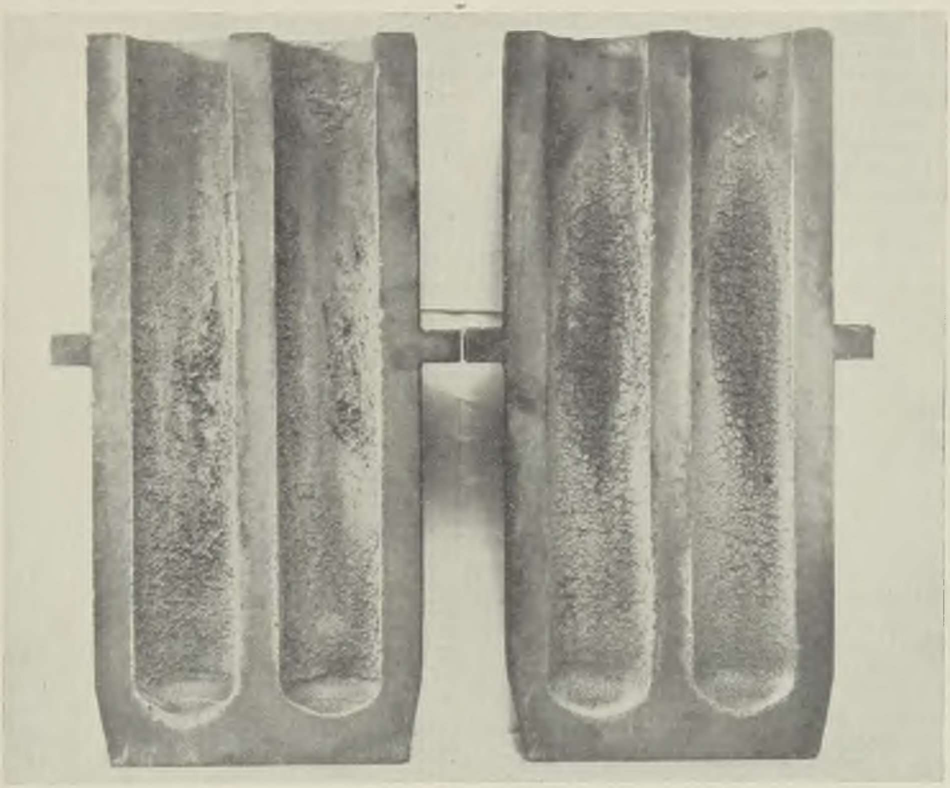


FIG. 1.—APPEARANCE OF "NI-RESIST" (LEFT) AND ORDINARY GREY IRON (RIGHT) HALF-MOULDS AFTER USE ON MANGANESE-BRONZE INGOT PRODUCTION.

Any cores that may be required for castings made in iron moulds can be of the ordinary sand type or where design permits of carbon, low-alloy or heat-resisting steel. In the majority of cases, the cheaper steels are employed except where the cores are small and apt to become overheated, when the use of heat-resisting steel becomes essential. The life of a cast-iron mould on non-ferrous work will vary considerably, according to the size, design and composition of the articles being made, and may be anything up to 10,000 castings.

The idea of making refractory moulds which can be used for more than one casting has long occupied the minds of many practical foundrymen, and there has been no lack of attempts in this direction. In 1928 particulars were given in "The Foundry Trade Journal" of the Büsselmann process developed in Germany for the production of grey iron castings, when it was claimed that by its use in the manufacture of large columns 33⅓ per cent. was saved on moulding time and 25 to 30 castings were repeatedly secured from one mould. The material used for the long-life mould was approximately:— 2 parts ground fireclay; 2 parts china clay; 1 part coke; 3 parts silica sand; 4 parts high-quality moulding sand; 3 parts clay water. These materials were ground and mixed in a pan mill to a ramming consistency with the addition of extra moisture if necessary. It was also pointed out that by the addition of 2 to 4 parts of asbestos fibre the permanence of the resulting mould could be increased by 20 to 25 per cent.

There is nothing original about this particular mixture, and it has been quoted primarily to illustrate the point that a fireclay mould has been successfully used for the production of more than one casting. The fact that iron castings were produced in this particular instance does not matter very much, as such a mould will obviously work equally well with non-ferrous material like gunmetal, etc., if due allowance be made for the difference in contraction between the two metals. It is, however, of great importance to remember that such a mould—and this applies to all refractory materials used for this purpose—must be handled gently both by men and metal. One appreciates that moulds of this type cannot be thrown about, but it is often forgotten that the stresses imposed upon the mould by the metal are liable to do just as much damage. Accordingly provision must be made for the contraction of the casting to be either taken up by some softer material than the mould, or to get it out of the mould before contraction commences.

It must also be emphasised that very thorough drying of fireclay long-life moulds at the highest possible temperature before use is of very great importance. This is required not only to remove moisture but to ensure that any volume change likely to arise on heating is developed throughout the mould, rather than to have a large differential volume change occur following contact with molten metal during the casting operation. In many instances, the high temperature required to stabilise the ordinary fireclay mould is beyond the capabilities of most foundries, but this can be overcome by using a

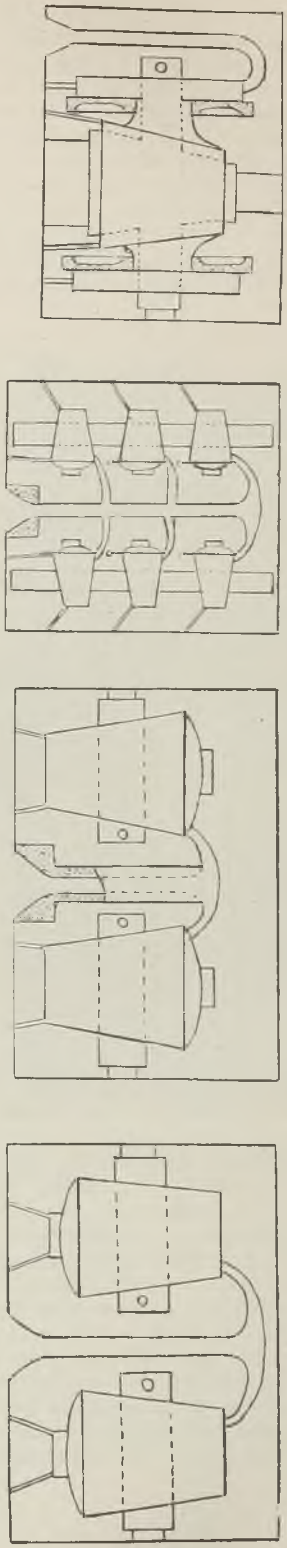


Fig. 2.—Possible Designs of Permanent Moulds for Gunmetal Castings.

A—Plugs for Cocks. (Medium and Large.) Bad design. Runner restricts contraction of the casting and runner and ingates are too long.

B—Plugs for Cocks. (Medium and Large.) Better design. No restriction on casting contraction. Runner and ingates short. Runner formed by renewable oil-sand or soft dry-sand bush, which enables hot metal to reach castings and permits free contraction of runner.

C—Plugs for Cocks. (Small.) Suggested method of making small plugs.

D—Plug Cock. Note collapsible cores to assist inward flange contraction. It may also prove advantageous to bush runner as in B.

refractory base which has already been stabilised, such as sillimanite or crushed old firebricks.

A permanent mould mixture made from either of these materials bonded with 3 to 5 per cent. sodium silicate is not only more resistant to thermal changes than fireclay mixtures but is also much stronger after drying. Such a mixture has not a high green-bond strength and accordingly requires a certain amount of care to be taken during moulding. It rapidly air-hardens, however, in a warm atmosphere and patterns can usually be drawn, if the freshly rammed mould is allowed to stand for some time. Alternatively gaggers or nails can be conveniently employed to reinforce weak or thin sections. The addition of a bonding material such as clay is not recommended. Old newspaper is the best parting medium.

All the silica-base, long-life mould materials have poor thermal conductivity and therefore do not exert much chilling effect on the casting. This can, however, be readily overcome by the use of a silicon-carbide mixture as previously suggested by the author.[3] In fact it is quite a practical proposition to employ a composite mould, using silicon carbide where chilling is required and a base of crushed firebricks elsewhere.

Suitable dressings for such refractory moulds comprise a mixture of plumbago with water to which has been added just enough sodium silicate or core gum to make it adhere to the mould. Application should be by means of a spray. If core gum be employed for bonding purposes, the mould should be dry-brushed and redressed after each cast. The mixture utilising sodium silicate is more permanent and will last two or three casts before renewal. It is inclined, however, to " build-up " and become patchy if care is not taken. Alternatively a coating of soot deposited by means of an acetylene flame can be employed.

In addition to the use of metal and refractory materials for permanent-mould work, mention might be briefly made of the Holley process[4] which is a combination of the two using a cast-iron mould faced with refractory (china clay bonded with sodium silicate). This process has been successfully applied to cast iron, and there appears to be no logical reason why it should not give results with copper-base non-ferrous alloys providing due consideration be given to the fundamental factors entailed in the founding of different metals.

Type of Castings Suitable for Production in Permanent Moulds

Following consideration of the factors which affect both mould and metal, the only other point outstanding is the question of the type of casting most suitable for production in permanent moulds. This will be principally determined by design and also, as previously pointed out, by the properties of the alloy employed.

So far as design is concerned it is obvious that simple symmetrical shapes are particularly adaptable to manufacture in long-life moulds, and it is surprising how many such castings are available. Valve bodies, taps, cocks, plugs, valve doors and valve wedges, valve lids, spindle nuts, handwheels, bearing shells, valve guides, small propellers, slip-rings, bushes, etc., are just a few examples which readily come to mind. All of these could be made from permanent moulds, but very few serious attempts have as yet been made to do so. Furthermore the advantages to be gained outweigh any practical difficulties likely to arise. The most troublesome factor is undoubtedly that of contraction, particularly in the case of bronzes and gunmetal; if unrelieved, it leads to actual cracking of the castings before they can be extracted from the mould. Much can, however, be done to minimise trouble in this direction by intelligent design of both casting and mould and, where necessary, the use of collapsible inserts made from oil sand or soft dry sand, as shown in Fig. 2. Particular attention should be given to the possible effect of runners and risers restricting contraction, and if there is any chance of this happening collapsible insert bushes should be again employed. Apart from relieving contraction this latter adaptation also materially assists in lifting and increasing the life of top parts if it has been found necessary to pass runners or risers through them. Very often contraction troubles can be reduced by placing runners at a different point. Alternatively it may be found expedient to overcome contraction effects by the use of a different alloy for casting purposes. For example, it will be extremely difficult to produce a gunmetal spoked handwheel of any size from a permanent mould without the presence of contraction cracks, and here the use of collapsible inserts cannot obviously be applied. However, by the use of aluminium bronze, with its lower liquid contraction, the job becomes feasible. If a still greater margin of safety be desired, the hot strength of aluminium bronze can be appreciably increased by the addition of 3 to 4 per cent. nickel. The substitution of tin by nickel in the bronzes and gunmetals is also useful in preventing cracking for similar reasons.

REFERENCES

[1] Roshirt, R. J. (manager, Permanent Mould Division, Bohn Aluminium and Brass Corporation): " Permanent Mould Castings in Aluminium," "Foundry Taade Journal," December 17, 1936, page 470.

[2] "Permanent Moulds for Iron Castings," "Foundry Trade Journal," December 13, 1928, page 435.

[3] Hudson, F.: "Heat Conductivity of Mould Materials," "Metal Industry," May 21, 1937. "Semi-Permanent Moulds for Non-Ferrous Casting Production," "Foundry Trade Journal," July 18, 1940, page 39.

[4] Hoenicke, E. C.: "Permanent-Mould Casting Developments," "Foundry Trade Journal," February 8, 1910, page 115, February 22, 1940 page 152.

DISCUSSION

Rate of Pouring

MR. R. H. BUCKLAND, who presided in the absence of Mr. S. E. Dawson through illness, opened the discussion by drawing attention to the physical propeıty figures given by chilled castings which he said in comparison with sand cast results were really astounding, and these facts indicated that a founder must know the peculiarities of the metal he was using before he should decide to introduce permanent moulds into the foundry. There was one point on which Mr. Hudson might elaborate, and that was in connection with the rate of pouring, on the life of the mould. It would appear that the more constant the temperature of the mould, the longer its life, and therefore the rate of pouring the moulds must be of considerable importance.

MR. HUDSON, in reply, said providing a reasonable attempt was made to control the temperature of a cast-iron mould a considerable life was obtained. If a large number of castings were available, the simplest way of controlling mould temperature was to ensure that sufficient moulds are available to take all the metal from one particlar heat. By the time the next heat was ready the moulds will have cooled down normally in air to a safe limit. The need for the control of mould temperature in the case of refractory moulds was, of course, not so important.

Object of Permanent Moulds

MR. F. DUNLEAVY asked whether a permanent mould or a long-life moulding only was used as a means of producing high-quality castings or was it a means of increasing production? How 150 castings could be produced from one permanent mould in one heat and maintain the heat of the mould at 200 to 250 deg. throughout the pouring of these castings was from personal experience, a difficult proposition. This experience, however, had been confined to producing castings from one permanent mould only, and he would like to ascertain how many moulds would be necessary to produce, say, 50 handwheel castings. With annually changing design this reacted unfavourably in the application of permanent moulds.

A personal problem was that non-ferrous castings were ordered to-day and it was expected they would either be "cast" the same day or at least the following day and delivered as fully machined castings from the machine shop the day after. This practice made the use of permanent moulds an impossibility. Had Mr. Hudson any experience in the direction of producing aluminium bronze castings in the form of chilled bars for billets, and had he successfully solved the problem of eliminating the formation of dross when producing such castings normally? He finally congratulated Mr. Hudson on the design of the dry sand insert in the permanent mould for the production of non-ferrous valve castings, to permit the normal metal shrinkage.

MR. HUDSON replied that he had attempted to give the advantages and disadvantages of permanent moulds in their application to the production of non-ferrous alloys and suggested that each individual foundry would have to satisfy itself how this type of mould could best be applied to its own requirements. One type of foundry may find it an advantage to use the permanent mould in the production of high-duty castings whilst another may use it to increase production.

Cooling Arrangements

No doubt a metal mould would increase in temperature when the castings were poured, but there are several methods by which the temperature of the mould could be controlled, such as for example by air-blast or water spray. The refractory type of mould with its lower thermal conductivity could, of course, be allowed to reach higher temperatures.

Permanent moulds could be used to advantage in the production of castings such as hand wheels because it was unlikely that any particular metal would be specified and a wide range of non-ferrous alloys was available. Every advantage should be taken of this and it would be easily possible to produce 50 castings per day from two moulds, increasing to 100 per day after practice. It would, of course, not be wise to select gunmetal or bronze for hand wheels as contraction difficulties would be nearly unsurmountable. There should, however, be little trouble in utilising either aluminium or manganese bronze.

The production of chill-cast aluminium bronze billets is not a difficult job. The author gave a Paper on this subject published in "The Foundry Trade Journal" (February 2, 1933, page 86), which fully covers the matter and the recent book on "Aluminium Bronze," obtainable free from the Copper Development Association, is also worthy of reference. Bottom-poured chill moulds should be used or top pouring by the Durville method. Dross is avoided by the absence of turbulence during pouring and is assisted by the use of a special flux (Albral, etc.) which removes alumina during melting. In castings of complicated design the formation of oxide can be minimised by filling the mould with carbon-dioxide or nitrogen and casting from a bottom-pouring ladle through a tube filled with one or other of the gases mentioned.

Bearing Bushes

MR. F. J. BUTTERS said there were two aspects which call for explanation. Since showing the slide giving the resultant strength of chilled and sand cast castings, also the illustration of castings suitable in design for permanent mould casting, it would appear these castings could run themselves, as they seem to be "moulders' dreams." One casting produced in quantities of 100,000 annually was a phosphor bronze bearing bush, of 2 in. diameter by $1\frac{1}{2}$ in. long, 1 in. cored hole, and cast as complete bush. Could this be produced cheaply by permanent mould method, because there was a pip on the side of the casting to prevent it revolving when assembled. Could the lecturer say how many moulds would be required and some suggestion as to the most suitable method of design. At the present time castings were produced 18 per box, and production time was 3 mins. per box. Would permanent mould production show a saving on the present method of production, and would it be essential to use an oil-sand core to produce this cored hole when using a permanent mould.

MR. HUDSON, in reply, said that general practice to-day was for phosphor bronze bushes to be produced from chill cast solid or cored sticks rather than from individual castings. Apart from the foundry, this method in the majority of cases facilitates operations in the machine shop. Might it not be possible for Mr. Butters to adopt a similar technique, which would conceivably simplify production and make the use of permanent moulds a practical proposition?

For the production of castings in this manner a cast-iron, top-poured chill mould would be required in three parts, consisting of two sides and a bottom. A print for the core would be located in the bottom mould portion, whilst the top of the core would be held by a cross-bar. Oil-sand or loam cores can be used providing they are stiffened by robust wire or core bar. The use of a rotary core-machine for oil-sand core production is useful, as this will turn out a cylindrical core with a hole down the centre to take the wire after drying.

Regarding the application of the data given in this Paper, it is for the foundry to decide by what method they could best be applied. Many of the examples shown might constitute "moulders' dreams," but nevertheless they are made in large numbers, and accordingly it is well worth while considering alternative methods of production, apart from making them in sand.

Porosity in Age-Hardened Alloys

MR. W. C. GLADWELL asked whether the lecturer could give further information as to the use of sodium silicate as used for mould dressing? He was interested in the production of the centrifugal bars, and would like more information regarding size and shape. With reference to porosity in age-hardened metal, was this defect present with non age-hardening alloys. Is it an advantage to pour quickly or slowly when teeming non-ferrous alloys into permanent moulds.

MR. HUDSON, in reply, said that a more common name for sodium silicate was waterglass. Regarding the production of centrifugally cast bars, the method employed had been described in "Aircraft Production," July, 1940, page 211, and reference should be made to this for any further information required. Centre porosity in chill-cast bars can be present regardless of whether the alloy was of the age-hardening type or otherwise. The presence of porosity was, however, of particular importance in alloys, which must be subsequently heat-treated, as it obviously prevented maximum mechanical properties being developed.

It was not feasible to give any general comment about the pouring speeds required in permanent mould practice as so much depended upon the design of casting being made and the type of alloy used. In the majority of cases, however, fairly rapid pouring was required to facilitate foundry practice.

Size Limitations

MR. T. GOODWIN thought anyone could adopt permanent moulds for non-ferrous work of a fairly simple nature if there was a sufficient quantity ordered. What size moulds would be best adapted to this practice? Mr. Hudson mentioned a German process for producing a semi-permanent refractory mould. Had the author ever seen it in service, and could he give any figures regarding the length of life of the mould; if so, were these figures accurate, because, obviously, when the figures given could not be confirmed, they were useless?

MR. HUDSON said the size of moulds which could be best adapted for this practice would largely depend upon design. It should not, however, be imagined that these will always be of relatively small size. He saw no serious objection to making quite large castings successfully in permanent moulds if due consideration was given to the factors mentioned in the Paper. He could not give any more facts about the German process than were disclosed by the article in "The Foundry Trade Journal," which stated that the length of life was between 20 and 30 castings, and he had no reason to doubt this information, because from personal experience refractory moulds had been known to produce this quantity of castings.

Age-Hardening Practice

Mr. E. Holland wrote that he was interested in the remarks relating to heat-treatment and age-hardening of certain non-ferrous alloys, and asked for comments on the following:—What was the temperature and duration of this treatment? What was the precise action of this treatment on the matrix of the metal? Was the age-hardening necessary, because the nickel was not finally in equilibrium and required stabilising, or was it merely an annealing action to normalise the effect of the chilling action of the mould?

Mr. Hudson wrote in reply that the heat-treatment to promote age-hardening in the case of the 5 per cent. nickel, 5 per cent. tin, 2 per cent. zinc bronze mentioned in the Paper was conducted in two stages. A solution treatment was first given consisting of reheating the castings at 760 deg. C. for about 2 hrs. and furnace-cooling down to 550 deg. C., and then quenching in water. This was followed by a low temperature hardening treatment, comprising reheating between 320 to 350 deg. C. for 5 hrs. and again quenching in water.

The precise action of this treatment on the structure of the metal cannot as yet be fully explained by the knowledge available, but it was not due to any segregational effects of nickel. After age-hardening, a definite structural change occurred which could be clearly observed under the microscope, introducing a third constituent, and it was due to this that the enhanced mechanical properties were obtained.

Vote of Thanks

Mr. H. J. Beck, in proposing a vote of thanks, said that the application of permanent mould would be studied with interest by all concerned

Mr. G. L. Harbach, in seconding, said he had listened with interest to the lecture, and would no doubt take advantage of Mr. Hudson's offer to reply to further questions by correspondence after the Paper had been published.

The vote of thanks was carried with applause, and Mr. Hudson suitably replied.

The Outline of Cupola Control*

By C. A PAYNE

The statement, "Every cupola is a law unto itself," is more correctly, "Every cupola operator takes the law unto himself." Melting metals in contact with solid fuel is based on fundamental chemical and physical principles. Variations in materials and melting conditions are the only causes of variations in the final product. Ideal conditions of chemical reactions cannot exist, but standardised conditions must be achieved for a control seeking maximum melting efficiency and a constant product. This is not necessarily molten metal at minimum cost per ton, but means minimum cost per ton of metal, converted into good castings.

This Paper expounds the following analysis of cupola control: —

- CUPOLA
  - Design
  - Maintenance
  - Preparation
- RAW MATERIALS
  - Metal
  - Fuel
  - Air
  - Fluxes
- MELTING
  - Charging
  - Air-Supply
  - Tending

The Cupola

Design

A given hourly tonnage is obtained under optimum conditions with a definite diameter inside the lining. All other dimensions can be expressed proportionally to this diameter. Height to charging-sill should give adequate cooling of gases by the stock without the weight of stock being sufficient to crush the bed-coke. The well-capacity, fixed by weight and rate of tapping, determines the height of slag-hole and tuyères.

The tuyère size should be adequate to admit the air for burning one coke charge in the requisite time. Tuyère shape should give uniform blast velocity and distribution, these being affected also by the dimensions—width especially—of the wind-belt. The blower should supply this air at minimum pressure consistent with penetration of the stock, the diameter of the blast-main giving minimum velocity changes.

The lining—parallel for best results—should keep the shell at reasonable temperatures, without being so thick as to raise structural and economic—replacement—difficulties.

Maintenance

Excessive lining irregularities indicate stripping and relining of the zones involved. "Armour-plating" below the charging-sill is to be recommended. Tuyères, on the first signs of warping or burning-on, should be replaced. Sight-holes and covers should be kept air-tight and easily manipulated. Leaks and obstructions in blast-main and wind-belt should be immediately rectified. Tapping and slag-spouts should be kept rigid, and replaced when burnt.

Preparation

This involves a definite routine, controlled materials, and efficient tools. Fettling, to remove slag and metal accretions, which overdone means excessive patching, and which insufficiently done involves unreliable patching. Patching, to restore the standard lining dimensions, requires minimum moisture compatible with plasticity and adhesion, maximum ramming, venting, and drying time. The bottom, of controlled material rammed to a standard slope, the tap-hole accurately located on this bottom, and the spout of consistent dimensions and uniform slope, are the final items.

Patching requires as long an air-drying as possible, final drying being by means of a fire kept below tuyère level. The bed-coke is put on a portion at a time, each portion burning through thoroughly before further additions. The bed-height, checked after poking and levelling, is fixed by the melting zone, and is a function of blast-pressure. Above this are required the layer of "safety-coke" and the layer of charge-coke for the first charge. The melting zone is best located by the position of maximum burning back of the lining.

Raw Materials

Metal Charges

Of each element to be controlled in the final product, the percentage present in every charge constituent—pig-iron, scrap steel, cast iron, etc.—must be determined. Mode of occurrence, and changes during melting, of each element affect the balance of the charge. Size, shape and cleanliness of materials are also vital points.

Fuel

Coke is essentially impure carbon. Carbon being the source of heat, impurities, as moisture,

* Winning entry to a short Paper Competition organised by the East Midlands Branch.

ash, etc., must be known. Impurities picked up by molten iron should be at a minimum. Strength, to support the charges in the cupola, should be at a maximum. Size, dependent on cupola diameter, should be regular.

Air

This is the vehicle for supplying oxygen. The quantity of oxygen per unit quantity of air is affected by the moisture, the temperature, and the pressure of the atmosphere. Changing atmospheric conditions necessitate changes in air supply to maintain a constant oxygen supply for constant combustion conditions.

Fluxes

All impurities forming slags with the active fluxing agent should be at a minimum.

Melting

Charging

The chemical analysis and physical properties required determine proportions of charge constituents. Cupola dimensions fix charge-weights and material dimensions—maxima for individual pieces to avoid scaffolding and baffling effects. Order of charging, more important with steel-bearing charges, is determined by the carbon pick-up characteristics of the cupola. Low pick-up cupolas require steel charging on to coke, followed by, say, return scrap and pig-iron, the reverse order being used with high pick-up cupolas, depending, of course, on carbon content required.

Level charging is vital; each coke-charge should be a complete layer between metal-charges. The charging-rate, fixed by melting-rate, should maintain the stock at charging-sill level.

The charge-coke weight, fixed by cupola dimensions as a 7 to 8 in. layer for optimum conditions, determines the weight of metal-charge according to the metal/coke ratio required. Compensations for coke compositional variations can be made to either coke or metal charge.

Air Supply

The melting-rate is a "carbon—or coke—burning-rate." For given combustion conditions the air—of predetermined oxygen content—to burn 1 lb. of carbon is fixed, hence, volume of air in unit time is fixed. Consistent product needs constant melting-rate, meaning constant volume at constant pressure. Reliable, correctly fitted gauges are needed.

The tapping-rate should coincide with the melting-rate. It is controlled by correct timing in intermittent, or correct tap-hole size in continuous tapping. Slagging-out, done most efficiently with a full well, should be at regular intervals. Tuyères should be kept slag-free by judicious poking which also keeps the coke-bed solid.

Cupola control ends with hot metal in really hot, clean ladles of known capacity—this hot metal having properties predetermined within very close limits. Regular observations of melting conditions, of the condition of the metal at the tapping-spout and in actual casting, and regular examinations of the slag, of the drop and the lining at the end of a blow are as vital to successful control as are regular analyses and physical tests of the final product. Only on accurate knowledge is stable progress based.

DISCUSSION

Mr. H. Bunting, in opening the discussion, congratulated Mr. Payne on being the winner, and also highly commended the other entrants, adding that they were the very best set of Papers ever submitted. The author of the winning Paper said the cupola was a law unto itself and the operator a law unto himself, but he did not think the reference to the law was correct. In a personal experience extending over 46 years in foundry work, he (the speaker) had not yet found a cupola that conformed to any law, and cupola operators are noted for being very temperamental. A second point was that the author recommended poking through the tuyère, which he doubted was good practice, and wondered if good results had been consistently obtained. Mr. Bunting said he was not clear as to pressure and volume, as it was suggested in the Paper that good pressure was preferable to good volume. Pressure was not the goal of cupola practice, and he considered volume to be more important than pressure.

What exactly did the author mean by patching and air drying, as foundries quite often operate two cupolas on alternate days; what was meant by "reasonable drying time"? The cupola must be ready for the next day even if it did not need patching. The author also mentioned carbon was a source of heat. Carbon must combine with oxygen, therefore oxygen was as important as carbon.

Tuyère Poking Practice

Mr. Payne, in reply, said the statement "Every cupola is a law unto itself" was a tacit admission of the large field of knowledge of the cupola yet to be gained. The greater knowledge possessed, the more definite would become general laws for all, *i.e.*, cupolas in general, not merely a certain cupola under consideration.

Poking through the tuyères in ideal practice would be not only bad practice but totally unnecessary. In actual practice, however, judicious poking was essential if slag-free tuyères and a solid bed were to be assured. This judicious poking had made a very noticeable improvement to the metal obtained on all cupolas of which the author had had experience.

Pressure of air was no criterion of melting conditions. It was the blast-volume that was paramount, but when a cupola was operating with a constant, optimum, air-volume, then pressure-variations could be taken as " barometer readings " of conditions inside the cupola.

When patching was applied to the lining, this material should be allowed to dry out for the longest possible time, at the normal atmospheric temperatures. The length of time available for this " air-drying " was governed by the frequency with which the cupola has to be used. In one case in the author's experience it had definitely paid to get a man working nights, to re-patch a cupola in daily use.

Carbon and oxygen individually were useless to the cupola operator, but when brought together in combustion, heat was produced, the carbon being the source of heat only as far as the solid fuel—coke—was concerned.

Formation of Tap-holes

Mr. J. C. Hallamore asked whether the cupola envisaged was one of imagination or reality. Was it charged manually or by mechanical method, and which method did the lecturer recommend? Mention was made of regular tapping. What method was used to form a regular sized tapping hole? The lecturer also stated that coke should be measured by weight. Did he consider this a better method than measuring coke charged by volume?

Mr. Payne said that the Paper did not describe the working of a particular cupola, but set out the principles on which every cupola could be operated. The use of hand or mechanical charging was immaterial, provided uniform and level charging was achieved—a factor needing control in either method. Regular tapping-holes would appear to be best formed by using shaped bricks, with the tap-hole or holes of standard dimensions to within fairly close limits. Refractory brick manufacturers had both plant and experience in production of standard shapes, and could best solve this problem.

The ultimate aim in charging coke was to charge a definite weight of carbon. Measuring coke by volume was not upset by variable moisture contents, but certainly did not correct for variations of ash or volatile contents,

Standardisation Amidst Variables

Mr. J. Roxburgh, who also congratulated Mr. Payne on his effort, stressed that the Author had chosen the title of his Paper well, because in the short time at his disposal it was only possible to outline the principles of control but, nevertheless, he had managed to put a great deal into a small space.

He endorsed Mr. Bunting's observations that every cupola seemed to have, so to speak, its own individuality. Personally, he had had experience of many cupolas and had found that design and practice did not appear to be standardised but, nevertheless, it would be agreed, there were always fundamental principles on which these should be based. In cupola practice, there were many variables to control but, it would be admitted, any process was better for some degree of scientific control which might be exercised.

Despite this control, however, one still obtained differences in temperature and composition of the metal. Cupola practice must be varied in the manufacture of different types of cast iron, for instance, different practice and conditions must prevail with high steel mixtures in comparison with those for high phosphoric irons. The fact, too, that a cupola might be regularly called upon to melt during one " blow " probably half a dozen different mixtures of iron, caused complications. In such cases, consideration must be given to the order of charging of these various mixtures and contamination of one with the other cannot really be avoided. Arising from this, too, the size of the well, which held the molten metal, and the amount and frequency of each tap. were important. It should be decided as to whether the well should be large enough to hold one, two or three charges and perhaps Mr. Payne would express his opinion on this point.

With special irons, high steel-mix or alloy, where the temperature of the metal when tapped was of paramount importance, the amount of coke used should be increased as the temperature of the metal should not be sacrificed for economy of coke. Some foundries had to charge large size scrap, up to 2 cwts., at times, into the cupola and naturally more coke was required than where small " pigs " and scrap are used. With regard to tuyères, what shape did Mr. Payne recommend and did he favour one row or several rows?

Cupola practice was a very wide subject and he would strongly recommend Mr. Payne to prepare a Paper, so that the members could have a further opportunity of discussion at greater length.

Well Capacity and True Coke Economy

Mr. Payne, in reply, said Mr. Roxburgh's appreciation of the Paper was most encouraging, and he agreed with his suggestion that the subject warranted a more extensive treatment. As far as the " individuality " of a cupola was concerned, the more details known of its design, and the more standardised the operation, the greater the ability to control and predict the result.

The results required in the castings determined the mix used, the type of mix determining the properties of the molten iron according to the coke ratio used. Level charging of both metal and coke, and a complete coke layer between each charge of metal, were the prime factors in reducing charge contamination or dilution, to a minimum. With level charging, the use of extra coke charges, to cause slight delays in the melting of the first charge of a different mix, began to take effect.

The well capacity in terms of number of charges was a combined function of the maximum tap weight required, and the diameter of the cupola. The capacity should never be less than one charge and never in fractional multiples of a charge.

Economy of coke was a phrase that had been grossly abused. The truest economy of coke was its use in the ratios, determined by carefully-made observations, to give greatest efficiency, assessed by a study of purely metallurgical foundry troubles arising during the periods covered by the observations. The optimum coke-ratio could not be determined in the cost office. The maximum weights of individual pieces of the charge would be governed by the diameter of the cupola, obviously the larger the cupola, the larger the pieces—within limits—that could be charged.

Tuyère designs were legion as regards both shapes and arrangements. The obvious criteria were the simplest shape and the minimum number of tuyères to admit the volume of air required with maximum uniformity of velocity and distribution over the cross-section of the cupola.

Vote of Thanks

Mr. C. D. Pollard, in proposing the vote of thanks, said the meeting had certainly listened to some very good Papers and it gave him great pleasure to assume this duty, as the winner was one of his colleagues. The discussion had shown how much these Papers were valued by the members and he would also include in this vote of thanks the names of the authors of the remaining three Papers; Mr. E. Holland, Mr. J. C. Hallamore, and Mr. L. L. Cox.

Mr. F. Dunleavy, who seconded the motion, said the chief fault was that time was far too short for a full discussion.

Mr. Payne, replying for the authors, said he had no doubt they had all enjoyed preparing the Papers and it was very gratifying to know that the members had received them with such interest.

Sand Testing with Special Reference to Flowability and Deformation

By Wm. Y. BUCHANAN

At the presentation of the author's last Paper[1] on sand testing, there was very little discussion, the subject matter being rather difficult to contradict successfully on a first hearing. One or two members, however, appeared to be not quite in agreement with all the ideas for modifying or improving the existing generally-used A.F.A. methods. Others do not appear to grasp quite why these modifications as suggested by the Author are required at all.

During the past few years various lines of argument have been put forward, mainly with the object of eliciting a clear explanation. In this the author appears for the most part to have failed.

However, one very good contribution to the discussion, written privately, is worth quoting extensively as it probably furnishes about the best case for the opposition and may represent the views of others who have perhaps not taken as much trouble to express themselves so clearly.

The author has always held that, whether or not the A.F.A. test procedure is maintained exactly as at present, though of considerable importance, is nevertheless not so important as the fact that if used in its present form, the interpretation of the test figures and their application to foundry practice should be carried out having due regard to the inherent defects in the design of the test-piece and other influences to which the method of ramming is subject at all times. These defects in design and influences affecting the formation of the A.F.A. test-piece, which tend to perform the function of the red herring in the well-known adage, have been clearly demonstrated with extensive experimental evidence in the author's previous Papers on the subject.

A Written Criticism

The extracts from the written discussion already referred to are given below in paragraph form for convenience of reference in the reply.

Paragraph 1.—" . . . . In the first place I would like to underline several sentences in the Paper, such as 'Sand testing is among the most difficult forms of mechanical testing to perform with the degree of precision one associates with the mechanical testing of metals.'

'The subject is not one to be tackled by mere deduction and argument.'

'Sand testing is by no means above ambiguity.'

'The rate of loading does not seem to have any effect on the compression strength.'

'Since the A.F.A. test piece is most commonly used by those in the committees dealing with the matter, it must be accepted as the standard for general use.'

'The A.F.A. procedure may be referred to as a test-piece made by a standard ramming machine, where the machine only is standard, the degree of ramming varying with all conditions.' "

Paragraph 2.—" It is very difficult to give a close definition to such terms as '*Standard Ramming*' and '*Degree of Ramming*,' and this accounts for much of the ambiguity and misunderstanding. To my mind, it is sufficient to regard the A.F.A. ramming procedure as a 'standard method,' and to assess the results accordingly. Provided this attitude is adopted I think the A.F.A. procedure is satisfactory, and there is no need for the complications of the '*Index of Ramming*' with its need for the determination of the true density of every sand mixture tested."

Paragraph 3.—" I understand that the index of ramming is used to calculate the green apparent density to which a sand should be rammed so that each test-piece contains the same volume of dry solid matter regardless of moisture content, grain size, distribution bond, and specific gravity. Thus, with a sand of uniform grain-size, each test piece would always contain the same number of sand grains no matter what the moisture content."

Paragraph 4.—" I agree that a good moulder will tend to control the energy of his ramming so as to produce the required *results* (*e.g.*, high permeability here, high strength there, and so on throughout the mould), but when you associate your index of ramming method with this idea, I think you reveal one of its shortcomings. For, by trying to simulate good moulding in the ramming of test pieces, you are virtually 'trying to control the *results* by varying the ramming energy,' thus in Fig. 1 both methods give test-pieces of equal permeability at 10 per cent. moisture, but as the moisture is decreased the index of ramming method requires an increase in ramming energy to raise the green apparent density so as to maintain the dry apparent density constant in accordance with the chosen index of 13. This increase in ramming energy neutralises the effect of reduced moisture, and it is not surprising that the permeability remains constant in spite of decreased moisture content when the ramming is controlled in this way. In your own words you are 'trying to control the results by varying the ramming energy,' and consequently your results are biased because they are based on biased ramming."

Paragraph 5.—"I am afraid I am not very wise on flowability and deformation, but have always understood that flowability increased with moisture content, yet in Fig. 9 you show the reverse of this. Perhaps it all depends on what you mean by flowability, and is this term suited to the testing method adopted? Does not the bottom hardness depend on the compressive strength of the sand more than anything else, as on this property depends the transmission of ramming force from one end of the test-piece to the other."

Author's Reply

With reference to *Paragraph 2,* it might be said that, merely calling the A.F.A. system of making the test-piece a standard method does not remove its defects. It is better considered as a standard ramming machine which produces test-pieces subject to variations due to changes in flowability, uneven ramming, wrong proportions for compression testing purposes, etc. The flowability of the sand greatly influences the results by the A.F.A. method in a number of ways, as has been shown in a Paper given by the Author to the Birmingham Branch of the Institute. This work should stand at least until refuted by equally conclusive work on the subject. "The subject is not one to be tackled by mere deduction and argument."

With reference to *Paragraph 3,* the statement here is quite correct. The same Index of Ramming may be called the same degree of ramming.

The line of argument at the beginning of *Paragraph 4* is not correct. The errors which occur in the A.F.A. test-piece due to changes in flowability in the sand are not always reflected in moulding practice as is always assumed by advocates of the method, and in fact the Index of Ramming system of control produces test-pieces more representative than the A.F.A. because the Index of Ramming chosen for routine testing is determined by making hardness or ramming measurements on moulds. Thus the Index of Ramming may represent a single specific mould or part thereof or by taking an average figure to represent a group of moulds. It is true that in the Index of Ramming method all variable factors set forth here are under control, whereas in the A.F.A. method none of them is under control, and they all affect the A.F.A. test-piece, even to the degree of uniformity of ramming or lack of it, in the test-piece. The argument in *Paragraph 4* seems to be put the wrong way round when one is supposed to be examining the effect of moisture and not the secondary effect it produces in the ramming of the test-piece. By using a combination of the two methods, after some of the more serious defects in the A.F.A. test-piece, such as the lack of uniformity, have been removed, the primary effect of the variable can be assessed separately from the combination of the primary effect and the secondary or flowability effect as given by the A.F.A. test.

In *Paragraph 6* one is reminded again of the second sentence quoted in *Paragraph 1* from the author's previous Paper.

If flowability be not understood then it is not surprising that the Index of Ramming appears an unnecessary refinement. The I. of R. method alone or in combination with the A.F.A. improved as suggested, is, in the present Author's opinion ideal, being comprehensive, highly informative, and adaptable to any form of routine test or investigation.

The compression strength in the green state is the opposing property to flowability, but it cannot be assumed that flowability is governed entirely by compression strength because plasticity is also an important factor, and although these properties are closely connected they must be assessed separately and problems connected with them investigated experimentally. Fig. 9 of the last Paper shows the relation between flowability, compression strength, and deformation.

The Effect of Moisture on Irvine or Similar Clay-free Sand

Dearden[2] examined the effect of moisture on this class of sand as a foundation for his study of the general effect of moisture on moulding sand. It was stated that while the moisture percentages used included those too low and others too high to have any relation to useful moulding sands, the trend of the tests in these extreme ranges would help to clarify conclusions in more normal ranges of moisture.

The present Author doubts whether there is any practical significance in this line of research, since in no case is a moulding sand composed of clay-free material and clean water. Even the case of loam, which has been brought in, with its excessive moisture content consists of grains of sand and a thin slurry of clay wash. Conclusions and research on moulding sand testing should, however, not be based on work done on loam, as the conditions in loam are unusual and not in the least representative.

However, it has been suggested that this line of work, *i.e.,* the effect of water additions to clay-free sands, would provide some proof of the intrinsic value of the A.F.A. method of making the test-piece, and some very definite conclusions were arrived at. For example, *that silica and other clay-free sands would not ram any harder with increased moisture.*

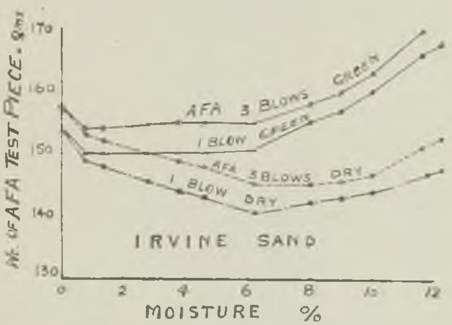


FIG. 1.—EFFECT OF MOISTURE ON IRVINE SEA SAND RAMMED BY THE A.F.A. RAMMER, SHOWING CONSIDERABLE CHANGE OF FLOWABILITY.

This, of course, is in direct contradiction to the underlying idea of the present author's statement that the A.F.A. test-piece is at all times subject to the effect of flowability in the sand being tested, since here is an example of a sand which, though not a legitimate example of a moulding sand, yet is good enough for the sake of the argument. In Dearden's example he found that, though the A.F.A. test-piece made in the standard way increased rapidly in weight over 2 per cent. moisture, the dry weight of the test-piece remained constant; that this increase was due only to the additional weight of the water. This, in effect, means that he concluded that the sand had a constant flowability.

The present Author checked this, using Irvine sand for comparison, when it was found that a distinct flowability was present even in this type of sand. With three blows of the A.F.A. rammer, this sand is inclined to be over-rammed, and it would not be surprising to find the flowability of the sand masked in these tests.

Fig. 1 shows a series of test-pieces made by the A.F.A. standard rammer, using three blows, and repeatedly using one blow to give lighter ramming. Since the same sand is used throughout the series, the true density is the same throughout, and so the Index of Ramming can be retained constant by keeping the dry apparent-density or dry weight of the test-piece constant with increase in moisture. The green-strength and permeability number will, of course, follow the trend of the change in weight of the dry test-piece, so the graphs of the dry weight of the test-piece against moisture are sufficient for the present purpose.

It will be seen from the dry weight that the degree of packing is greatest at 0 per cent. moisture, and that from 0 to 6 per cent. the moisture progressively reduces flowability, when it begins to rise again up to 12 per cent. Here,

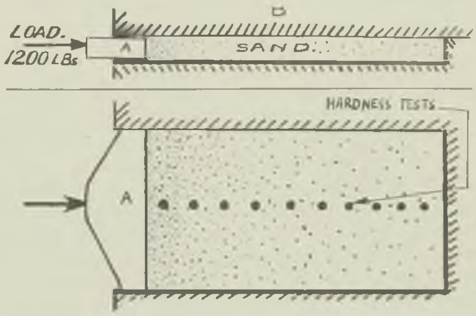


FIG. 2.—DIAGRAM OF KYLE'S FIRST METHOD OF MEASURING FLOWABILITY OF SAND.

then, is distinct evidence of a flowability change, and where the effect of moisture alone was to be studied there is a combination of the flowability effect and the true moisture effect in the A.F.A. test results and conclusions drawn therefrom. The effect of moisture on the other types of sand given in Dearden's Paper have been covered in a previous Paper by the present Author, in which the need for separating the true effect of moisture from the flowability effect is shown, and there seems little need to repeat it here.

Flowability

Flowability is the property which enables sand to flow throughout the mass when ramming energy is applied to the outside of that mass. This property is possessed in a varying degree by all moulding sands, and must be considered in relation to mould finish and freedom from voids or loosely packed areas, which in turn cause roughness or even ragged projections on the casting due to metal penetration. Very high flowability is found in oil sand, bonded with, say, pure linseed oil and very low flowability in certain types of heavily-bonded " steel " sands.

For machine moulding, using well-finished pattern plates, a sand having good flowability is essential, otherwise much additional hand-moulding will be required on what should otherwise be a finished mould. In addition, low flowability will greatly increase the effort required in ramming the mould, whether by hand, jolting machine, or jolt-squeeze machine.

The only Papers dealing with the subject of flowability, apart from the Author's work is that of Kyle which appeared recently in the A.F.A. publications, and that of Dietert and F. Valtier, also in the A.F.A. publications in 1934. This Paper by Kyle is well worth studying because he has not merely quoted available data but has set about the study of the subject independently, and the value of the Paper to the foundry industry is enhanced by the scarcity of similar independent research from other sources. While the present Author would not care to recommend the methods put forward by Kyle for measuring flowability in foundry practice, the value of the work in the Paper is not detracted from on that account.

In this Paper, the suggestion is made, or inferred, that flowability has two distinct phases, first, the flow of the sand as force is applied during a moulding operation; and second, the flow of sand due to the weight of molten metal in the mould during casting. This point of view is rather interesting but its development into any real practical application may be quite a different matter because the principle underlying this idea would make it possible to have a set of conditions where a sand would flow readily under pressure of the metal at a later stage. These preparations are contradictory, because a good flowability during moulding would hardly disappear later unless ramming was reasonably near the limit and at best the second stage of flowability is merely the completion of a moulding operation. On that account the method proposed by Dietert has some theoretical interest because the hardness can be recorded after each successive blow of the rammer and the degree of ramming carried to any extreme. While this method may give data of theoretical interest primarily, as concerning the behaviour of sand under a particular set of conditions, the present Author has always contended that the Dietert and Valtier method was not representative of foundry practice so far as moulding is concerned. It would, no doubt, furnish some information if a particular mould were rammed to a hardness equivalent to the A.F.A. test-piece made by four blows of the rammer, in which case the probable tendency to swelling under metal pressure would be indicated by the reading of flowability obtained.

Kyle describes three methods for measuring flowability: (1) A hardness gradient method of his own design; (2) a hardness differential method somewhat similar to the present Author's

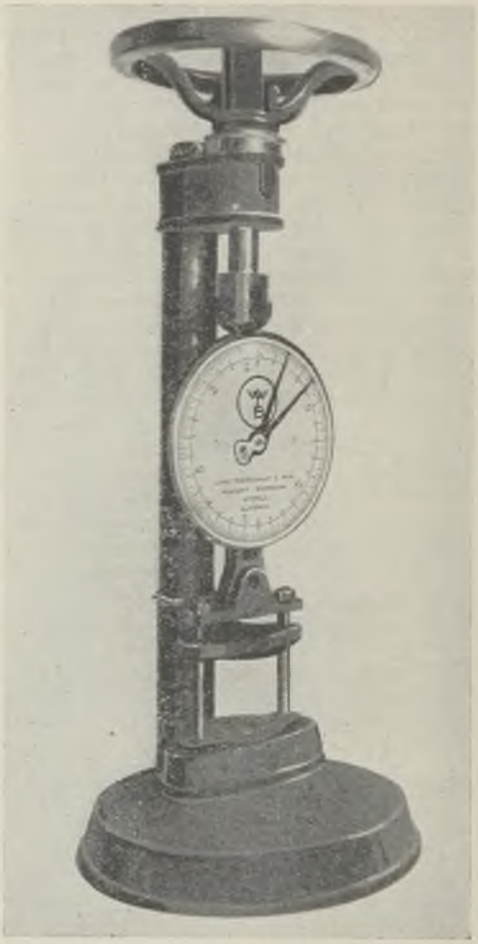


FIG. 3.—COMPRESSION TESTING MACHINE SPECIALLY MADE FOR DEFORMATION TESTS.

method; and (3) sand movement method as used by Dietert and Valtier. The third method was used by Kyle to get comparison with the other two methods on which he was working.

It should be noted here that the present Author's method was put before the Institute's Sub-Committee on Sands at least two years before Dietert's sand movement method was published and it might usefully have been considered then. The method of measuring the hardness was by the Author's own penetration hardness tester at first, and later, more conveniently by Dietert's small hardness gauge. The present Author's method of measuring flowability consists of a 2¼ in. by 1⅛ in. diameter test-piece of the same equivalent weight as the standard A.F.A. test-piece, and rammed by squeezing in one direction only, then tested for hardness top and bottom by Dietert's hardness gauge. For routine tests a weight of sand equivalent to that found in the A.F.A. test-piece is used and when studying the effect of specific variables like moisture, the test-pieces can be made to the same Index of Ramming. The exact degree of ramming of any mould or part thereof can thus be reproduced for the determination of flowability if required.

$$\frac{\text{Hardness Top}}{\text{Hardness Bottom}} \times 100 = \text{Flowability per cent.}$$

It is true that a difference exists between a test-piece made by a steady squeeze and one formed by any kind of blow; but it is not thought that two types of flowability test are necessary for sands intended for squeezing machines on the one hand and jolting machines on the other. The test-piece made by compression as described should cover both.

Kyle does not consider that it is likely that the ratio of top hardness to bottom hardness in a test-piece can be used for deep moulds because of the difficulty of eliminating errors due to the "non-uniform placement of sand during ramming."

Whilst agreeing with the underlying idea of this statement, namely that the best type of test would really be on a full practical scale, *i.e.*, that all moulds should be tested in some direct way, but this of course is impossible in practice, and it is for this very reason that small tests have been developed in sands and in other lines as well, as for example in metal testing.

Then again the "non-uniform placement of sand" in a mould is not a function of flowability proper, but is dependent on the condition of the sand, such as the relative degree of aeration in preparation and the method and degree of care in filling the box before ramming.

First Method of Measuring Flowability as Used by Kyle

With reference to Kyle's first method for measuring flowability (see Fig. 2), the metal mould has a sand capacity of 1 in. by 12 in. wide and a maximum length of about 12¾ in., with one end of the mould fixed and the other end movable. For filling, the movable end A is placed at a definite position, and sand sieved into the mould as carefully as possible so as to give good distribution, and struck off level with a straight edge. The top of the mould B is then put in position and secured. A load of about 1,200 lb. can then be applied, and this constitutes a squeeze test, or the mould may be set up vertically on a special jolter in order to produce a jolt test, or similarly a jolt-squeeze test may be made. The top B is then removed and the hardness measured by Dietert's hardness tester down the centre of the exposed sand surface. On consideration of this method it will be observed that there are several distinct objections to it. First, the apparatus required is both large and heavy. Secondly, a special machine may not be available for the application of a load of the order of 1,200 lb. Thirdly, the quantity of sand used for each test is controlled by volume.

It is well known that where, say, a bucket is filled with sand by sieving from a fixed height and striking off level, the weight of sand filling the bucket varies with the moisture content, and that the weight decreases rapidly as the moisture increases to the best temper figure and then above that figure the weight again increases.

Table I.—*Flowability Results using Dieter's Hardness Gauge.*

Readings.					Flowability. Per cent.
Top	42	45	39	40..	55.0
Bottom	22	23	27	18..	
Top	35	36	32	28..	48.5
Bottom	18	16	14	17..	
Top	30	32	34	30..	68.0
Bottom	20	18	20	25..	
Top	28	30	31	36	48.5
Bottom	12	17	15	16..	
Top	28	31	28	35..	65.5
Bottom	16	17	23	25..	
Top	29	30	34	35..	55.0
Bottom	20	13	18	19..	

The present Author carried out a good deal of work in an attempt to apply the measurement of sand by volume instead of by weight in the making of the small 1⅛ in. by 2¼ in. test-piece. This was recorded in a Paper given to the Edinburgh Section of the Institute. On encountering the above-mentioned phenomenon the method was shelved. Kyle's test is evidently subject to this effect, and in order to check this, a mould was made in wood to the required dimensions and filled, as directed, by sieving and striking off level. At about 8 per cent. moisture the successive weights in three consecutive tests were:—2,315 gm.; 2,223 gm., and 2,200 gm., showing a decrease probably with drying of the sand.

Then the sand was dried to 6 per cent. moisture and the tests were:—2,390 gm.; 2,452 gm., and 2,515 gm., showing a decided increase in weight as the moisture further decreases. The size of the sample makes it difficult to keep the moisture constant during testing. The figures clearly show that the method of filling introduces a very important variable, *before* the ramming force is applied for the flowability test proper, and this point should be kept in mind. The error is likely to be accumulative at times, and when it is so, it will give an apparent sensitivity to the test-piece which may prove misleading. The only way to eliminate this factor, is to use the Index of Ramming method of determining the weight of sand to be used for each test.

Another point in connection with Kyle's test, is the necessity for drawing a graph which might be eliminated by merely using the hardness measurements at the top and bottom, which give the same information as the graph. In this case, the test would become much the same as that of the present Author, except for the variation of weight with moisture as referred to above. The same might apply to any variable affecting flowability such as clay and the like, the flowability of the sand would be seriously affected by the weight of sand for the test, and this would be distinct from the flowability of the sand under pressure during test, although the test-graph obtained would be the result of their combination. The application of so heavy a load to the movable part of the test would

TABLE II.—*Author's Sand Tests showing Agreement, in Duplicate Tests. Dry Sand Sampled on December 26, 1940.*

ixture	2½ barrows black sand (95 per cent.); 1 shovel rock sand (3 per cent.); and 10 lbs. Bentonite (1.4 per cent.)	
		Averages.
Moisture	8.2 per cent.; 8.0 per cent...	8.1 per cent.
Permeability ..	9.8 cms. 31 secs. .. .. 9.8 cms. 31 secs. .. .. } 99.6	99.6
Green strength (compression)	21½ lbs. 20½ lbs. 20½ lbs.	6.68 lbs. per sq. in.
Dry strength (compression)	440 lbs. 460 lbs.	143.3 lbs. per sq. in.
Deformation (W.Y.B. method)	50 51 52 51 50	25.4 thous. or 0.0254 in. per in.
Flowability (W.Y.B. method)	Bottom 42 46 48 46 Top 74 75 73 75 = 61.3 per cent.	65.9 per cent.
	Bottom 51 52 51 54 Top 71 73 75 74 = 70.8 ,, ...	
	Bottom 47 46 52 52 Top 76 76 77 78 = 64.2 ,, ...	
	Bottom 52 52 53 54 Top 74 76 73 74 = 71.0 ,, ...	
	Bottom 52 52 52 51 Top 75 77 77 78 = 67.3 ,, ...	
	Bottom 48 48 50 51 Top 80 79 82 82 = 60.9 ,, ...	
Flowability. Kyle's method. A.F.A. test piece, 1 blow ½ in. ..	Bottom 18 18 19 18 Top 34 39 37 35 = 50.3 per cent.	43.2 per cent.
	Bottom 18 18 17 22 Top 37 39 40 41 = 47.8 ,, ...	
	Bottom 19 21 20 19 Top 37 36 34 39 = 54.1 ,, ...	
	Bottom 9 12 10 14 Top 25 35 34 33 = 35.9 ,, ...	
	Bottom 9 8 15 12 Top 26 34 31 29 = 36.7 ,, ...	
	Bottom 9 11 13 20 Top 42 33 41 38 = 34.4 ,, ...	

require a large machine and probably a somewhat critical rate of loading.

Second Method for Measuring Flowability used by Kyle

The second method of measuring flowability used by Kyle consisted of an A.F.A. test made by one blow of the rammer falling $\frac{1}{4}$ in. and testing for hardness on the top and bottom. The test-piece was made two inches long as usual but the manner in which the rod and weight of the rammer was lowered on the sand appears to affect the result by its effect on the preliminary condition of the ramming.

Consecutive tests from the same batch of sand taken from a mixing drum in order to prevent variations of moisture during testing, gave the figures shown in Table I.

The figures of Table I were obtained whilst taking care to lower the rammer and weight on to the sand as gently and as near as possible with the same amount of care. These figures indicate that to get a 2 in. test-piece, a weight of sand as low as 142 gm. was required instead of the usual 170 gm. and the test-piece produced has a hardness much below that of normal practice, even on the top, while the bottom hardness has no relation to moulding practice. The figures also show that duplicate measurements on the ends of each test-piece are not in good agreement, and also that the percentage flowability expressed by these consecutive tests is variable—the range being from 48 to 68 per cent.

The effect of the degree of care with which the rammer is lowered was found to have a considerable influence on the figures, thus:—

Top	39	43	42	42	yielding 58.4 per cent.
Bottom	19	30	22	26	

flowability, when the rammer was lowered with moderate care.

Top	42	36	34	35	yielding 46.3 per cent.
Bottom	10	16	18	24	

flowability, when the rammer was lowered with special care.

Thus the personal element appears to have too much influence on the results of this test. The A.F.A. test-piece is too short or squat for a test of this kind, having been designed to eliminate the degree of hardness difference, which Kyle now seeks to magnify sufficiently to serve as a flowability measurement.

Third Method of Measuring Flowability used by Kyle

The third method used by Kyle for measurement of flowability was that developed by Dietert and Valtier. The amount of contraction in the length of the A.F.A. test-piece during ramming, between the fourth and fifth blow of the rammer, is measured in thousandths of an inch and taken as a measure of flowability.

With regard to this method Kyle found that "the property being measured seems to be something akin to flowability but the method of expressing the results gives the reverse indication." The present Author has always held the opinion that tests of this kind should not be carried out at a degree of ramming which is so much above that required for normal moulding practice and would be inclined to seek another method on that account alone.

Deformation Test

The green-strength alone is unsatisfactory, and may indeed be definitely misleading, because a high green-strength can be associated with a dry brittle sand, which is unfit for moulding. The term moulding signifies the need for plasticity, and it is this plasticity which is measured by the deformation test. The lack of "deformation" will result in a bad draw associated with additional patching, which itself will be difficult to accomplish for the same reason.

Author's Method for Deformation Determination

The wooden block used in the test hitherto was replaced by a specially made gauge, constructed of light steel tube and disc ends. This turned out test-pieces weighing 135 gm., *i.e.*, not heavier than the A.F.A. test-piece, which is usually about 170 gm. It was carefully ground to 2.000 in. and kept in a small felt-lined box when not in use. This gauge is used to calibrate the machine, and is found to be much better than the wood block. Good apparatus is essential in sand testing, and the failure of most attempts to use the deformation test in one form or other is undoubtedly due to lack of accuracy in the machines.

The procedure is as follows:—

(1) The test-piece is placed in the machine and the length measured with a light load of 1 lb. to ensure that all the backlash in the system is taken up.

From this reading any variation from "true" (2.000 in.) is noted, and this reading, say 12 thousandths, may be positive or negative.

(2) The load is then applied steadily until the point of commencement of fracture, taking care not to over-shoot the mark, and the reading in pounds and fractions taken as well as the micrometer reading. The maximum compression strength reading is best obtained using a loose pointer, and this applies more particularly to the deformation test.

(3) Without moving the load screw, the compression plate of the machine is then depressed in order to allow the introduction of the 2.000

in. gauge. This operation brings the pointer of the spring balance to a much higher reading, and, by rotating the load-screw carrying the micrometer, the pointer of the spring balance is returned to the exact reading of the maximum strength already noted. The difference in these micrometer readings between the maximum-compression reading on the deformed test-piece and the spring-balance reading when the 2.000 in. gauge is substituted is the deformation, except for the necessary length correction, as the A.F.A. test-piece is, of course, never exactly 2.000 in. The preliminary length measurement furnishes by comparison with the 2.000 in. gauge the correction to add or subtract.

The plates of the machine must at all times be quite free from grains of sand, as these introduce errors in measurement. The slides of the compression motion must be quite free, as even a slight friction will readily introduce errors in the micrometer readings. The test-piece should be well formed, with the faces parallel, and have no ragged edges likely to crumble in handling and so introduce grains of sand between the test-piece and the compression plates. However, with these precautions, which, after all, are an every-day necessity in all cases of measurements of these dimensions, duplicate tests give very close results.

The A.F.A. test-piece, if made by the standard drop-weight, should be made as already indicated, with the tube floating on the third blow, and if the tube has a slight clearance on the rammer head, a horseshoe-shaped distance-piece, such as described in previous Papers, should be used in order to hold the tube quite vertical during the first and second blows, and thereby ensure that the test-piece faces are quite parallel. A distance-piece of about $\frac{1}{8}$ in. thickness seems quite sufficient for the purpose.

Examples of duplicate tests on the same sample of sand gave the following deformation on 2 in.—55, 54, 56, 54, 53 thousandths when carried out after one day's practice with the apparatus.

Table II gives a series of tests as used by the present Author carried out on one sample of sand which was kept in a mixing drum throughout the testing in order to eliminate drying, and this procedure is strongly recommended.

Preparation of the Sample

The sand was mixed in a No. 2 Simpson mixer, aerated, put through a $\frac{1}{8}$ in. mesh riddle, and transferred to the mixing drum for testing.

Moisture

The moisture percentage was obtained by direct weighing after drying.

Making the Test-piece

The test-piece is rammed by the method suggested in previous Papers, two blows with a distance piece under the tube or mould and the third blow with the tube free to move. This procedure makes a test-piece which, although not perfect is at least much freer from uneven ramming across both the horizontal and vertical sections. The Author strongly recommends this practice both to the individual foundryman and also to the American Foundrymen's Association Sub-Committee on Testing.

Permeability

The permeability numbers are calculated from readings of time and pressure during test, using the standard formula.

Green Compression Strength

This test is carried out on the spring balance type of machine incorporating the improved B.C.I.R.A. arrangement to eliminate side movement in the piece as illustrated in Fig. 3.

Deformation

This test is incorporated in the green-strength test, and presents no difficulty as a routine test, provided it is not attempted on the actual foundry floor. The duplicates are very good indeed and require no further elaboration.

Dry Strength

This test is carried out in the Author's hydraulic machine such as was put before the Sands and Refractories Sub-Committee, and has been used in one or two forms elsewhere with varying degrees of success.

Flowability

This test has been carried out on both the present Author's method and that of Kyle nearest to it. Both of these methods are fully described elsewhere in the Paper.

REFERENCES

[1] Proc. I.B.F., Vol. XXXIII, 1939-40, p. 233.
[2] Proc. I.B.F., Vol. XXXII, 1938-39, p. 381

Formation of Blisters, Pinholes and Black Specks on Vitreous-Enamelled Cast Iron*

By A. L. NORBURY, D.Sc.

Stages in Formation

Fig. 1 shows in a diagrammatic manner the gas bubbles forming and increasing in size and bursting from the enamel surface. It will be noted that between the enamel A and the cast iron C there is a layer of discoloured enamel B which is formed by reaction between the enamel and the iron. When a bubble bursts, this discoloured layer (or dark ground coat, if present) is forced to the surface of the enamel and produces discoloration. If gas is still being evolved when the enamel sets, the burst bubble will not heal up and a pinhole will result. If, however, the gas evolution ceases soon after the bubble bursts the enamel will tend to heal up and a black speck will result. (Black specks may, of course, also be caused by particles of iron or dirt in the enamel.) The diagram only shows the formation of the bubbles, and during the cooling of the enamelled casting it must be imagined that if the thermal contraction of the bubbles is greater than the expansion due to gas still being evolved, the bubble will contract and cause a depression on the enamel surface.

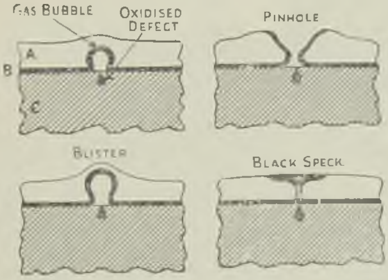


Fig. 1.—Stages in Formation of Blisters, Pinholes and Black Specks. (A = Enamel. B = Discoloured Enamel. C = Cast Iron.)

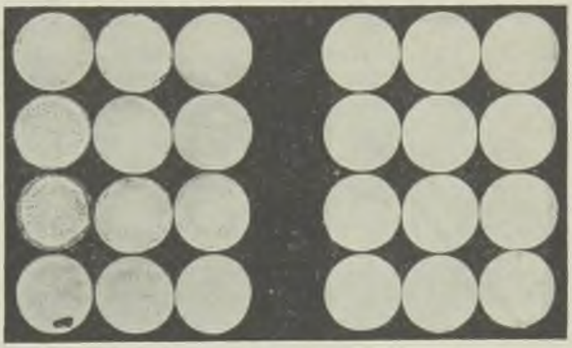


Fig. 2.—Sections of 3-in. dia. Silal Bars Enamelled Without Annealing. Chill-Cast Bars (Left) contained Entrapped Gases which produced Bubble Defects. Sand-Cast Bars (Right) did not. × 1/2.

Sources of Gas Bubbles

In Fig. 1 it has been assumed that the gas is formed from a reaction between an oxidised defect and carbon in the metal, with the formation of CO_2 and CO. This is, however, only one type of gas evolution. A second type arises from a reaction between graphite or carbide in the metal and oxide in the enamel, again with the formation of CO and CO_2. Certain enamel constituents such as tin oxide, which is reduced to metallic tin, react rapidly, while others, such as silica, are, of course, not reactive at the enamelling temperature. A third type of gas bubbling arises from the liberation of gases which have been entrapped in the solid metal during solidification. (Rusting after spraying may also produce gas from the oxide-carbon reaction.)

In what follows the various different ways in which the above defects can arise are discussed.

* This Paper was prepared for presentation to a joint meeting of the Institute of British Foundrymen and the Institute of Vitreous Enamellers. It was originally privately presented at the British Cast Iron Research Association's Third Study Course.

In practice, it may happen that defects on a single casting are not always due to a *single* cause, but to two or more causes which may operate separately, each producing its own defects, or they may operate together and only produce bad defects when they are operating together.

Bubbles due to Entrapped Gases Escaping

Considering the "entrapped gas" type of gas bubble formation first, since it is the simplest, Fig. 2 shows sections of 3-in. dia. bars, the left-hand group of which were cast in a chilled mould and the right-hand in a sand mould. The top bars in each group are high in total carbon and have open structures, and the bottom bars have lower carbons and closer structures. The iron used was a 5 per cent. silicon iron which was very resistant to oxidation at 760 deg. C. The sections shown in the figure were enamelled *without annealing*, and it will be seen that the rapidly solidified chill-cast sections evolved gas, while the more slowly solidified sand-cast sections did not. When annealed before enamelling none of the sections showed the gas bubble defects on enamelling. This shows that cast iron, if rapidly solidified, may contain entrapped gases which escape on enamelling, if the metal has not been previously annealed. The difference between sand-cast metal and chill-cast metal is only one of degree, and sand-cast sections may contain entrapped gas if they are sufficiently rapidly cooled.

For example, Fig. 3 shows a casting $\frac{1}{8}$ in. thick by 2 in. by $3\frac{1}{4}$ in., which, again *without previous annealing*, was enamelled on both sides at once, with the exception of a small area in the centre which was not enamelled on the reverse side. It will be seen that entrapped gas has escaped from the casting and caused bubbling all over, except for the small area in the centre which is free from bubbling, owing to the fact that the entrapped gases found it easier to escape from the unenamelled area at the back than to burst through the enamel. This pressure effect is also shown by the violence with which the bubbles burst from the surface of a casting during enamelling, particles of enamel being shot up into the air to a height of several inches.

This question of entrapped gas is not usually of practical importance since most castings are annealed before enamelling and such gases are eliminated. The question of enamelling a casting on only one side or both sides is, however, important, since enamelling on both sides at once is more likely to allow gases from any source to set up sufficient pressure to burst through the enamel. If a sintered porous ground coat is used the pores act as a reservoir in which gases can collect without setting up sufficient pressure to burst through the enamel. Such sintered coats are also less easily reduced by carbon with the formation of gas, since they do not contain easily reduced oxides such as tin oxide.

The following explanation has been given of the function of grip coats: "As regards the use of grip this contains borax, quartz and clay, and is very hard. The use of grip usually eliminates the enamel boil experienced when enamelling normally. It is thought that during the high-temperature firing of the grip, gas evolution takes place before it fuses over, and the resulting impervious layer prevents gas evolution, during subsequent fusion of the enamel proper at a lower temperature." Moreover, the grip coat does not react with carbon in the metal to produce gas, as discussed below.

Fig. 3.—Casting $\frac{1}{8}$ in. × 2 in. × $3\frac{1}{4}$ in. Enamelled Without Annealing on Both Sides at once, except for Small Centre Area which was Not Enamelled on Reverse Side. Entrapped Gases from Central Area have Escaped through Enamel-Free Surface on Reverse Side. × [illegible].

Bubbles due to Reaction between Enamel and Graphite

Another possible source of gas evolution is that from a reaction between graphite in the metal and certain oxides in the enamel. That graphite reacts vigorously with enamel, giving off gas, is shown by pushing a graphite rod into molten enamel. The reaction is very vigorous, but ceases rapidly owing to the inability of the enamel and the graphite to diffuse into one another. Actually, graphite can be enamelled perfectly, provided there is a vent through which the initially formed gas can escape. This reaction also happens in the case of grey cast iron and in the dry enamelling process is known as the Manson effect, which is that, when the enamel is first dusted on, there is no further gas evolution.

Gas formed from this reaction in the wet enamelling process only forms defects if the graphite size is large, as illustrated by Figs. 4A, B, C, D, which show four different graphite sizes in a cross-section cut from a slab of cast iron 2 in. wide by 6 in. high by 8 in. long, which was cast against a chill on the underside and then cut vertically into $\frac{1}{4}$ in. thick sections. When one of these sections was enamelled (without previous annealing) the parts near the chill, whose microstructures are shown in Figs. 4A and 4B, did not show any bubbles on enamelling. The parts farther away from the chill, however, with the structures shown in Figs. 4C and 4D, showed increased amount of boiling.

FIG. 4A. × 50.

FIG. 4C. × 50.

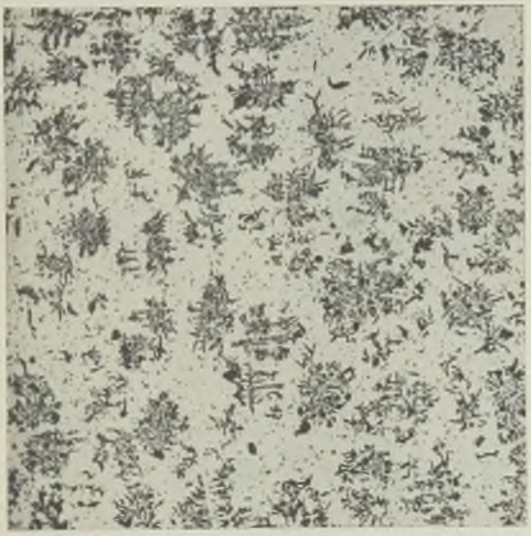


FIG. 4B. × 50.

The fine graphite in Figs. 4A and 4B did not give blisters on enamelling, since the gas bubbles formed by the reaction between the graphite and the enamel were too small to coalesce.

FIG. 4D. × 50.

The coarse graphite structures in Figs. 4C and 4D gave blisters on enamelling.

Apparently the gas bubbles formed by the small graphite flakes were too small to coalesce, while those formed by the larger flakes were able to do so and produce sufficiently large bubbles to produce visible blisters.

The boiling on the coarser parts of such sections was considerable if they were shot-blasted before enamelling, but was almost absent if they were emery-papered or honed before enamelling. Other conditions being equal, the boiling was less if the section was annealed before enamelling, presumably owing to graphite being burnt away during annealing. The explanation of the shot-blasting differences appears to be that shot-blasting burnished over the surface graphite and delayed it reacting with the enamel until the latter had fused, after which the attack of the molten enamel on the surface of the metal and the annealing effect of the enamelling temperature each had the effect of uncovering the graphite flakes and allowing them to react with the enamel and produce gas at a later stage in the enamelling operation.

Defects due to coarse graphite tend to be found over a thick boss or along a thick section of the casting, or opposite a runner, that is to say, in the most slowly cooled parts of the casting. Another effect of coarse graphite is that it tends to produce a higher combined carbon in the iron than is produced when the graphite is fine, and combined carbon, as discussed below, is another source of gas formation.

Bubbles due to Reaction between Enamel and Combined Carbon

Combined carbon in cast iron reacts with the enamel in a similar way to graphite, but if not present in too large amounts, may not cause sufficient gas evolution to produce defects. Its presence is, however, undesirable, since it is a potential source of gas evolution. If the combined carbon is considerable in amount, due, for example, to the manganese content being insufficient to neutralise the sulphur present, the resulting high combined carbon will probably produce boiling all over.

In this connection the silicon content is also of great importance, since the lower the silicon content the lower the "critical temperature" of the iron, and if the silicon content is below a certain figure, of about 1.5 per cent., the iron at the enamelling temperature will not be below its critical temperature. This critical temperature is the temperature above which graphite can dissolve and diffuse in the solid iron to form more combined carbon. Consequently, if during enamelling the iron is above its critical temperature, more combined carbon will be formed and can diffuse to replace that which has reacted at the surface of the metal with the enamel, so that instead of the gas evolution ceasing, it will proceed continuously and cause considerable general boiling. If, however, the silicon content is sufficiently high, for example, about 2.5 per cent., the iron will not be above its critical temperature during enamelling, and the reaction between the enamel and the surface combined carbon will cease very early in the enamelling process, owing to lack of diffusion, and the gas evolution will not cause defects as in the previous case, when the reaction went on continuously.

Bubbles due to Reaction between Oxidised Metal and Carbon in the Metal

Another type of gas evolution may arise from a reaction between carbon in the metal and oxidised defects below the surface. Oxidised defects right on the surface are removed by efficient shot-blasting. If, however, shot-blasting is not effective in removing this surface oxide—and this is most likely to occur at re-entrants on the surface of the casting—the above oxide-carbon reaction will cause defects. The importance of efficient shot-blasting needs no emphasis.

FIG. 5.—SECTION OF PHOSPHORIC PIG-IRON ANNEALED AT 800 DEG. C. FOR 20 MIN., SCRATCH-BRUSHED AND CROSS-GROUND TO A DEPTH OF $\frac{1}{16}$ IN., THEN ENAMELLED. THE REACTION BETWEEN OXIDISED SURFACE AND CARBON IN METAL HAS PRODUCED GAS DEFECTS. × ½.

As an example, Fig. 5 shows a section of phosphoric pig-iron which was annealed in a muffle so that oxidation penetrated a short distance below the surface, down the graphite flakes. It was then cooled, wire-brushed, then the St. Andrew's cross ground on it with an emery wheel to a depth of about $\frac{1}{16}$ in., then sprayed and enamelled in the ordinary way. It will be seen that no bubbling has occurred on the ground, oxide-free cross, whereas vigorous bubbling has occurred elsewhere, due to surface and sub-surface oxide reacting with graphite in the metal.

Formation of Sub-Surface Oxidised Defects

Sub-surface oxide is probably one of the most common sources of defects in actual practice, and may form, as shown in the above case, down coarse graphite flakes. It may also form, as shown in Fig. 6, in what is probably a gas-hole defect near the surface of the casting. The defect was found beneath a crop of pinholes in the enamel, and had become oxidised, probably

Fig. 6.—Cross-Section of Edge of Casting below Pinholes in Enamel, showing Oxidised Porous Area which reacted with Carbon in Metal to produce Gas. × 100.

chiefly at high temperatures, while the casting was cooling in the mould and, to a lesser extent, while it was being annealed and while it was being heated up for enamelling.

Such gas defects in the metal tend to form in the last part of the microstructure to solidify —*i.e.*, round the phosphide—and are more likely to be produced if the metal is poured too cold or if the mould is insufficiently permeable to allow the escape of mould gases. They may be due to sand particles coated with coal dust and clay becoming detached from the mould and giving off gas in the solidifying metal, or they may be due to oxidising slag particles in the metal, such as might arise from the use of a dirty ladle, that is to say, one with an oxidised skull whose oxides react with the metal right up to the moment of pouring.

Sub-Surface Defects due to Included Sand Grains

That sand grains can become detached from the mould and cause surface and sub-surface defects is shown in Fig. 7, which shows sand grains which have become entangled in the surface of a Silal casting. When blistering of the enamel is due to such defects it will usually be found that if the enamel is removed by shot-blasting, under each enamel defect there will be found a small hole in the casting containing sand grains, as shown in Fig. 7. It will also

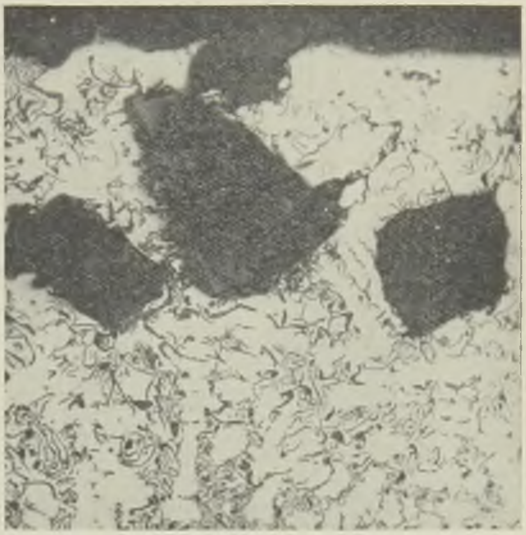


Fig. 7.—Cross-Section of Edge of Casting showing Entrapped Sand Grains. × 100.

be found that the holes which communicate freely with the outside of the casting do not give such a bad defect as deeper-seated holes which have only a small aperture connecting them to the outside and which are consequently less effectively cleaned out by shot-blasting. Defects due to entrapped sand grains are often localised in certain parts of the casting—such as the rim of a bath—where the sand is most likely to collect.

Incidentally, it will be noted in Fig. 7 that the graphite flakes are coarsest round the sand grains and at the outside of the casting. Fig. 7 does not illustrate this particularly well, but it has been repeatedly found in castings having supercooled graphite structures that the outside edge, in contact with the sand mould, is coarsened, just as if the sand had an "inoculating" effect, giving coarse graphite where it is least wanted from the enamelling point of view.

Effect of Composition on Enamel

The nature of the enamel will also obviously have a considerable influence on the size of the above gas bubble defects, according to the temperature necessary to fuse it; to whether it will frit at a low temperature and entrap a greater amount of gas than if it fritted at a higher temperature; to its fluidity at the highest temperature and the ease with which it will allow gas to escape and be able to heal up gas holes without forming visible defects. The reactivity of its constituents will also affect the rate at which gas is formed by their reaction with carbon in the metal. The composition of the enamel also, of course, affects its adhesion, liability to crazing, colour, lustre, opacity, corrosion, heat-resistance, etc., but consideration of these properties is outside the present scope.

Solidification of Aluminium Bronze

By C. H. MEIGH

The duplex range of aluminium bronze alloys which are under consideration are illustrated in the form of a "micro-scale" in Figs. 1 and 2. At one extremity is shown an example in the alpha range, *i.e.*, almost entirely white—containing less than 7.5 per cent. aluminium—and at the other, an example in the beta range, almost entirely black—containing over 11 per cent. aluminium.

This method of presenting micro-structures in the form of a scale, simplifies the use of the microscope as a method of controlling the chemical composition of an alloy, or, the tensile properties of any given part of a casting without disfiguring the casting.

Fig. 2 represents a typical alloy in the duplex range containing 9.7 per cent. aluminium, 3 per cent. manganese, 3 per cent. iron and 3 per cent. nickel, cast in a sand mould, in thicknesses varying from 6 in. to $\frac{3}{16}$ in., and giving 7 different structures corresponding to different solidification speeds. Alloys containing nickel are becoming increasingly popular and F. Hudson's name is to be associated with their development. It will be noticed that, as the grain size decreases so the mechanical properties increase in value, from 35 tons per sq. in. in heavy sections, to 46 tons in thin scantlings, or sections that solidify rapidly.

The data shown in Fig. 2 were obtained from test-pieces cut from the different steps as shown in Fig. 3 and also from a block of metal 6 in. by 6 in. by $7\frac{1}{2}$ in., which, in the form of a sand casting, may be considered as possessing minimum qualities which are unaffected by any further increase in mass.

In the casting, Fig. 3, each step has an influence on the solidification of the adjacent steps, for a certain distance, but test-pieces and etched specimens were taken from each thickness outside the affected zones. The figures given are averages of a number of tests, as any individual test may be falsified and, as it is not always an easy matter to visualise how metal solidifies in a profiled casting, a number of the stepped castings were moulded, so that the end of each step came to the top of the mould and solidification could be observed and timed.

The casting temperature was about 1,150 deg. C., the average time taken to fill the mould was 40 seconds, and the castings weighed 26 lb. each. After the mould was full, the $\frac{3}{16}$-in., $\frac{3}{8}$-in., and $\frac{3}{4}$-in. steps solidified in 5, 14, and 32.5 seconds respectively, showing that solidification had taken place during the pouring period to the extent of 35/40 or 87 per cent. volume of the $\frac{3}{16}$-in. step; 65 per cent. volume of the $\frac{3}{8}$-in. step; and 20 per cent. volume of the $\frac{3}{4}$-in. step. Leaving the $1\frac{1}{2}$-in. and 3-in. steps with the heart of the mass still molten—they solidified after periods of 78 and 210 seconds respectively. The expression "the heart of the mass" is used because solidification had started in layers parallel to the walls of the mould. With the object of obtaining comparative figures for the solidification speeds of a non-magnetic alloy containing 9.7 per cent. Al, 3 per cent. Mn, and the rest copper, and the complex alloy, previously mentioned, containing iron and nickel, other castings were run in, as far as possible, similar conditions.

In the non-magnetic alloy, the $\frac{3}{16}$-in. step solidified 15 sec. after the mould was full, as compared with 5 sec. for the nickel alloy. In terms of volume, 37.5 per cent. of the $\frac{3}{16}$-in. step in the non-magnetic alloy had solidified during the pouring, as compared with 87 per cent. of the nickel alloy, and, the other steps in the non-magnetic alloy were still molten at the heart, while the nickel alloy had solidified as previously mentioned.

The comparative behaviour of the two alloys is shown on Fig. 4. It is obvious that the pouring speed of the nickel alloy can be increased, to a certain extent, to compensate for its more rapid solidification, but there are limits of thickness and area, after which the nickel content must be cut down or eliminated, if moulds are to be filled under practical working conditions.

Thin sections solidify *in their entire thickness,* but the heavier sections solidify in layers approximately parallel to the mould walls and, as the total period of solidification in the 6-in. section is 750 sec. for the nickel alloy, and 1,300 sec. for the non-magnetic, $\frac{1}{16}$ in. thickness of metal is solidified after 7.5 sec. in the former and 130 sec. in the latter; 1 in. thickness is solidified after a period of 116 sec. for the nickel alloy, and 227 sec. for the non-magnetic alloy. While, under average conditions, flow stops and piping starts after 395 sec. for the nickel alloy, and 645 sec. for the non-magnetic alloy, leaving a final solidification or feeding period of 360 sec. for the nickel alloy, and 645 sec. for th non-magnetic alloy.

Referring to Fig. 2, it is obvious that the speed of solidification, for any given thickness of section, can be influenced by a number of outside factors, and that the structure will vary accordingly, but a given structure has a definite ultimate tensile strength value. Micro-examination can therefore be used as a gauge of the tensile properties, rather than as an indication

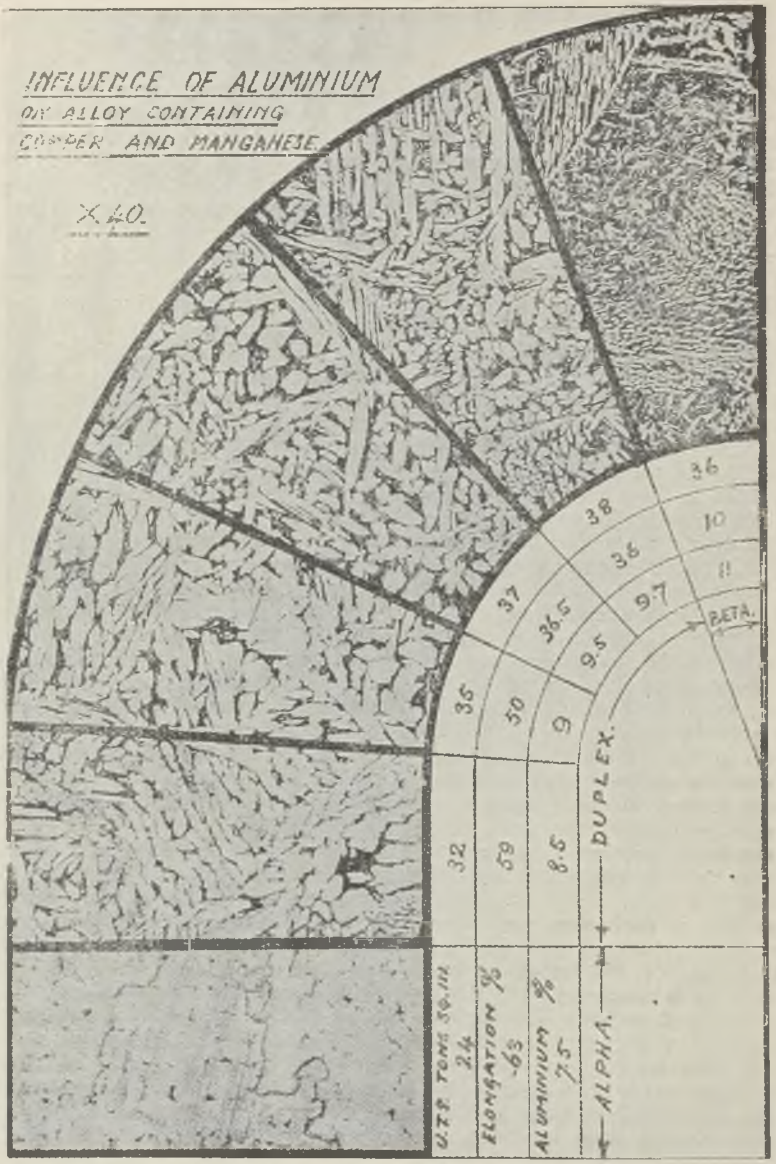


Fig. 1.—Influence of Aluminium on the Micro-Structure of an Alloy containing Copper and Manganese.

of thickness or speed of solidification in seconds, which are only given here to complete a picture.

The particle size of the constituents depends upon the composition of the alloy, the speed of solidification, the subsequent heat-treatment and the mechanical or physical treatment which the metal receives at different stages after solidification, but a given particle size represents a given tensile strength in a given alloy.

Whatever the composition of the alloy, the particle size is the greatest in the annealed state or in the "as-cast" state, in the case of heavy masses. There are several ways of obtaining a given structure, but it is proposed to limit this discussion to the modifications of structure brought about by different solidification speeds.

Speed of solidification, and heat-treatment after solidification, have as much influence as

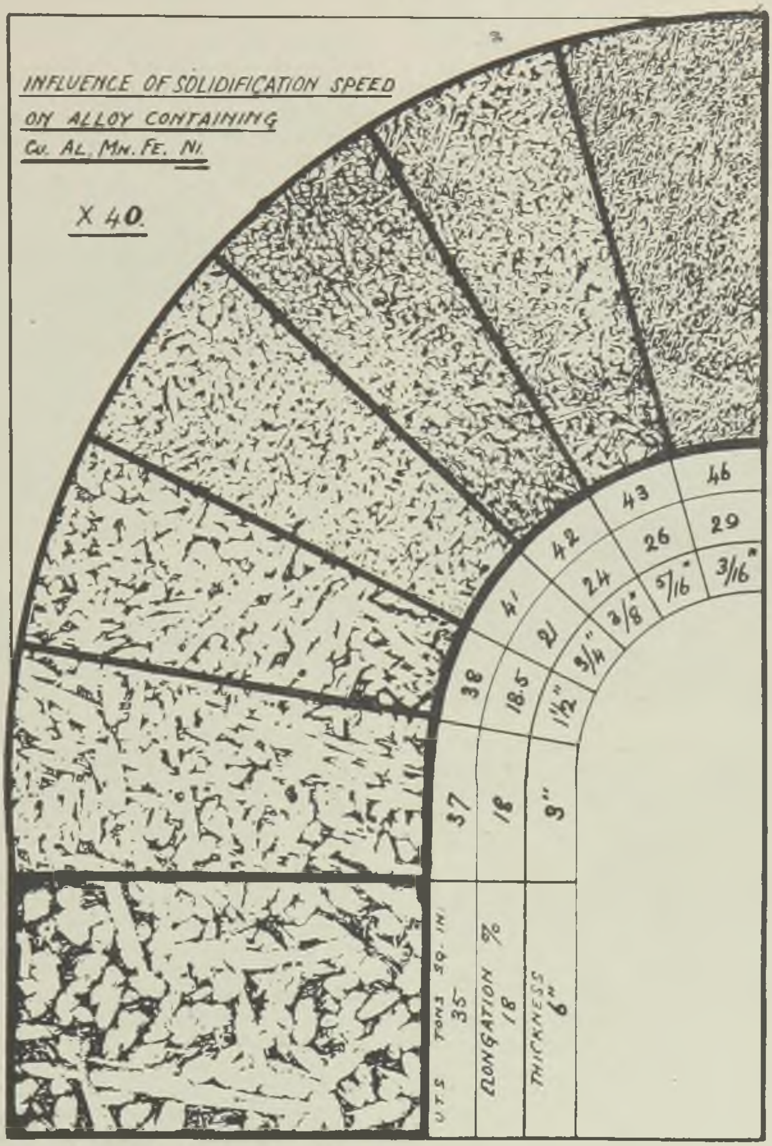


FIG. 2.—INFLUENCE OF SOLIDIFICATION SPEED ON THE MICRO-STRUCTURE OF A COPPER-ALUMINIUM-MANGANESE-IRON-NICKEL ALLOY.

mechanical treatment on the micro-structure, and hence on the physical and mechanical properties of aluminium bronze. Such technical information as has hitherto been published on the subject of solidification speed gives the impression that there are only two possibilities, namely, those arising from sand and from chill casting, and that the latter must essentially be restricted to the relatively few castings that can be cast in a metallic mould. This impression is entirely erroneous, and the data given on the scales show how qualities may be varied in a sand casting, and how this variation depends upon mass, and has nothing to do with the use of chill moulds.

These data also show the fallacy of relying too much on results obtained from standard test-pieces no matter whether they are cast-on or separate. Such test-pieces give valuable indications as to the quality of the metal from the furnace, but not in the casting.

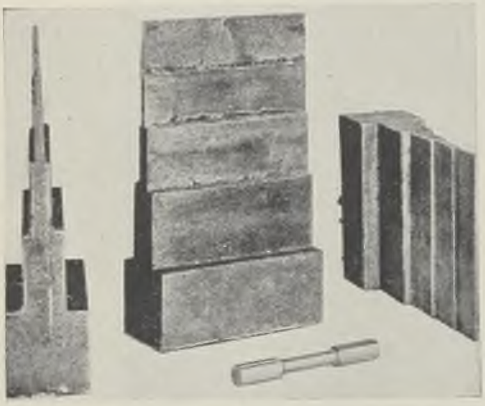


FIG. 3.—STEPPED CASTING FOR TESTING THE INFLUENCE OF THICKNESS ON MECHANICAL PROPERTIES.

Design

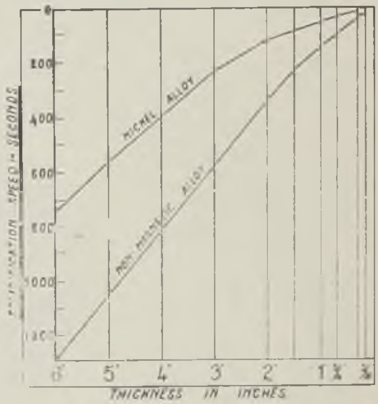
The characteristics given in Fig. 2 show, that although exceptionally good properties are obtained in thick sections, they are improved in every respect, as sections are reduced and solidification is correspondingly accelerated.

Perfectly satisfactory aluminium bronze castings can be made from patterns intended for other metals. The fullest advantage, however, can only be taken of the properties of these alloys by specialised design, reducing thicknesses where it is desirable to do so, and thus effecting the maximum economy, not only in the intrinsic value of the metal employed, but also in moulding cost.

It is obvious that an appropriately lightened design, whilst affording these economies will, at the same time, offer a degree of security equal to one in which thick and heavy sections are employed, more by force of habit than from a stand point of practical utility.

Aluminium copper alloys pass almost instantaneously from the liquid to the solid state, and in doing so the metal is reduced to 9/10ths of its liquid volume before the commencement of ordinary lineal contraction.

These conditions of solidification offer very considerable advantage over those of alloys which pass through a "pasty" phase prior to complete solidification. At the same time they necessitate special treatment during the casting operation, to ensure that an adequate supply of metal is provided, to replenish what would otherwise be empty space caused by reduction in volume. This reduction in volume may be



THICKNESS	SOLIDIFICATION SPEED SECONDS	
	NICKEL	NON MAG.
3/16"	5	15
3/8"	14	45
3/4"	32	99
1"	49	142
1½"	78	227
2"	116	337
3"	227	575
4"	392	827
5"	555	1060
6"	730	1300

FIG. 4.—SOLIDIFICATION SPEEDS TO BE ASSOCIATED WITH INCREASING METAL SECTION.

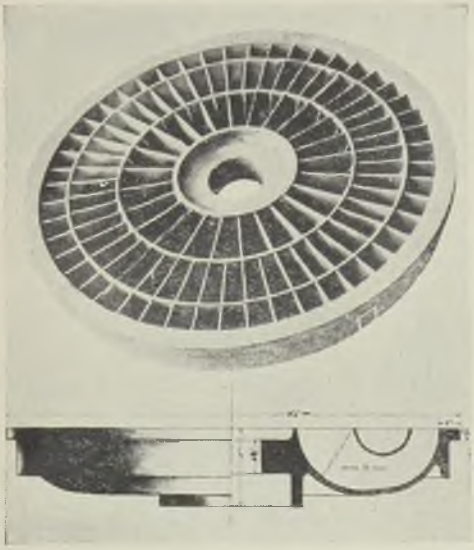
termed "internal contraction" as opposed to shrinkage or surface contraction.

Fig. 5 shows a casting consisting of a heavy boss 4¾ in. thick, and a heavy outer flange and ring 1⅝ in. thick, united by light webs, ⅜ in. thick. It affords a good illustration of the advantages of single-phase solidification. In the commoner bronzes the webs solidify and begin to shrink while the boss, and outer flange, are still in a more or less pasty condition.

Fractures are thus caused in the paste, which has neither strength nor ductility. In aluminium copper alloys, the webs solidify and act as cooling fins, thereby accelerating solidification in those parts of the molten masses in their immediate vicinity. As soon as the metal solidifies, it possesses both strength and ductility, and the lineal contraction, which is normally 1.8 per cent. and which would otherwise set up internal stresses, is compensated either by the sand being crushed or by the elongation or deformation of the metal up to a maximum of 1.8 per cent., whilst it is still at a temperature within the annealing range.

If the moulding material has a uniform coefficient of conductivity, a casting of uniform thickness solidifies in layers parallel to the mould face.

Fig. 7 represents a flywheel with a heavy rim and boss, and with spokes of different design, and shows the order of solidification. Where a thin section joins on to a thick section, *i.e.*, the rim and boss, it accelerates solidification at a place near its point of contact I and J, whilst in section H, of much greater thickness, there is the reverse effect. If the rim and boss were cast separately, solidification would occur in



Figs. 5 and 6.—Primary Wheel for Hydraulic Clutch weighing as Cast 2,366 lbs. (Courtesy, Barclay, Curle & Company, Limited.)

layers of uniform thickness, A, C and D representing the layer solidified after the first period, and B that after the second period. Total solidification might occupy 30 min. If the other sections, E, F, G and H, are cast with the rim and boss, solidification of both the latter is modified according to the respective heat-absorbing effects of the arms. The section E is, say, $\frac{3}{4}$ in. thick, and solidifies in, say, 170 secs., and, while part of its lineal contraction is taking place, it cools the metal in the rim and boss, I and J. At the same time, the general fall in temperature is producing solidification layers, A, C and D.

During the second period of, say, 15 min., the area shown as grey becomes solidified, and has fed the metal previously frozen. Solidification will then progress, and the last places to freeze will be L, M and N respectively. These places in turn will be fed by suitable headers, and a perfectly sound casting will be produced without the use of artificial chills. The tensile properties of each part of the casting will vary according to the speed of solidification, but neither weak places nor internal stresses will exist.

When radii are used for spoke F, the chilling effect on the masses is slightly reduced. This effect is still further reduced by the addition of necks and radii, as in spoke G. By increasing the section as at K, the mass of the rim is increased, and solidification is retarded, as shown by the black area.

It will be noticed that the use of radii or necks for joining thin to thick section is of no disadvantage. This is not the case, however, when two thin sections are joined together as is shown in Fig. 8, which illustrates suitable, and unsuitable methods. In this illustration P

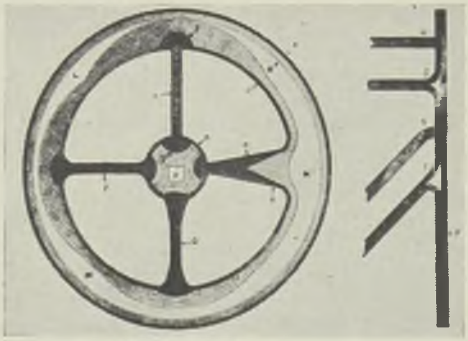


Fig. 7 (Left)—Flywheel showing Order of Solidification; and Fig. 8 (Right) showing Use of Radii in Design.

represents the wall of a chamber; and the metal in the walls of even thickness solidify in, say, 30 seconds, for the junctions Q and R have no retarding effect on solidification. If, however, radii are used as at S and T. solidification takes much longer at the junctions, and as there is usually no possibility of providing a supply of feeding metal, cavities or porous zones are formed, which weaken the casting, at places where extra strength was expected by the designer. This effect may be overcome by the use of artificial chills, but the operation is costly. Moreover, it is unnecessary, if the designer appreciates the difference between the single-phase solidification of aluminium copper alloys, and the dual-phase solidification of those alloys of lower tensile strength, that are in more general use.

Use of Chills

Chills are used in the foundry either to ensure sound castings or to produce local increase of tensile strength in vital parts. Their use is costly and should be avoided whenever possible. Much may be done in this direction by designing to ensure the maximum uniformity of thickness throughout a casting. When a local increase of thickness is required, such places should be situated where they can be attached by feeder heads, or else they must be chilled.

It must be remembered that the machining allowances result in increases of mass, and that although a casting may be designed with uniform thickness, the thickness "as cast" may vary considerably. These remarks apply to such castings as valve seats, but the thickening up of flanges, for machining, presents no difficulty—the flanges being easily fed or chilled, while the chilling of the valve seats would be at least a costly operation, and in some cases extremely difficult.

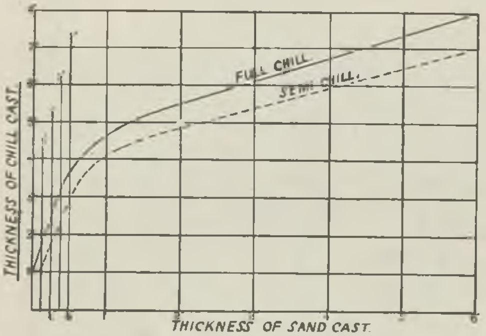


Fig. 9.—Relationship in Mechanical Properties of Chill and Sand Castings.

There is a limit to the effect of chills, usually dependent on the proportion of the surface of the mass that can be covered by them. To illustrate this point Fig. 9 shows the comparative effects, produced on different thicknesses, by full chill, semi-chill and sand casting. For example, a cube of the alloy with 8-in. faces chilled on five sides will solidify at the same speed as one with 7-in. faces chilled on one side, or as a 6-in. cube cast in sand without chills. In thinner sections for instance, a 3-in. thickness in the form of a plate chilled on both sides, would solidify at the same speed as a 2-in. thickness chilled on one side, or $\frac{5}{16}$-in. thickness without chills, or a 2-in. thickness chilled on both sides would solidify at the same speed as $1\frac{1}{2}$-in. thickness chilled on one side or $\frac{3}{16}$-in. thickness without chill.

Such figures as these must be regarded as only approximate, since they are influenced by a number of outside factors. They indicate, however, the limits within which sound castings can be produced in spite of inappropriate design, or alternatively, the extent to which vital parts of castings can be given increased tensile strength.

By reference to an appropriate micro-scale, such as Fig. 2, and the corresponding graph, it is easy to determine, in advance, properties which may be given to the different parts of the casting, by taking into consideration the thickness of the metal and possibility of using chills.

Chilling in the mould, though beneficial when used in the manner described, should be followed by a stress-relieving treatment, to eliminate internal stresses. Such stress-relieving occurs automatically under ordinary conditions of cooling in a sand mould.

Shrinkage

The shrinkage of aluminium bronze depends to a great extent on the method of pouring, the

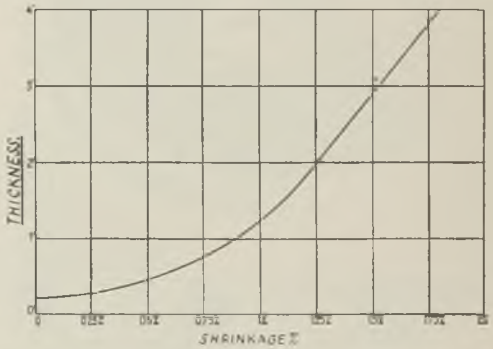


Fig. 10.—Shrinkage in Castings of Different Sections.

speed at which the mould is filled and the thickness of the casting. The maximum shrinkage of these alloys is 2.4 per cent., but the conditions under which such a high figure is reached are extremely rare. They occur, in fact, only in the case of such castings as bars, which are cast very rapidly and are free to contract without hindrance.

In profiled castings of all kinds there are various influences which have their effect upon shrinkages. These are as follow: —

(1) Slow pouring allows the metal to solidify, and to start shrinking while the mould is actually being filled, thus reducing the amount of shrinkage in the finished casting. It has the greatest effect in the vertical direction in which a casting is being run, where it reduces contraction to about half that in other directions. Take, for example, the stepped casting already mentioned in which 87 per cent. volume of the

$\frac{3}{16}$ in. step: 65 per cent. of the $\frac{3}{8}$ in. and 20 per cent. of the $\frac{3}{4}$ in. step solidified during the pouring period.

TABLE I.—*Solidification Conditions in Different Thicknesses*

Percentage volume solidified during pouring.	Thickness in inches.	Speed in seconds.		Percentage volume solidified during pouring.
		Nickel alloy.	Non-magnetic	
87	$\frac{3}{16}$	5.0	15	37.5
65	$\frac{3}{8}$	14.2	45	Molten.
20	$\frac{3}{4}$	32.5	99	,,
Molten	1	49.5	142	,,
,,	$1\frac{1}{2}$	78.0	227	,,
,,	2	116.0	337	,,
,,	3	227.0	575	,,
,,	4	392.0	827	,,
,,	5	555.0	1,060	,,
,,	6	750.0	1,300	,,

Layers of Solidification in 6-in. Cube.

Alloy.	Percentage volume solidified.	Time in seconds.	Thickness in inches.
Nickel	73.0	555.0	Piping.
,,	52.5	392.0	,,
,,	30.5	227.0	2.1
,,	15.5	116.0	0.95
,,	10.5	78.0	0.63
,,	1.0	7.5	0.06
Non-magnetic	82.0	1,060.0	Piping.
,,	64.0	827.0	,,
,,	49.5	645.0	,,
,,	44.0	576.0	2.55
,,	26.0	337.0	1.53
,,	17.5	227.0	1.05
,,	11.0	142.0	0.66
,,	1.0	130.0	0.06

(2) The extreme plasticity of these alloys, just below their melting point, allows them to "give" when resistance is encountered from a core, or projection on the mould, which again results in reduced shrinkage in the casting. This plasticity produces its greatest effect in very thin sections, which are not strong enough to crush the sand. There is seldom any measureable contraction in the walls of a casting $\frac{3}{16}$ in. thick.

(3) The high degree of tensile strength which the metal possesses at temperatures of from 700 deg. C. downwards enables it to crush the sand in the hardest mould. The thicker the casting the more pronounced is this effect, as, although thick sections are normally cast much more slowly than thin, the layers of metal which solidify while the mould is being filled attain sufficient strength to crush the sand before filling is completed. This tends to increase shrinkage of the finished casting.

Whilst these influences make it impossible to formulate definite rules for the estimation of shrinkage, the figures given in Fig. 10 may be taken as a general guide.

In cases where accuracy of dimensions is of great importance, it is advisable to allow for a lower rate of shrinkage in a bore, and a higher rate in overall outside lengths, and to leave an extra machining allowance to compensate for any error which may occur. After the first casting has been made from any pattern, the latter may be rectified so that normal machining allowances are left on it for future use.

The author wishes to express his indebtedness to the McGraw-Hill Publishing Company, Limited, for permission to use some of the data appearing in his book, "Practical Application of Aluminium Bronze."

L

Recent European Developments in Pig-Iron Manufacture

By N. L. EVANS, B.Sc., A.I.C.

Prior to the outbreak of the present war, certain new developments connected with pig-iron production were being investigated on the continent of Europe, and as they are related to problems now arising in Great Britain, it is felt that the following account of some of the developments which took place may be of value to the iron industry in this country.

The difficulties which were encountered in England in the early 1930's, when the low-grade aluminous iron-ore deposits of Northamptonshire were being developed for basic steelmaking, were first overcome by the processes introduced by H. A. Brassert & Company, Limited, in the plant built at Corby for Stewarts and Lloyds, Limited, and were also being investigated by Paschke & Peetz, and by the Röchlingsche Eisen- und Stahlwerek A-G., at Völklingen in Germany. The key to the whole situation was the modification of the burden of the blast furnace in such a manner that the slags formed were of low melting point. It was well known that slags of high lime together with high alumina content have high melting points, with consequent difficulties of operation. These slags of low melting point may have a lower capacity for carrying sulphur than high lime slags of common practice, and in the manufacture of basic pig-iron it is, in general, essential that the liquid iron shall be desulphurised after tapping the metal from the blast furnace.

The desulphurisation of pig-iron is carried out in several different ways, among them being:—(*a*) By the use of a limey slag in the blast furnace: (*b*) by manganese additions to the blast-furnace burden, and (*c*) by treatment with sodium carbonate in a ladle, after the iron is tapped from the furnace.

Methods (*a*) and (*b*) have certain limitations both from the operational and the economic points of view, whereas (*c*) is capable of application to a very wide range of pig-irons.

Continental Work

The sodium-carbonate desulphurising process is not new, but it has only been widely developed commercially during the past ten or twelve years as a result of research work carried out in Great Britain. The method afterwards quickly found favour in Luxemburg, France, Belgium and Germany, until in 1938-39 the consumption of sodium carbonate for metal refining in these countries was at the rate of 80,000 to 100,000 tons per annum, representing the treatment of something like 6,000,000 tons of iron.

The first major Continental development employing sodium-carbonate treatment was the "O.M." (*ohne Mangan* or manganese-free) process, *i.e.*, the manufacture of pig-iron without additions of manganese ore to the blast-furnace burden. The reason for this was probably mainly economic. Manganese had to be imported, and, particularly in Germany where the doctrine of economic self-sufficiency was being pushed to the limit, there was a strong inducement to use as little of it as possible. In addition, there were certain technical reasons which favoured the "O.M." process. Manganese is less easily reduced than iron in the blast furnace, and a considerable proportion of the amount charged with the burden is lost in the slag.

In order to minimise the proportion of the manganese oxide which is thus lost, additional limestone has to be used. Further, the reduction of manganese oxides can only be completed in the bosh of the blast furnace by solid carbon, and, as a result of these two factors, the coke consumption is increased proportionately to the percentage of manganese oxide in the burden. This in turn reduces the rate of output and increases the liability to scaffolding in the furnace and the production of falling slags. Manganese oxide is also said to render the slag less suitable for cement manufacture, as it impairs the hydraulic properties[1] of the cement.

The Minette ores native to Northern France, Luxemburg and Belgium contain sufficient manganese to give a maximum of about 0.7 per cent. of manganese in the pig-iron made from them. This is regarded as the upper limit for irons within the "O.M." range. Often, much less manganese than 0.7 per cent. is present. This compares with 1.2 to 1.6 per cent. of manganese which was formerly considered desirable in basic iron. An important function of added manganese is to remove sulphur from the iron in the form of manganese sulphide. This method of desulphurisation has been replaced, in the "O.M." process, by sodium-carbonate treatment.

Luxemburg Experiments

In a series of experiments carried out at a works in Luxemburg, the addition of manganese ore to the blast-furnace burden was progressively lowered, as shown in Table I. The furnace, which was making basic iron, was operated with a slag having a basicity ratio $CaO : SiO_2 = 1.45 : 1$. Each successive diminution of manganese in the burden caused a corresponding increase in the sulphur content of the iron.

The iron was desulphurised in a ladle by treatment with sodium carbonate. This reagent was put into the bottom of the ladle, and the iron was tapped on to it, special precautions being taken to prevent any siliceous slag becoming mixed with the soda slag. The treatment was carried out after the iron left the mixer A (Fig. 1) from which it was poured into ladle B. The sodium carbonate was run from the hopper E into ladle D, and before the iron reached this it was passed through the ladle B, which was of the "teapot" type and effected a separation of the metal from any slag coming from the mixer. The teapot ladle had a capacity of 15 tons, and had a rammed acid lining with a bottom made of silica-alumina firebrick. Two spouts were pro-

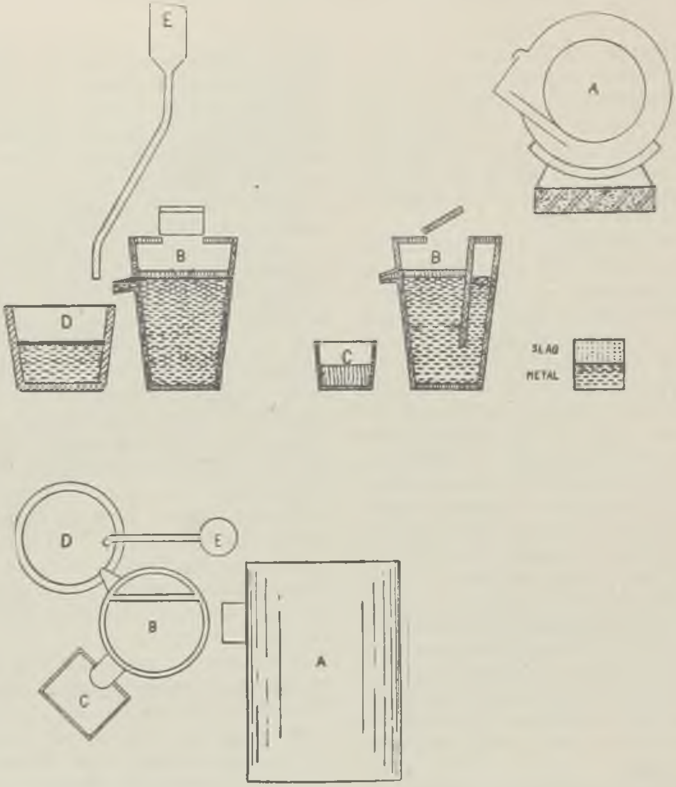


Fig. 1.—Desulphurisation of Mixer Metal made by the "O.M." Process.

A—Mixer from which molten iron runs into—

B—A syphon ladle of 15 tons capacity, lined with loam, and having a firebrick bottom. This separates the metal from mixer slag.

C—A slag trough into which the mixer slag overflows.

D—Is the ladle which receives clean metal from B and, at the same time, a charge of sodium carbonate from the hopper E.

vided, one about two-thirds of the way up, for clean metal to overflow into ladle D, and the other slightly higher, for running off the soda slag into the slag pan C. The ladle D, in which

TABLE I.—*Influence of Manganese Additions to Blast-Furnace Burdens.*

Manganese metal added to the burden. Lbs. per ton of iron.	Analysis of iron.			
	Si. Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.
48.5	—	—	—	—
33.0	0.43	1.00	0.063	1.77
22.0	0.44	0.62	0.075	1.80
22.0	0.47	0.62	0.073	1.82
17.5	0.52	0.57	0.080	1.86
17.5	0.45	0.52	0.097	1.84
11.0	0.46	0.45	0.100	1.84
0	0.54	0.34	0.080	1.84
0	0.55	0.26	0.082	1.79

the sodium-carbonate treatment was carried out, was deslagged by tilting it and allowing the fluid soda slag to run away, assisted by a rabble. The iron was then taken to the basic-Bessemer converter to be blown to steel.

An Improved Product

The consumption of sodium carbonate was about 11 lbs. per ton of iron. One part of anthracite was mixed with five parts of sodium carbonate, it being claimed that this minimised the amount of iron passing into the slag. The average decrease in the sulphur content of the metal was 38 per cent., *i.e.*, from 0.08 per cent. to rather less than 0.05 per cent., a further reduction taking place in the basic converter. At the end of the dephosphorisation stage in the converter, the residual manganese in the iron was 0.08 per cent., as compared with 0.20 per cent. when the blast furnace was operated with manganese additions. The usual manganese additions were made to the steel after blowing. Steel made by this process, of an extra soft quality for wire manufacture, was found to give very good results in the manufacturing operation. An improvement was also noted in the ductility of sheet steel (as measured by the Erichsen test) when made from "O.M." iron desulphurised with sodium carbonate. Theisen[4] reported fewer rolling-mill rejects after adopting the desulphurisation process, and the "O.M." method of operation effected a considerable reduction in costs.

It has been demonstrated that sodium-carbonate treatment of basic-Bessemer cast iron improves its temperature and fluidity. At a French works, where sodium carbonate has been used for a very long period, the monthly average analysis of the iron after treatment was as follows:—

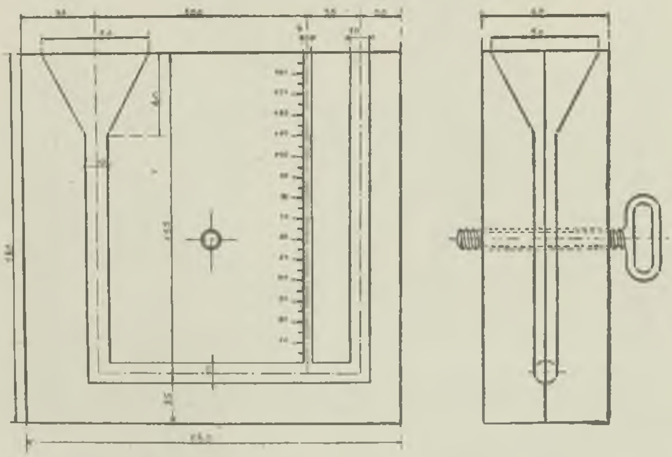


FIG. 2.—APPARATUS FOR MEASURING THE FLUIDITY OF MOLTEN CAST IRON.

	Per cent.
Silicon	0.30
Manganese	0.90
Phosphorus	1.80
Sulphur	0.03

The following temperatures, which are uncorrected readings with an optical pyrometer, are averages of observations taken over a very long period.

Untreated iron at the mixer spout ..	1,240 deg. C.
" " entering the basic-Bessemer converter ..	1,210 deg. C.
Treated iron entering the converter ..	1,230 deg. C.

The higher temperature of the treated metal is not unexpected, and confirms experience in this country in the treatment of foundry iron. Desulphurisation itself is probably an endothermic reaction, but it is usually accompanied by a slight desiliconising reaction which is exothermic, and more than counterbalances the loss of heat in desulphurisation.

An Interesting Fluidity Test

Fluidity tests, which are regularly carried out at these works, offer a striking confirmation of these results, and prove that, other conditions remaining constant, treated iron is much more fluid than untreated.

The gauge used for measuring fluidity is illustrated in Fig. 2. It consists of a cast-iron mould in two parts screwed together, comprising a U tube of 10 mm. dia. with a tun-dish on the top of one limb. A third limb, 4 mm. in dia., is graduated in millimetres along its length. The molten metal under test is poured into the tundish until it reaches the top of the other 10-mm. limb. The distance of the flow along the 4-mm. limb before solidification takes place is a measure of fluidity of the metal under test. Results over a period of a month are as follow:—

	Height of 4-mm. limb.
Undesulphurised metal at the mixer spout	55 to 65 mm.
Desulphurised metal before going to converter	85 to 95 mm.

An important practical effect attributed to this greater fluidity is that desulphurised iron can be blown in the basic Bessemer in three to five minutes less than untreated iron.

Desulphurisation is in some cases carried out in ladles with a basic lining of dolomite. These have a longer life (800 to 1,000 heats) than silica-alumina firebrick linings (400 to 600 heats). When not in use they are kept hot over burners using blast-furnace gas. Preliminary tests carried out by the author suggest that the use of a basic lining may sometimes result in a desiliconising reaction greater than that occurring in an acid lining, and this may have accentuated the temperature rise and the improved fluidity noted in the French tests. This aspect is to be the subject of further investigation.

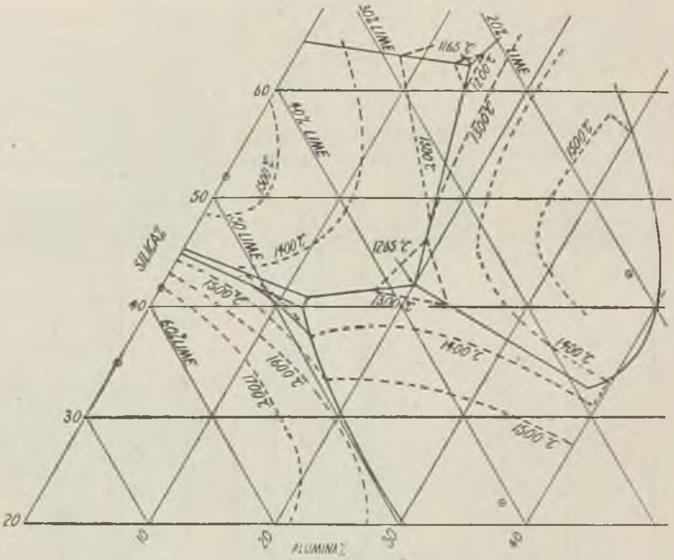


FIG. 3.—TERNARY DIAGRAM OF SYSTEM CaO-SiO_2-Al_2O_3. (RANKIN AND WRIGHT, AMERICAN JOURNAL OF SCIENCE, 1915, VOL. 49, P. 40.)

German Experiments

Many of the ores used in France and Luxemburg are of a calcareous nature, and have proved suitable for processing by the "O.M." method without further modification to the blast-furnace burden. In Germany, however, the pre-war drive for economic self-sufficiency, involving the use of the lean native Dogger ores as well as the omission of manganese ore from the burden, necessitated still further modifications. In 1936 Germany produced only slightly more than a quarter of her total requirements of iron ore. The subsequent developments have aimed at increasing the use of native ores. A typical analysis of the native German Dogger ore is as follows:—

	Per cent.
Iron	20.0
Phosphorus	0.42
Manganese	0.20
Sulphur	0.45
Silica	19.6
Lime	11.5
Magnesia	1.9
Alumina	7.5

The difficulties involved in smelting ore of this composition by conventional blast-furnace methods are obvious. Not only is the iron content very low, but the gangue of the ore is excessively rich in silica. To obtain a slag with a normal basicity ratio of $CaO:SiO_2 = 1.5:1$ would involve the addition of such a large proportion of limestone that the rate of output of the blast furnace would be severely restricted and the coke rate would soar to a hopelessly uneconomic figure.

This difficulty was tackled along lines which had been highly successful in the development of Northamptonshire ore in this country, but taking into account the conditions peculiar to the composition of the German ore. A representative analysis of certain types of Northamptonshire ore is as follows:—

	Per cent.
Iron	29.8
Phosphorus	0.55
Manganese	0.2
Sulphur	0.4
Silica	7.9
Lime	6.4
Magnesia	1.0
Alumina	5.6

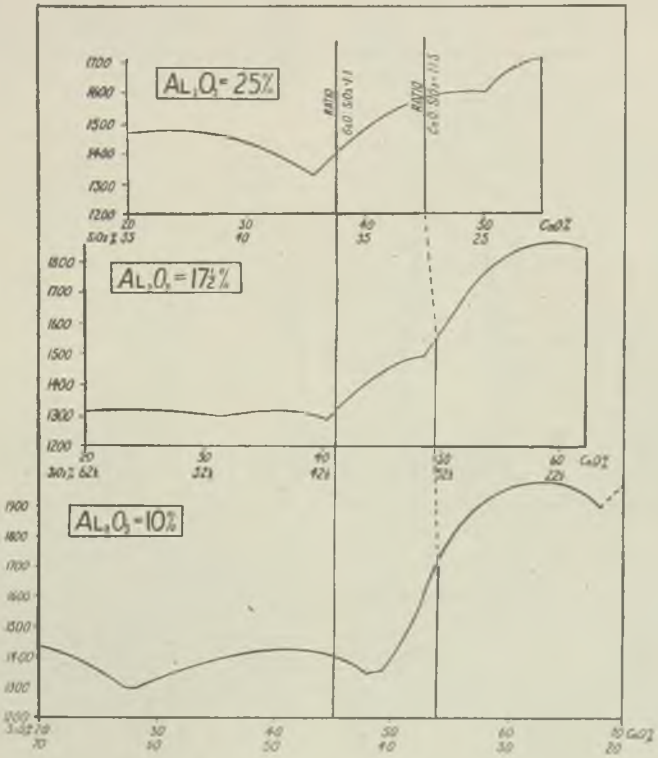


FIG. 4.—SECTIONS OF THE TERNARY SYSTEM $CaO-SiO_2-Al_2O_3$ SHOWING THE MELTING POINTS OF MIXTURES CONTAINING 10, 17½ AND 25 PER CENT. OF Al_2O_3.

Advantages of Northamptonshire Ore

When this ore is smelted with practically no additions of limestone, the resulting slag contains 33 per cent. of both lime and silica, *i.e.*, these two oxides are present in the ratio of 1:1. This ratio has definite advantages from the point of view of furnace operation as compared with the more usual ratio of lime:silica = 1.5:1. These advantages are best illustrated by reference to the ternary diagram of the relevant part of the system $CaO-SiO_2-Al_2O_3$ (Fig. 3). Usually these three oxides constitute about 90 per cent. or more of any blast-furnace slag. The ternary diagram indicates the melting points of the series of oxide mixtures. In Fig. 4, three cross-sections of the diagram are shown, representing slags containing 10 per cent., 17.5 per cent. and 25 per cent. of alumina respectively. It will be seen that the lowest melting-point slags in all cases are very near to the composition coinciding with a basicity ratio $CaO:SiO_2$ = 1:1, this ratio coinciding approximately with the eutectic of gehlenite and anorthite or gehlenite and wollastonite. There is a sharp rise from these melting points to those of slags having a basicity ratio 1.5:1. The slags of low melting point have also a low viscosity at the working temperature, and as a result their sulphur-carrying capacity is reasonably high. The capacity of a slag for carrying sulphur depends not only on its composition, but on the degree of superheat which is possesses. The omission of limestone from the burden enables an increased rate of output to be obtained from the furnace, with the minimum coke consumption per ton of iron, because the limestone is replaced by iron ore. The application of these principles in conjunction with the sodium-carbonate desulphurising process in Northamptonshire and elsewhere in Great Britain has been attended with considerable success.

In Germany, however, the problem was more difficult on account of the high silica content and low iron content of the Dogger ore. The ratio $CaO:SiO_2$ in the ore itself is about 0.6:1. Lennings,[2] who describes the early experiments using varying proportions up to 100 per cent. of this and other native German ores, added sufficient limestone to bring the basicity ratio to 0.83:1. He later replaced some of the limestone by dolomite to raise the magnesia content of the slag from 2.3 per cent. to 4.5 per cent., thus improving its fluidity. The coke consumption per ton of pig-iron was 3,820 lb., the slag weight 5,600 lb. per ton of pig-iron, and the output 304 tons of pig-iron per 24 hr. The hot-blast temperature was 825 deg. C. The average sulphur content of the iron on tapping was 0.448 per cent., and this was reduced to 0.082 per cent. at the mixer entry by treatment with a mixture of sodium carbonate and limestone in the proportion of 52.5 lb. of sodium carbonate and 31 lb. of limestone chippings per ton of pig-iron. This is a very heavy consumption of sodium carbonate, and Lennings was criticised in that connection by Holschuh,[3] who had operated the acid burden process at Völklingen, desulphurising with molten sodium carbonate. British practice is to use a mixture of sodium carbonate, limestone and fluorspar, which has proved to be more efficient.

It is recognised that if the acid burden process is to be operated economically with native ores in Germany, some method of beneficiation of the low-grade ores before smelting will be

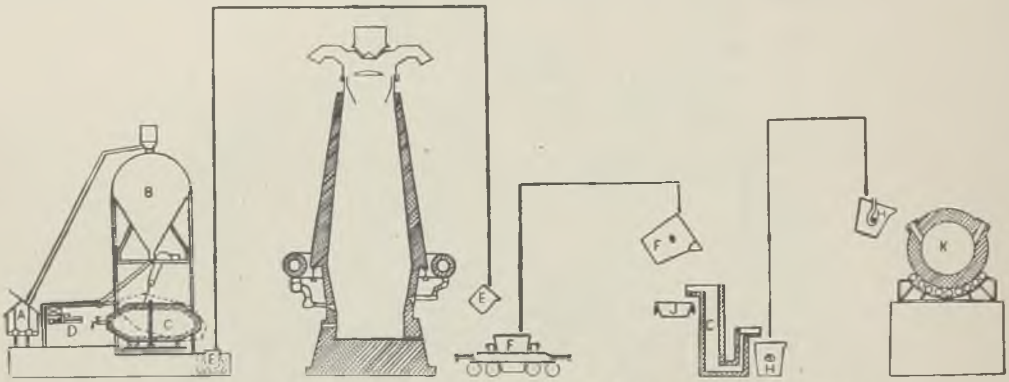


FIG. 5.—DESULPHURISATION OF CAST IRON WITH MOLTEN SODIUM CARBONATE.

A—Covered wagon for bulk delivery of sodium carbonate.
B—Silo for storing sodium carbonate, filled from A by pneumatic power.
C—Rotary furnace lined with tar/dolomite; charged with sodium carbonate by means of the worm conveyor D.
E—Ladle made of steel plate, unlined; preheated, and used for conveying molten sodium carbonate to the blast furnace.
F—The hot-metal ladle, into which molten iron and molten sodium carbonate are poured at the same time.
G—Tall syphon ladle lined with tar/dolomite for separating metal from soda slag. Slag-free metal runs into the ladle H, and is conveyed to the mixer K. Soda slag overflows into the slag pan J.

essential. Lennings considered that his best results were obtained with a ratio of lime: silica = 0.75 : 1. Although the slag volume might be further reduced by using less limestone, several disadvantages outweigh this. The viscosity of the slag increases as it becomes more siliceous, and so does its iron oxide content and the iron lost as pellets in the slag ("shoddy"). A minimum magnesia content of 4 per cent. in the slag is recommended to give the necessary fluidity.

Table II.—*Slag and Metal Analyses in British and German Applications of Acid Burdening.*

	Northamptonshire ores.[5]		German Dogger ores.[2]	
	Normal practice.	Acid practice.	Normal practice.	Acid practice.
	Per cent.	Per cent.		Per cent.
*Slag composition**				
SiO_2	30.9	33.6		44.1
Al_2O_3	22.1	26.0		15.1
CaO	40.0	35.7		36.3
MgO	7.0	4.7		4.6
Ratio $CaO:SiO_2$	1.29	1.06		0.83
Iron analysis—				
Si	0.55	0.6	No	1.58
S	0.05	0.13	figures	0.448
P	1.85	2.00	avail-	1.95
Mn	1.42	1.4	able.	0.18
	Lbs.	Lbs.		Lbs.
Limestone per ton of iron ..	1,120	50		1,610
Coke per ton of iron	2,875	2,425		3,950
	Per cent.	Per cent.		Per cent.
Sulphur in slag	1.42	1.80		0.69

* The four main constituents calculated to 100 per cent.

In Table II is given a comparison of slag and metal analyses in British and German applications of acid burdening.

The Völklingen Process

The author visited Völklingen in 1938 and saw the acid burden process in operation at the Röchlingsche Eisen- und Stahlwerke A.-G. At that time this works was not smelting 100 per cent. of lean ores, but used a mixture, of which the Dogger ore was dried and calcined to give an iron content of 25 per cent. The basicity ratio $CaO:SiO_2$ in the blast-furnace slag was 1.22:1. With this comparatively limey slag the sulphur content of the iron was usually no more than 0.12 per cent. at the taphole. This was an early stage in the intended transition to 100 per cent. Dogger ore. Anticipating that when the final stage was reached, very high sulphur irons might be made (1 per cent. sulphur was even envisaged), an interesting modification of the sodium-carbonate process was introduced, *viz.*, the use of molten sodium carbonate, mentioned above.

The sodium carbonate (see Fig. 5) was delivered to the works in bulk wagons and was unloaded by pneumatic power which carried it along a pipe to a silo. From the silo it was fed through a worm conveyor into a rotary furnace lined with a mixture of dolomite and tar, and fired with coke-oven gas. In this furnace the sodium carbonate was melted, and, when required for use, it was tapped into an unlined ladle which had been preheated internally by means of a coke-oven gas burner projecting downwards from a lid. The lid was only in position while the ladle was empty. When filled with molten soda, the ladle was carried along on a monorail and the soda poured through a tundish into the stream of iron in the blast-furnace runner and thence into the hot-metal ladle, which was lined with firebrick containing 32 per cent. of alumina, and which had a capacity of 25 tons. By the use of molten sodium carbonate in the proportion of 1 per cent. of the weight of metal, the sulphur content of the iron was reduced to 0.4 per cent., *i.e.*, $66\frac{2}{3}$ per cent. of the sulphur was removed. An iron containing 0.18 per cent. sulphur had this reduced to 0.06 per cent. by treating with 1.2 per cent. of sodium carbonate. Holschuh claimed to get from 20 to 25 per cent. more desulphurisation with molten sodium carbonate than with the solid form.[3]

The iron ladles were transported to the steel plant, and there the soda slag was separated from the metal by pouring through a teapot ladle into another ladle in which it was carried to a mixer. The teapot ladle was lined with a mixture of tar and dolomite similar to that used for lining the soda melting furnace. At the time of the author's visit the lining had been used for some 12,000 tons of iron, and it was subsequently stated[1] that its life was 20,000 tons per lining. A feature of the ladle is its tall shape, giving it an unusual depth. This is in order to prevent small traces of soda slag passing right through the teapot spout, and also to allow the iron to be poured through a deep layer of sodium-carbonate slag. This depth of soda slag remaining in the larger limb of the ladle gives a greater degree of desulphurisation than would otherwise be obtained. The ladle is never emptied during the life of a lining, so it is kept continuously hot, as is necessary for the dolomite lining.

In Germany a use has been found for the waste soda slag. It is crushed and mixed with Florida phosphate rock and the mixture is melted in a horizontal retort heated by coke-oven gas to a temperature of 1,200 deg. C. The molten mixture is granulated by running it into water, and, after being ground, it is used as a fertiliser. It has a P_2O_5 content of 20 per cent., of which 96 to 98 per cent. is soluble in citric acid. Being a double phosphate of lime and soda, it has not the same acidifying action on the soil as has superphosphate.

Among other details which have been the subject of investigation in Germany in relation to the acid burden process, is the utilisation of acid blast-furnace slag. This problem is not so easy to deal with there as it is in Northamptonshire, where, by applying well-known and tried principles, the acid slag provides a high-class roadmaking material. The more siliceous slag produced from the German Dogger ores has a tendency to be glassy rather than stoney. By suitable mixing and other treatment it has been utilised for cement manufacture and for brickmaking.[6]

In Great Britain, the use of sodium carbonate as a desulphurising reagent has been established for some years. It has been used extensively in basic iron manufacture, but its application to other grades of iron has been limited by the fact that hot-metal ladles have not been extensively employed. Instead, the metal has been run from the blast furnace on to a sand pig-bed. This state of affairs is now being rectified on a wide scale by a growing appreciation of the advantages of hot-metal ladles and pig-casting machines. In the production of foundry irons, the uniformity of composition throughout a cast of metal as a result of the whole having been well mixed in a ladle, and its freedom from sand when it is cast in chill moulds, are both points of great value in the scientific conduct of foundries, which must ultimately replace the "rule-of-thumb" methods still used in some cases.

Application of the "O.M." Process

The use of the "O.M." process in this country raises certain more controversial problems. Its value in relation to basic Bessemer practice may be taken as proved, but there are differing views as to the need or otherwise for a certain minimum residual manganese content at the end of the steelmaking operation in the basic open-hearth process. It seems at least possible that under present conditions it may become desirable to reduce the manganese content of the pig-iron to some extent even if manganese ore is not entirely omitted from the burden. In such an event the best use would be made of such manganese as was present in the burden, and the sulphur content of the metal could be controlled with certainty by sodium-carbonate treatment.

Desulphurisation has another important application as a result of the revival of the "Armstrong Whitworth" process for the production of high-carbon iron from remelted scrap as a substitute for pig-iron in the manufacture of steel. In the manufacture of high-grade alloy steels, scrap nickel-chrome or other alloy steel is remelted in a basic open-hearth furnace together with carbonaceous matter. The resultant high-carbon steel is cast into ingots and remelted in the acid open-hearth furnace. On tapping from the basic furnace, desulphurisation may be desirable and may justify a considerable expenditure on reagents, etc. It is well known that the desulphurisation of low-sulphur iron is more difficult than that of irons of moderate or high sulphur content. The use of basic-lined ladles such as have been employed on the Continent offers great possibilities. The efficiency of sodium carbonate as a desulphurising reagent is impaired when it is contaminated by silica. Invariably such contamination occurs when an acid-lined vessel is used or when siliceous furnace slag is allowed to enter the ladle. A normal soda slag contains up to 35 per cent. of silica. The author is at present investigating the use of ladles with a tar/dolomite lining, and has succeeded in reducing the silica content of the soda slag, with a resulting marked improvement in the degree of desulphurisation of the iron.

The acid burden process originated in Great Britain and has become a well-established practice. The urgent need for increasing the consumption of home-produced ores at the present time should act as a spur to its still wider adoption. Much of the ore which is being made available is of the high alumina type, which has been successfully smelted by the acid process for years and cannot be used easily for making basic iron by any other process.

Because of the very limited amount of limestone needed for acid smelting, the maximum rate of output is obtained from the blast furnace with a minimum coke rate. Under very favourable conditions, phenomenal increases in production rates have been obtained, and in the average case, an increase of the order of 10 per cent. may be expected. This factor would be of inestimable value in helping to remedy any potential shortage of foundry pig-iron.

As regards hematite iron manufacture, it is customary to operate blast furnaces with a lime content of 50 per cent. or more in the slag in order to ensure a low sulphur content in the iron. Such a slag has a high melting point, and it would appear to be worth exploring the possibility of making a small reduction in the limestone charge. This would reduce the melting point of the slag and make for smoother operation of the furnace and the elimination of scaffolding. The rate of output would be favourably affected, and any slight increase in the sulphur content of the iron could be effectively corrected by sodium-carbonate treatment, which has the additional advantage of freeing the metal from unreduced oxides and other undesirable non-metallic inclusions.

REFERENCES.

[1] "Use of Sodium Carbonate in the Basic-Bessemer Steel Process," "Deutsche Bergwerks Zeitung," June 9, 1939.

[2] "Production of Basic-Bessmer Iron from Low-Grade German Ores in the Blast Furnace with Acid Slag," W. Lennings, "Stahl u. Eisen," January, 1938, vol. 58, pp. 25-34 and 52-58.

[3] Discussion of Lennings' Paper (2, above), "Stahl u. Eisen," June 9, 1938, pp. 623-630.

[4] "Desulphurisation of Pig-Iron with Sodium Carbonate," N. Theisen, "Stahl u. Eisen," July 21, 1938, pp. 773-9.

[5] "Constitution of Blast-Furnace Slags in relation to Pig-Iron Manufacture," T. P. Colclough, J. Iron and Steel Inst., No. 2, 1936.

[6] "Utilisation of Blast-Furnace Slags Produced by Acid Smelting," G. Mussgnug, "Stahl u. Eisen," August 3, 1939, pp. 889-95.

[7]. Verarbeitung von Doggererz nach dem Röchling-Verfahren.

Cupola-Melted Blackheart Malleable Castings

By V. N. WOOD

The production of sound cupola-melted blackheart castings is a series of processes which necessitates strict metallurgical control throughout, otherwise many difficulties will appear. Most of these have root at the melting operation, and prevail right through to any machining operations which may be necessary on the finished product. Although any Paper on this subject must necessarily introduce some metallurgical considerations, the author will endeavour to avoid any involved technicalities and present the Paper from as practical a viewpoint as possible.

Choice of Raw Materials and Metal Composition

During the present times, the choice of the correct raw materials constitutes a problem in itself, and the careful utilisation of substitutes is a matter which demands a great deal of attention from the metallurgist if he is to maintain the quality of the product at the standard possible in normal times and using standard materials.

The successful manufacture of blackheart malleable castings initially depends on producing a white iron within narrow limits of composition which are such that a rather small variation in any one of its vital constituents is likely to introduce difficulties by either giving an iron too grey in character to be of any use as malleable iron or conversely a completely white iron having a deficiency in such elements as silicon and carbon. These are necessary in certain amounts to promote satisfactory annealing treatment later in the process.

A typical composition for cupola-melted blackheart malleable iron is:—T.C, 3.1; Si, 0.7; Mn, 0.50; S, 0.15; and P, 0.10 per cent.

The cupola was considered some years ago as being unsuitable for melting iron for malleable castings. It is now recognised, however, that a regular supply of hot metal of the desired uniformity can be obtained from the cupola for this purpose, provided that attention be given to every detail of cupola operation.

In the first place, owing to the lack of latitude permissible in the chemical composition of the iron, it is important that the charges of raw materials which generally consist of hard white iron scrap, hematite pig, steel scrap, small percentages of annealed scrap and ferro-alloys such as speigel and ferro-silicon, should be carefully weighed in their correct proportion. One consideration at the present time may be the variation in the size of steel scrap. One consignment may consist of clean pieces of substantial dimensions, whilst others may be of small rusty variety. On no account should the type of steel vary from charge to charge, it being a far wiser plan to mix small and large together. This should assist in preventing excessive oxidation, as would be the case if all small steel was used. As small steel would tend to be selectively melted much quicker than the larger accompanying pieces of pig-iron and iron scrap, the foregoing suggestion should prevent different melting rates of the charges and consequent variations in the metal from tap to tap, especially if the well of the cupola is of small capacity. If a large mixing ladle or receiver is used, variation from this source may not be so prevalent.

Manganese steel should be strictly avoided and care should be taken in the handling of machinery steel, which is often of the alloy type and may contain considerable amounts of chromium. The presence of small amounts of chromium in standard malleable castings renders them useless for the subsequent annealing process. The chromium content of the metal when tapped should not exceed 0.05 per cent.

Special care is necessary to ensure that the coke bed is made up to the same height for each successive melt. Too high a bed will give a metal of too high a carbon content, and the fracture will tend to be grey, giving danger of primary graphite in the castings, which is a great source of mechanical weakness in the annealed product. On the other hand, a low bed will give rise to metal of low carbon content, which will generally be cold and sluggish in character. Even with the best of conditions, molten white iron for malleable castings has a short "life," due to relatively low silicon, carbon and phosphorus contents, and it is essential that it should be transported and poured into the moulds as quickly as possible. Moreover, too low a carbon content along with low silicon will give difficulty in the annealing process, as will be seen later.

Another important factor is to maintain as far as possible the same rate of oxidation throughout the duration of the run. For this purpose the volume of the blast should remain as constant as possible and variations in pressure avoided.

Metal Consistency Controlled by Analyses and Fracture

Although frequent chemical analysis of the metal at regular intervals is necessary, the results in general cannot be obtained quickly enough to make modifications in the charges to correct any sudden divergence of metal composition due to any unforeseen irregularity in cupola operation, which are sometimes bound to occur in the most carefully regulated practice, often due to circumstances beyond the control of the metallurgist on the spot. They do, however, give a good idea of the general condition of the iron, and to some extent the working condition of the cupola with respect to the bed, coke and metal charges.

As a quicker additional check by fracture, a rough, but reliable, indication of metal composition can be obtained by pouring test-bars, allowing them to cool to a somewhat dull red temperature, at which the structure will be stable, and finally quenching in water. The quenched bar is then broken and the fracture examined, the time which elapses between the pouring and examination of the bar being controlled to a previously determined standard. If the fracture is not as desired, a further test-bar should be poured, and, if this is still unsatisfactory, the metallurgist can then make a correction by adjustments to the amounts of ferro-alloys, blast pressure and volume, or the weight of the coke charge.

A test bar which shows a rather mottled fracture may be attributed to too high a silicon content—the excess of coke giving high carbon content, deficiency of air or irregularity of tapping. A bar which is excessively white and brittle may be due to too low silicon, insufficient coke, too much air, especially at high pressure, and again irregularity of tapping.

Another useful purpose of the fractured test bar is, that it indicates the type and size of casting which shall be poured with the metal which is being tapped at the time. It is well known that two castings of different average metal thicknesses will give totally different fractures when poured with metal of the same composition. If the test bar contains a considerable number of grey mottles it may be permissible to pour castings of thin section without fear of primary graphite in the castings, whilst the pouring of castings of heavier section should be avoided. Similarly if the test piece shows freedom from mottle it can be taken for granted that castings of reasonably heavy section can be poured with safety.

Dangers of Very White Iron

One great source of trouble in the production of malleable castings is that of shrinkage. This is a matter which can largely be left in the hands of a capable patternmaker. However, the metallurgist in charge of the melting process can assist somewhat in this direction by the avoidance of metal of exceptionally-low silicon content; also, excessive amounts of hard iron, as cracks in castings can be traced to this source. Again, the tendency of the metal to excessive shrinkage can be observed in the fracture of the test bars, and although it is not always the case depending to some extent on the pouring temperature of the metal, the magnitude of the shrink in the bar varies with the whiteness and composition of the metal.

Another danger of very white and sluggishly pouring metal is the formation of blowholes and inclusions of trapped slag—it being insufficiently fluid to allow for the escape of released gases either from cores or air drawn in through the gates in pouring. The product in the cast state is naturally very hard and brittle, and must be malleablised by subjecting to an annealing treatment, which should be carried out under the constant supervision of an experienced metallurgist.

Annealing Furnace and Loading of Product

An annealing furnace of the batch type consists of a firebrick chamber, the size of which depends on the quantity of castings to be annealed. The flues for taking away the products of combustion may be constructed in the floor of the furnace, the floor also consisting of firebrick. The walls and roof should be completely encased with a layer of light insulating brick. Burners for the fuel may be located in the roof or walls, the position depending upon the shape of the furnace and the type of fuel used. Annealing furnaces may be fired either with pulverised coal, gas, fuel oil or coal. Access to the inside of the furnace for loading and unloading purposes is made possible by a thick, well-fitting firebrick lined door.

The castings are placed in round, square or rectangular white iron cans or pots, which may be built into a tier three or four high. The pots, which are usually flanged at the top, may be built into a tier up to 6 or 7 feet in height, depending of course upon the height of the annealing furnace. Beneath the bottom pot a robust stool with good strong legs should be used. This serves two purposes, first, to facilitate the handling of a full tier of castings by allowing the prongs of the lifting gear on a petrol or electric truck to pass underneath, and secondly to enable the hot furnace atmosphere to circulate beneath the bottom pot of the tier. If the base of the bottom pot were resting on the floor of the furnace the temperature of this part of the pot would lag behind the rest. Different types of castings require different means of packing before annealing.

It is important that thin and intricate castings should be carefully packed in some inert material such as burnt sand in order to prevent warping. More robust products may be loaded into pots without packing material providing that sound pots and lids are used. It is also very important that the furnace atmosphere which at times may be of an oxidising nature, should not come into direct contact with the castings. To minimise this danger a liberal application of a strong wet luting mixture, which may consist of fine sand and intimately mixed clay, is well rubbed into the joints formed by the bottom of each pot on the projecting flange of the one directly underneath. A sound and well fitting lid should cover the top pot of the tier which in turn should be rendered absolutely airtight by means of an application of luting mixture.

During the firing of a furnace in the initial stages, the location of the zone of combustion is generally somewhat better than the remainder of the furnace, so judgment should be exercised in the distribution of the weight of product to be placed in the furnace. Tiers of pots containing heavy castings or small jobs with a large ratio of metal weight to air space should be placed in the parts of the furnace which are known to receive the most heat. This precaution of placing the most weight in the area of the furnace which receives the most heat tends to even out any temperature differences likely to occur, particularly during the initial stages of the firing. The tiers should be loaded into the furnace so that the air space between each is even and sufficiently large to allow ample circulation of the furnace atmosphere.

Fig. 1.—Completely Annealed Metal. Unetched. × 50.

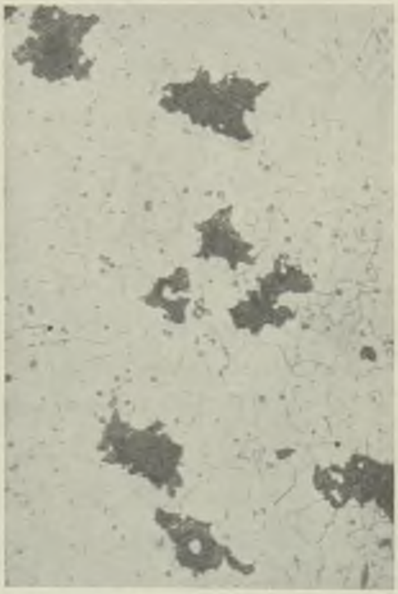


Fig. 2.—Completely Annealed Metal. Etched. × 100.

For the best results, a soft rolling flame must be maintained during the whole firing operation. This is produced by using the minimum amount of air required in excess of that necessary for complete combustion of the fuel. In addition it is essential to have as part of the air used, an adequate amount of draft through the furnace to allow flexibility of flame control. The control should be carefully exercised by suitable flue dampers, as too much draft is likely to cause a rather fierce flame which may result in hot spots or zones. During the whole annealing process the temperature must be strictly controlled by means of reliable temperature recorders.

Stages in the Annealing Cycle

Annealing of blackheart malleable iron consists of three essential stages.

(1) *Heating-up Period.*—A period in which to raise the furnace to a predetermined temperature, known as the "at heat" temperature, generally between 850 and 950 deg. C., the choice depending upon the desired class and quality of the product, and to a great extent upon the average composition of the metal. The temperature gradient must not be forced, but maintained at such a rate that the heating is uniform throughout the furnace. For instance, with too rapid heating, the outside portion of a tier of castings may be really hot, whilst the castings in the centre may be comparatively cold.

The rate of heating is, of course, controlled by the size and capacity of the furnace, and with large furnaces holding 40 tons or more of metal the time required may be in the region of 36 to 40 hrs. or more. The rate of heating then, to the "at heat" temperature, should be so gradual as to ensure thorough and uniform heat penetration of the mass of product in the furnace.

(2) *Soaking Period.*—The next stage is to maintain the furnace at the required temperature for a sufficiently long period to promote and complete first-stage graphitisation. This operation is the breaking up of the massive cementite or carbide of iron, which is the hardest structural chief constituent of white iron, into a softer material, known as pearlite, along with nodules of graphite commonly known as temper carbon. The length of time required for this purpose depends upon the control temperature. The higher the temperature, the quicker the reaction. At 850 deg. C. the period required for the conversion would be 60 to 70 hr., whilst at 950 deg. C. the reaction may be complete in about 36 hr.

A finer-grained metal is obtained by the use of lower temperatures, but the time factor involved is a great disadvantage in quantity production work. With metal of suitable analysis, reasonably fine-grained fractures can be obtained with higher annealing temperatures, though excessively high temperatures give poor, coarse-grained metal.

(3) *Cooling-Down Period.*—The third and final stage of the annealing process is the cooling-down period, during which second-stage graphitisation takes place. When the furnace has been maintained at the desired temperature for the required time, the fuel is shut off, any dampers closed, and all openings to the atmosphere should be filled up with refractory material, thereby completely insulating or sealing off the furnace. The rate of cooling is extremely important, especially in the range 730 to 700 deg. C., and care is necessary to ensure that it does not exceed 7 deg. per hr. through this range, and preferably slower than this rate. Furnaces may be so small that the cooling rate is in excess of that desired, but it may be retarded by relighting the furnace when the temperature has fallen to 730 deg. C., and gradu-

FIG. 3.—WHITE IRON. ETCHED. × 50.

ally reducing the fuel supply so that it takes up to 10 hrs. for the temperature to fall from 730 to 700 deg. C. With the larger types of furnaces this procedure is usually unnecessary, as the cooling rate is naturally slow, due to the larger bulk contained therein, but nevertheless the cooling rate should be carefully observed at the critical period as a precaution against leaking flues or faulty insulation. This slow rate of cooling is necessary in order to decompose the pearlite, which consists of alternate bands of cementite and ferrite. The cementite of the pearlite contains all the residual combined carbon, the latter being set free as temper carbon in fine, evenly dispersed nodules and ferrite, *id est* carbonless iron in which is dissolved the manganese and silicon. The structural composition of fully annealed blackheart malleable iron, then, is a matrix of ferrite to which the iron owes its ductility, and fine, evenly distributed particles of free carbon, known as temper carbon (Figs. 1 and 2). The structure of the metal in the "as cast" or unannealed condition is that of a normal white iron (see Fig. 3), *i.e.*, a cementite-pearlite structure. To obtain the condition of maximum strength and ductility, the annealing procedure must be given the correct attention.

Some Possible Failures after Annealing

After annealing, a good blackheart malleable iron has a fine black fracture, as shown in Fig. 4 (1). This fracture exhibits a silky sheen when turned at certain angles to the light. However, a small number of waster castings may be found after annealing treatment, due either to undesirable metal composition or to other causes. Distorted castings are those which have usually been subject to an annealing temperature high enough to render the material sufficiently plastic under heat to deform under their own weight, or the weight of other material directly above. Such castings usually have a coarse fracture, as shown in Fig. 4 (2).

A white and hard fracture, after annealing, can be attributed to several causes, such as insufficient time at the annealing temperature, or too low an annealing temperature, due to either faulty pyrometric equipment or cold spots in a badly designed or controlled furnace. It may also be caused by very low silicon, alone or together with low carbon content, the lack of sufficient quantities of which, and especially in the case of silicon, greatly retards the rate of graphitisation. Manganese also affects the rate of annealing to some degree. It should be present a little in excess of that required to combine with the sulphur to form manganese sulphide; at the same time the excess should not be too great, otherwise under-annealing difficulties may be introduced due to the stabilising effect of manganese on carbide, especially during second-stage graphitisation and possibly due to the introduction of manganese carbide itself. The presence of chromium even in very small amounts, is capable of retarding graphitisation to such an extent that successful and complete annealing is virtually impossible.

A casting will sometimes be found which is weak and brittle, and examination of the fracture reveals a rather dull black interior, with a considerably lighter coloured lustreless edge, as is illustrated in Fig. 4 (3). A defective casting of this type is caused by metal which in the hard state was mottled with primary graphite. A microscopical examination will show large segregations of graphite in the centre of the casting, many of which follow the grain boundaries, whilst at the edge there will be a band of finer and more plentiful primary graphite. This structure is shown in Figs. 5 and 6. The primary graphite flakes greatly break up the continuity of the ferrite ground mass, causing a serious loss of strength and malleability.

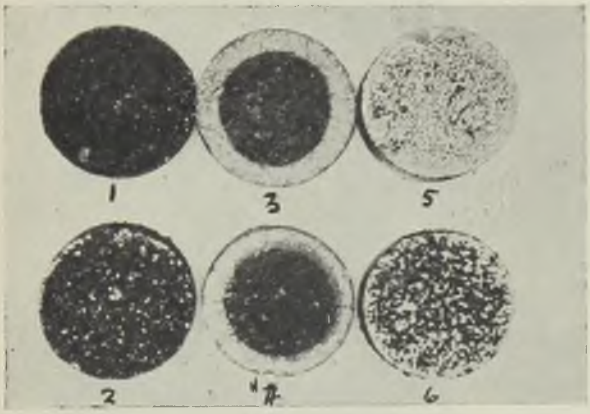


Fig. 4.—(1) Good Fracture; (2) Coarse Fracture such as obtained by Treatment at High Temperatures; (3) Metal inclined to be Grey; (4) Decarburised; (5) Pearlitic; (6) Coarse Pearlitic-low Si and C.

Another defect, which at first sight appears to be similar to that of grey metal just referred to, is that of decarburisation, which is the burning or oxidising away of the surface carbon.

A closer examination of the fracture will show that the appearance of the inside of the casting is quite normal but the outside layer is rather lighter and somewhat steely in aspect as is shown in Fig. 4 (4). Decarburisation is always caused by the castings being subjected to oxidising conditions and the depth of decarburisation varies according to the severity of, and the time exposed to these conditions (Fig. 7). When they are particularly severe the carbon may be completely removed throughout castings of thin section, and in many such cases there is oxide penetration into the iron as shown in Fig. 8, especially at the grain boundaries at the edge of the casting. There are several causes of decarburisation—employment of air much in excess of that required for complete combustion of the fuel, and especially is this the case when pots are not airtight due to inefficient luting, or premature failure of the pot itself by the employment of one which has insufficient metal thickness to withstand the oxidising conditions. Decarburisation is generally associated with a considerable amount of scaling of the castings and after cleaning they may be appreciably "off size."

only a small amount of ductility. Nodules of graphite or temper carbon may be plentiful and can be seen with the naked eye, giving a fine mottled appearance to the fracture and the material is not unduly hard. This type of material, shown in Fig. 4 (5), is known as pearlitic—the hardest constituent of the original white iron, namely, cementite—has not been wholly decomposed, and some of the pearlite which contains a quantity of the carbon in the combined form still persists. This is shown in Fig. 9. A common cause of this type of fracture after annealing is too rapid a cooling rate through the critical temperature range 730 to 700 deg. C. Also too high a manganese content along with low silicon and carbon may

Fig. 5.—Grey Metal Edge of Casting. Unetched. × 50.

Fig. 6.—Grey Metal; Centre of Casting. × 100.

Incidentally the life of the annealing pots, which should allow for use several times, is considerably curtailed if constantly used in furnaces where oxidising conditions prevail. To minimise the occurrence of this furnace condition, and to correct, if possible, when present, it is a wise precaution to take gas analyses or check with a portable furnace atmosphere analyser. Castings, which by reason of their shape or small thickness, are packed in sand or other substances, may also suffer some decarburisation if the packing material contains any red oxide of iron, and is not completely burnt before use.

Cases sometimes occur where the metal has a tensile strength well above the average but be responsible as is illustrated in Fig. 4 (6). Less frequently, exceptionally low manganese and silicon will also produce pearlitic malleable. Cases may occur where the fracture is not completely pearlitic, but the pearlite may be present as a white rim running at various depths near the edges of the castings and material of this description is often referred to as "picture frame" malleable, and the cause can often be traced to either very high or very low manganese.

Behaviour of Various Structures in Machining

Several of these divergences from the normal desired structure frequently give trouble when the castings are subjected to any machining operations. Theoretically, owing to the soft nature of blackheart malleable iron and the presence of fine, evenly-distributed temper carbon, machining should not introduce any difficulties; in fact, machinability is invariably excellent. If the metal is sound and correctly annealed, tool life should be long, and it should be possible to maintain high cutting-speeds. The presence of temper carbon in blackheart malleable iron assists machining both by breaking up the chip and by acting as a lubricant for the chip and tool.

However, with the case of under-annealed material and especially that in which the annealing is so imperfect as to retain some of the original hard cementite-pearlite structure of

Fig. 7.—Decarburised Casting. Unetched. × 25.

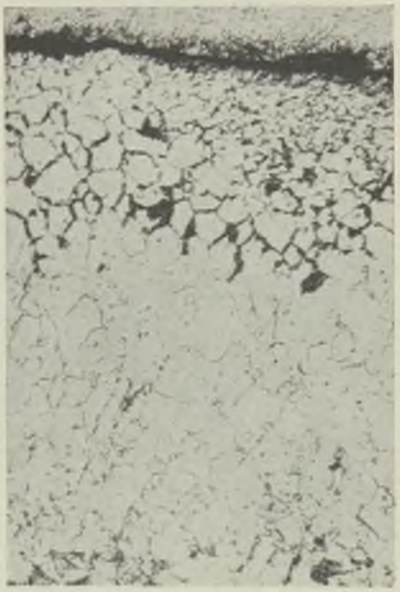


Fig. 8.—Decarburised Metal with Oxide Penetration. Etched. × 100.

the white iron, very heavy tool loads are set up, and very early failure of the cutting edge results.

With material which has been decarburised to an appreciable extent owing to the tough character of the ferrite and absence of the lubricating properties of temper carbon, the cutting speed must be considerably reduced, otherwise a rough surface appears on the work, and it is very difficult to produce a fine smooth and clean thread. Ferrite, the product of decarburisation, tends to cut in rather long chips. As a result, the flutes in taps, dies or reamers may become clogged and prevent a clean cut. It is a common occurrence for the tool to bind in the work and fracture. Time and money is then lost in making and setting up new tools in the machine. It is therefore obvious that decarburisation is very objectionable in castings for machining, especially if its presence is unsuspected.

Conclusion

In conclusion, the foregoing survey covers the two main processes employed in the production of blackheart malleable iron castings, namely, melting and annealing of the iron. This branch of foundry work is perhaps one of the most specialised in the whole of the foundry industry, and the precautions involved to produce sound castings are numerous and varied, but if thoroughly understood and the processes are skilfully and technically controlled, it is possible to produce good and metallurgically sound material with almost unbroken regularity.

The author wishes to express his thanks to Crane, Limited, and their chief metallurgist, Mr. H. H. Shepherd, for permission to present this Paper.

DISCUSSION

Mr. J. L. Francis said it appealed to him as a good point in melting steel scrap to mix large and small pieces together as an aid to more uniform melting and less oxidation loss. He also emphasised the importance to the war effort of a process, such as had been described, which allowed of iron castings replacing those of steel in certain circumstances and to a greater extent. Another point was the effect of section thickness on the annealing process. Were thick and thin castings classified? The lecturer had stressed the importance of metallurgical control at all stages, and Mr. Francis said he could easily appreciate this with a material requiring such close limits of composition and with the

Fig. 9.—Casting Too Quickly Cooled after Annealing. Etched. × 300.

difficulties occasioned by its naturally high shrinkage.

Mr. C. H. Kain congratulated the author upon the excellence of the photomicrographs with which the Paper was illustrated. He also commented upon the composition of the white iron as given by the lecturer, saying that it seemed rather high in sulphur. Was the melt desulphurised by soda ash? Did the author deliberately employ such a high sulphur figure or was it accidental? Referring to the inert material in which the castings were annealed, Mr. Kain said that he had found burnt slag to have a greater heat-conductivity than sand. The annealing temperatures given were higher than for rotary furnace malleable where 880 deg. C. was a maximum figure.

Mr. A. F. Hammond also raised the point whether thick and thin castings were annealed together in the same pot. He also asked whether loose packing or air spaces had any effect on the anneal.

Mr. L. R. W. Davey asked if, in view of the difficulty of control of the last charges melted in the cupola when using steel scrap, the blast was cut down.

Mr. T. W. Ruffle inquired as to what fuel was used in the annealing ovens and the composition of the oven atmosphere. He also asked if a coarse grain developed by high-temperature annealing could be restored by subsequent heat-treatment.

Mr. D. Carrick, referring to core practice, asked whether it needed modification to suit malleable cast iron. He also asked for a comparison between blackheart malleable and mild steel for strength.

Author's Reply

In reply, the Author thanked all those who had made complimentary remarks on his Paper. Dealing with the question of section thickness, he said it did not effect speed of annealing, but did effect the heating up. The castings were sorted and the thickest ones were placed in the hottest part of the oven, experience being the guide. Packing material used in the blackheart process was only to prevent sagging or warping of castings.

The high sulphur came chiefly from the hard scrap and was normal for cupola-melted white iron. Malleable castings made from the rotary or air furnace were annealed at lower temperatures, as they usually were of high-class requirements where small grain size was desired. The annealing time would, however, be longer.

With respect to Mr. Davey's question, Mr. Wood said that iron from the last few taps tended to melt whiter and hotter, and the blast was cut down. The fuel for the annealing ovens was pulverised coal or fuel oil. Oxygen in the ovens was below 1 per cent. It was possible to refine a coarse grain caused by high annealing temperature by subsequent thermal treatment.

Cores for malleable iron castings must be as soft as possible; otherwise there was a danger of hard iron cracks. Blackheart malleable had a tensile strength equivalent to that of 0.1 per cent. carbon steel, but the ductility was less.

Mr. H. H. Shepherd (Branch-President) congratulated Mr. Wood on the Paper and illustrations. He said there was not much latitude in the manufacture of cupola blackheart malleable, rather less than for whiteheart. Air-furnace malleable was lower in total carbon and sulphur and higher in silicon.

Factors in the Production of Sound Castings in High-Duty Iron

By J. KING

This Paper deals with some of the factors influencing the production of sound castings in Meehanite, for sound castings are the primary aim of every foundryman. Soundness is governed by a number of factors, including metal composition, melting conditions, casting temperature, sand control, gating, etc. To discuss all, or even several factors, would entail too much time and space. In the main the author deals in detail with the results of personal experience.

Sand Control

This plays a very important part in the production of castings, and is responsible for many wasters, usually through lack of permeability. Permeability can be increased by judicious venting, but few moulders seem able to use a vent wire properly, and therefore sand should, where possible, be graded and mixed to give the desired permeability without resort to the vent wire. This can be proved by experimenting with sand moulds using sands of varying permeability. Low refractoriness in sands is responsible for surface defects and machining troubles due to sand adhering or fusing to the surface of the metal. This increases machining difficulties and fettling costs rather than being a cause of unsoundness.

Control of moisture content is also essential in order to avoid blow-holes and loss of permeability. It will also possibly affect the structure of the casting, as steam and gases generated by the contact of hot metal with the water in sand pass through the metal. Excess moisture also causes chilled edges, etc. Care should be taken in ramming the mould, which is generally done more efficiently by machine. The author's firm uses a fusion test of sand—believing it to be essential for heavy work, especially for tops of moulds for large castings. For instance, if a riser blows air (commonly called "drawing" air in the foundry) it gives an idea as to the heat to which the top face of the mould is subjected as the hot metal rises to it, especially if the top has facing strips on it.

One job to which it seems desirable to refer is a casting made off the old one used as the pattern. It was a 100-ton press casting, a combination of two cylinders and table, weighing 11 tons 10 cwt. Sand, control played a big part in making this a successful job, which is illustrated in Figs. 1 to 3. The casting used as a pattern was over thirty years old, and was analysed to discover its composition. Samples were taken which gave a tensile test of less than 9 tons per sq. in., and the analysis was that of a very poor iron. The new casting was made in an ordinary grade of Meehanite, which gave a tensile of 18 tons per sq. in.

For successful results, the sand requirements for cores are similar to those already mentioned, and sand testing and control contribute greatly towards this end. The author recognises the progress made in sand research in this country. To-day executives can confidently operate their foundries with every property in sand practice under direct control. This is as it should be, since the mould for containing the hot metal is just as important as the metal itself in the production of quality castings. However, it might be as well for all to remember at all times that just testing sands, or trying to make synthetic sands, does not make castings. Foundrymen must in all cases employ judgment as to results from sand tests, and especially is this the case in the manufacture of synthetic sand.

Interpretation Needed

Hasty judgment in connection with either of these procedures leads to negative results. Sound knowledge, coupled with proper interpretation, is of vast importance to anyone interested in the proper selection and use of sands in the foundry. It now appears clear that foundrymen can look forward with confidence to great improvements in sand practice in the near future. Rapid changes are developing in the mechanical treatment, more use is being made of clays for re-bonding, and even cement is also used. With these developments the industry should soon be in a position to select, blend, and use sands located anywhere in the country with good success, for iron, steel, or non-ferrous castings. Sand testing and control in conjunction with the proper blending makes possible the use of local materials in place of moulding sands located perhaps scores of miles away.

Operations of this sort develop economies of considerable value to foundrymen. Selection of sands for use in the foundry is based primarily on needs as related to the range in size of the castings to be made. It is now a simple matter to select approved moulding and core sands with the assurance that in use they will yield satisfactory results. Founders can if they wish submit specifications to the sand suppliers, and they in turn will, with reasonable accuracy, supply the sand in accordance with the specification. However, some foundries are still ordering by trade names and not by specification.

Here is an initial opportunity for simplicity, for an effort should be made to have the least number of sands possible in the foundry. This procedure avoids complications. For example, if a coarse sand with high permeability for heavy work be needed, an endeavour should be made to use that type of sand exclusively for heavy work. At no time should a very fine sand be mixed with it, because in doing so the advantages of open grain and high permeability are lost through small grains and interstitial congestion in the fine sand.

The author's practice consists in the use of one type of sand for light and medium work, and another for heavy tops, etc. It is quite customary to find jobbing foundries operating with a great variety of moulding sands of different grain-size, clay content and permeability. It is also quite usual in jobbing foundries to find moulders free to use their own judgment in mixing and blending any of the sands in the shop.

The mixing and blending of sands with widely different physical properties is wrong, and runs contrary to established knowledge of better sand control. In making specific recommendations for sand practice in foundries, one should always take into consideration the shop conditions under which the sands will be used.

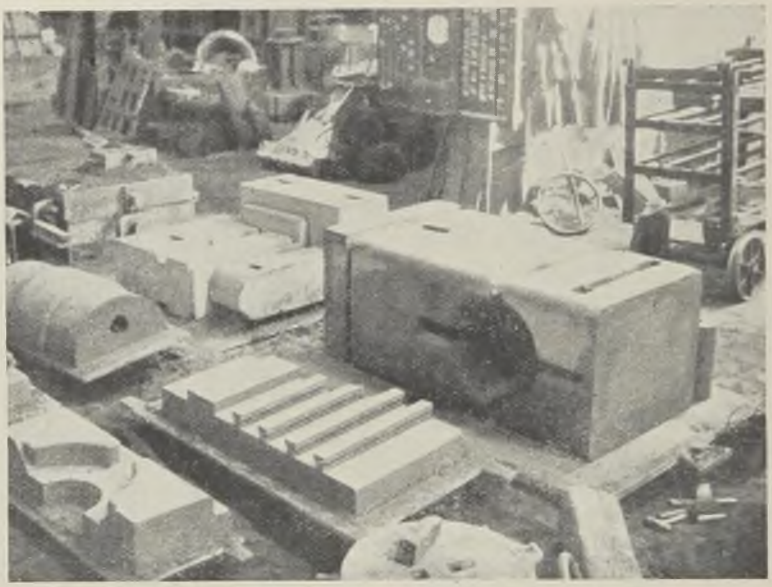


Fig. 1.—Some of the Cores used for the Making of a 10-ton Casting using a Discarded Casting as a Pattern.

It is not sound to suggest the use of any sand unless the methods of operation in the foundry are known. Then only can constructive advice be given on the type of sand best suited to that particular practice. For example, one foundry may use a continuous sand handling system, another may use muller mixing operations, and a third one employs machines of the Royer type or sand cutter.

All mechanical treatments are good, but they produce widely different results. This must be borne in mind when making definite recommendations. Simplicity has been strongly emphasised throughout this reference, both from the standpoint of selection and use, as well as testing and control of sands.

Runners and Risers

In leaving this subject it seems clear that by careful selection to begin with, followed by suitable preparation for the work in hand and then applying commonsense methods of testing and control, foundrymen can accomplish much in the manufacture of castings. In most foundries engaged in making a miscellaneous line of castings, and this applies to practically all Meehanite foundries, the question of risers, their size, shape and location is one that calls for profound attention and consideration—more than is given in a good many cases. Considering the variety of castings as wide as in most foundries known to the author, the risers used are few in number. It is true the author's firm has perhaps a little better chance to develop their shop practice because most of their work is for use in their own machine shops, and for their own line of machines of various types, but there is no chance of anything being accepted by the Inspection Department, unless it is entirely satisfactory in material and in workmanship.

The author was convinced that in many cases some foundries would be rather glad of a chance to take for their use some of the castings his firm scrap as not being up to standard. However successful or otherwise the firm may be, or have been, in succeeding without extensive use of risers, it is not his purpose to say whether risers should or should not be used in other shops as they are now being used. It is possible this practice is correct, and, while it may be expensive in that it reduces the yield in saleable castings per ton of metal melted, yet it may be a measure of insurance against the loss of a casting for which the customer may be in quite a hurry. Then, again, risering may do more harm than good. An interesting Paper given on runners and risers, to which reference is strongly commended, was given to the Scottish Branch by J. Longden (Paper No. 624, Volume XXX, 1936-1937).

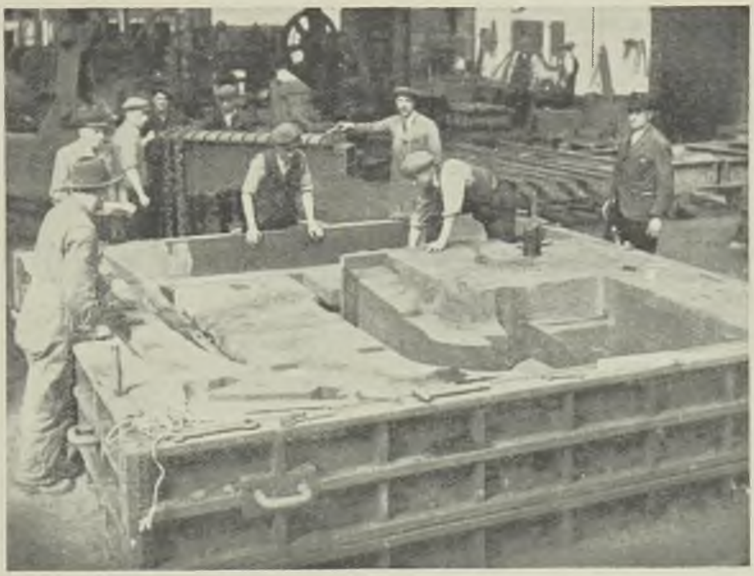


Fig. 2.—Cores being Assembled in the Mould.

Defective Castings

Everybody has heard that some foundries have no scrap, whilst others have 5 to 10 per cent. The Author has his own opinion of the so-called 100 per cent. no-scrap foundry, so he will try to help the alleged 5 to 10 per cent. scrap category. Three basic factors must be considered in this connection: (1) Mental attitude towards defectives; (2) management responsibility; and (3) nature and conditions of work.

Mental Attitude.—In considering the basic conditions responsible for defective work, it is evident that the main factor is that defective castings are tolerated in the foundry. In other words, the mental attitude of management and staff is to expect defective castings. They are accepted as a matter of course, and, provided that they are kept down to what is considered a normal working range no great attention is paid to the matter. It is frequently argued that the foundry loses nothing by defective work since this is covered by the estimated loss included in the price.

This is an example of the mental attitude which is responsible for defectives.

Management Responsibility.—The scrap problem is essentially a management problem, in fact, it may be stated as a general rule that the percentage of defective work is inversely proportional to the attention given by the foundry management to this matter. Management is directly concerned with obtaining the maximum operating efficiency, and elimination of defectives is as closely related to efficiency as is production capacity.

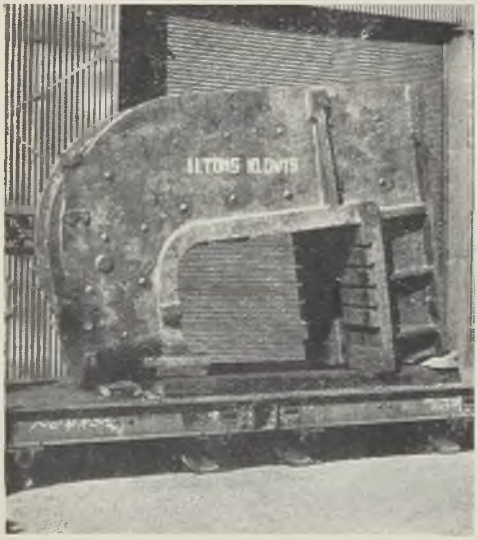


Fig. 3.—The Finished Casting.

Nature and Conditions of Work.—Defective castings may be classified into two main divisions: (1) Defective materials, and (2) defective workmanship. Both of these conditions are traceable to the management whose duties include: (1) Suitable places for men to work; (2) supply of the correct working materials for the men; and (3) education and supervision of men in correct methods of working. Owing to the nature of foundry work, these duties become of vital importance in foundry management. In the days of apprenticeship a casting made just before leaving off for the day, and known to be a waster, would cause a restless night, but by experience it has been found that worry will not remove the cause. An inquest on the defective will prevent a repetition. No replacement should be made until the cause of the trouble is ascertained. Mr. L. J. Tibbenham, in his presidential address, referred to defective castings. Since then, the Author has thought that a Paper on the subject would be most opportune. It is hard to obtain 100 per cent. good castings, but an effort is made to get as near to it as possible, and tackling this defective problem objectively will help the foundry to reach this goal.

Defectives in the Machine Shop

A large proportion of the castings found defective in the machine shop are due to the lack of collaboration between designer and machine shop. In the production of castings there is involved the work of the designer, the patternmaker, the foundryman, and the machine shop engineer. Much of the difficulty of collaboration between these departments is due to the lack of appreciation of the difficulties involved in other work and in particular to the fact that each talks in a different technical language.

The collaboration should be divided into three. First, choice of materials—information available to the designer for the selection of the material best suited to the service involved. Secondly, collaboration between designer and foundry to reduce moulding and metallurgical problems. Thirdly, collaboration between foundry and machine shop to facilitate machining operations.

Each of the subjects touched upon are such that a Paper could be given on each, and a very interesting Paper, too. These subjects were selected from experience in changing from ordinary cast iron to Meehanite. In conclusion, the author would like to thank the management of Ransomes & Rapier, Limited, also the International Meehanite Metal Corporation, for permission to give this Paper.

DISCUSSION

Mr. J. L. Francis congratulated the author on his practical Paper, and put the following questions:—(1) Are denseners employed? and (2) is any rod feeding practised? Commenting on the standardised pouring basins, runners and gates, moulded from proper patterns, he said how often one saw every care taken with moulds and cores whilst ingates were cut at the moulder's discretion and any odd piece of wood employed to form a downgate. This haphazard method tended towards a surface made up of disturbed sand grains which came away with the metal stream. All the metal entering a mould must pass through the runners and, therefore, they should have at least as much care and attention as the mould itself. Gates and runners supplied as part of the pattern ensured the same undisturbed sand surface as mould and cores, and made a serious contribution towards soundness in castings.

Mr. Geo. Hall thanked Mr. King for his foundryman's lecture to foundrymen. He asked whether the pencil runners used were invariably the diameter of a pencil and more or less used according to the size and weight of the casting. As Mr. King employed no horse manure in his sand, what did he use in place of it? Mr. Hall had used sawdust successfully, but it had to be from wood containing a minimum of oil, as otherwise difficulty was experienced in the blacking of the sand surfaces.

Mr. D. Carrick inquired as to the time taken in pouring moulds, and asked if Mr. King made use of any means of calculating the size of gates and runners relative to the weight and size of the casting.

Mr. L. E. Slater asked if Mr. King made fluidity tests, and said also that where sand burnt on it was more often due to unsuitable sand than the fault of the runner. He also asked whether the author had tried feeding from the side and bottom of, for example, a flywheel with clutch plate, the latter cast in the bottom.

Mr. H. H. Shepherd said that Meehanite metal had the right to rank as high as any other metallurgical development of recent years. The lecturer had given instances of Meehanite replacing castings of malleable cast iron. Such high grade irons, however, had not been successful in making the replacement in all cases, and service equipment subject to blast effect was a case in point. A beneficial feature of the use of strainer cores was their prevention of air sucking in with the metal. Finally he proposed a hearty vote of thanks to Mr. King for his excellent practical talk.

Author's Reply

Mr. King, in replying, expressed appreciation for the way in which his Paper had been received. Denseners were used round the outside of some castings, but not internally. Rod feeding was used, but by standardised methods of running and risering as explained, he had cut down this method of feeding by 20 per cent.

With regard to pencil runners, these were approximately the diameter of a pencil, and could only be applied for top running. In place of manure he employed cocoanut fibre, cut about 1 in. long. Mr. Francis had used spent hops as obtained from breweries with success.

In reply to Mr. Carrick, Mr. King said that sizes of down gates and runners were fixed empirically, and from experience accumulated by recording pouring times for various castings over a period.

Mr. Francis, intervening, said that Dietert had done much work on this subject in America, and had evolved formulæ by means of which size of choke and height of runner could be calculated relative to weight and section thickness.

On the question of fluidity, Mr. King said it was mainly a question of correct distribution of metal in one mould which avoided trouble. He considered that the feeding methods mentioned by Mr. Slater would not be so good as top feeding. If rapid flow and squirting of the metal were prevented by opening the choke, liquid shrinkage was largely taken up as pouring progressed.

The Production of Steel Castings

By C. H. KAIN

This Paper is intended to be a general description of the production of carbon steel castings, and is divided into seven headings:—(1) General considerations; (2) preparation of liquid steel; (3) pouring practice; (4) moulding and core practice; (5) fettling (welding); (6) heat-treatment; and (7) tests and testing.

General Considerations

Steel is usually defined as an alloy of iron and carbon containing less than 1.7 per cent. of carbon. There are other elements present (Si, Mn, S and P), but carbon is the most important. From the foundryman's viewpoint, the chief difference from cast iron lies in the much higher melting point, and in the much greater shrinkage and contraction. Both these are the result of the greater purity, *i.e.*, lower proportion of alloying elements.

Table I shows the difference in chemical composition of steels and cast irons made to meet the latest B.S.I. Specifications, the figures for cast iron being taken from J. F. Francis's* Diploma Paper last year. The main difference lies in the carbon and silicon as alloying elements and in sulphur and phosphorus as impurities. Manganese is a sort of universal scavenger and deoxidant, and is fairly constant at around 1 per cent. Silicon is present mainly as a deoxidant and degasifier, and not for any effect upon structure. It increases the solubility of iron for the CO and CO_2, which are always present as a result of the melting process, all of which are oxidising at some stage.

The steelmaker aims at keeping sulphur and phosphorus as low as possible, as they embrittle the steel, especially in the higher carbon grades. In addition, sulphur makes the steel hot short. The accuracy with which the desired composition is attained varies with the steelmaking process, and the basic electric furnace may reduce the sulphur and phosphorus as low as 0.015 per cent. each.

The iron/iron-carbide equilibrium diagram (commonly known as the iron-carbon diagram), Fig. 1 shows clearly the very high melting point of steels. Most steel castings are under 0.5 per cent. C and have a melting point in the

TABLE I.—*Characteristics of Steels and Cast Irons.*

	Steel.			Ordinary grey cast iron.		High-duty cast iron.		
B.S.I. Specification and grade.	592/1940.			321/1938.		786/1938.		
	28/35 ton.	35/40 ton.	No test.	(A).	(C).	(i).	(ii).	(iii).
Per cent.			Max.					
C	0.25	0.36	0.45	3.3	3.3	3.20	3.00	3.00
Si	0.30	0.30	0.30	2.3	2.3	1.65	1.15	1.15
Mn	0.80	0.80	0.80	0.75	0.75	1.00	1.00	1.00
S	} 0.06	} 0.06	} 0.08	0.08	0.08	0.10	0.10	0.10
P	} max.	} max.	} max.	0.85	1.40	0.55	0.45	0.45
Yield point } Tons per sq. in.	Min. 14	Min. 17.5	—	—	—	—	—	—
Max. stress } Tons per sq. in.	28/35	35/40	—	Min. 12*	Min. 10*	Min. 15*	Min. 18*	Min. 22*
Per cent. elongation	Min. 20	Min. 15	—	—	—	—	—	—
Per cent. reduction of area—Bend	120 deg.	90 deg.	—	—	—	—	—	—

* On 0.875 in. diam. cast bar.

* Proc. I.B.F., Vol. XXXIII, 1939-40, p. 21.

region of 1,500 deg. C. Some alloy steels (*e.g.*, manganese steel) have a carbon content over 1.0 per cent., but even these have a melting point of over 1,450 deg. C. Good quality cast iron is in the region of 1,250 to 1,350 deg. C. (phosphoric irons are much lower). In each case it is necessary to superheat to enable the

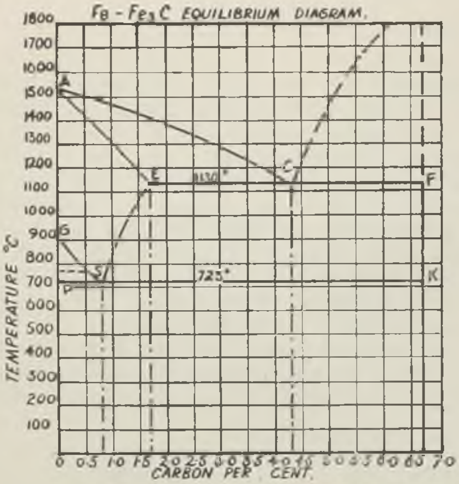


FIG. 1.—IRON/IRON CARBIDE EQUILIBRIUM DIAGRAM.

FIG. 2.—GENERAL CONSTRUCTION OF HIGH-FREQUENCY FURNACE.

liquid metal to be handled and poured. This is usually 80 to 120 deg. C., which means that steel is poured at a temperature between 1,550 and 1,700 deg. C. The diagram shows clearly the short freezing range of steel, and why it is necessary to make such extensive provision for feeding the steel.

Preparation of Liquid Steel

The methods of preparing the liquid steel may be divided into (*a*) melting processes, such as the crucible and high-frequency furnaces, in

FIG. 3.—ONE-TON CONVERTER IN BLOWING POSITION.

which no major change in composition takes place, and (*b*) conversion or refining processes where impure metal, such as pig and scrap, is refined to the quality desired. Of these, the most important conversion processes are the converter (Bessemer), the acid open-hearth (Siemens Martin) and the acid electric furnace.

Of these the only true refining furnace is the

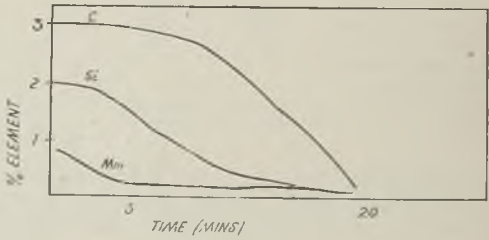


FIG. 4.—REDUCTION OF OXIDISABLE ELEMENTS.

basic electric, as it is the only furnace which can remove both sulphur and phosphorus.

Crucible Process

The crucible process as used in the steel foundry differs little from that in use in the non-ferrous foundry. Forced draft is usually used when coke firing, but gas-fired furnaces are often employed. The process, whether with clay or plumbago crucibles, is acid in character and very small changes in composition take place. Carbon and manganese are usually somewhat reduced by oxidation, silicon often

FIG. 5.—OLD TYPE OF TWO-ELECTRODE THREE-PHASE FURNACE.

increases by the reduction of silica from the crucible, and there is a slight pick-up of sulphur and phosphorus. If the raw materials are carefully selected, crucible steel is of excellent quality.

High-Frequency Process

Fig. 2 shows the general construction of the high-frequency furnace. The metal is contained in a crucible and heating is obtained by induced current in the metal itself. This is generated by a water-cooled copper coil surrounding the crucible, which was originally of clay, but is now usually rammed in place and fritted by the melt. The process may be acid or basic, the basic method being essential for alloy steels containing a high proportion of manganese.

FIG. 6.—OPERATING GEAR ON LADLE, WITH LADLE INVERTED FOR PREHEATING.

Converter Process

The charge of scrap and pig is usually melted in a cupola, but in the "Stock" process, melting takes place in the converter itself, the molten metal containing: C, approx. 3.0; Si, 1.0 to 2.5; Mn, 0.3 to 0.8, and S and P, under 0.06 per cent.

FIG. 7.—CONSTRUCTION OF LADLE PLUG.

Fig. 3 shows a one-ton vessel in the blowing position, the air being introduced on the surface of the metal at a pressure of 3 to 4 lbs. per sq. in. In the original Bessemer process the air was blown in through the bottom of the vessel at much higher pressure. At first Bessemer heated the vessel, but it was quickly

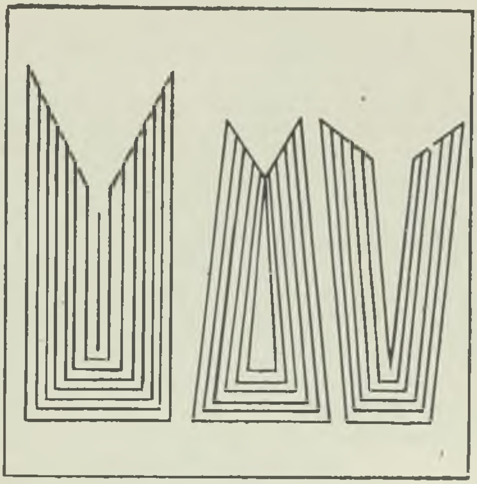


FIG. 8.—IDEAL COOLING AND FREEZING CONDITIONS IN PARALLEL AND TAPERED SIDED INGOTS.

found that the oxidation of the C, Si and Mn provided all the heat necessary. The vessel may be lined with brick or a rammed material, and great care is necessary in drying out and preheating. The main reactions are as follow: —

$O_2 + 2Fe \rightarrow 2FeO$ (heat)

$2FeO + 2C \rightarrow 2CO \uparrow + 2Fe$ (heat)

$2CO + O_2 \rightarrow 2CO_2 \uparrow$ (heat and flame)

$2FeO + Mn \rightarrow 2MnO_2$ (slag) $+ 2Fe$ (heat)

$2FeO + Si \rightarrow SiO_2$ (slag) $+ 2Fe$ (heat)

Most of the heating comes from the oxidation of the silicon and manganese, the time of the blow varying according to the amounts present, and may be from 10 to 30 mins.

The end of the blow is shown by the drop of the flame at the mouth of the vessel, but there may be several "false drops" before the final end is reached. Fig. 4 shows diagrammatically how the reduction of the oxidisable elements takes place.

Fig. 9.—Section of "Keel"-Type Test-Block with Pipe formed through Centre.

At the end of the blow there is a bath of highly oxidised almost pure iron. Excess oxidation is removed by the addition of ferro-manganese, ferro-silicon, aluminium or ferro-titanium, and the carbon is adjusted by the addition of cupola metal. There is a slight gain of sulphur and phosphorus, due to loss of metal and oxidation of the constituents. Sulphur is widely controlled by the use of the soda ash process in the cupola metal, but it is essential to employ low phosphorus materials. The melting and conversion losses are heavy, and vary between 15 and 20 per cent. of the total metal charged to the cupola. Only the acid process is used in the foundry.

Open-Hearth Process

This consists essentially of a broad shallow bath of metal heated by producer gas. Both the gas and the air for combustion are pre-heated by recuperation. The charge consists of scrap steel and pig-iron.

In the acid process, the hearth is siliceous, and C, Si and Mn are removed by similar reactions to those in the converter, except that the oxygen is obtained by the addition of iron ore instead of from the air. In the basic process the hearth is of dolomite, and a heavy lime slag is employed to carry the phosphorus. Very large tonnages are made by this process, furnaces varying from 5 to 200 tons capacity. The time of the melt may be from 6 to 12 hrs.

The Electrode Furnace

This consists essentially of a steel frame supporting a hearth in which the steel is heated by one or more electric arcs, usually on the surface of the metal. Indirect arc furnaces are widely employed for cast-iron and non-ferrous metals, but only on a limited scale for steel.

Fig. 10.—Typical Steel Casting showing System of Risers.

Fig. 5 shows an old type of two-electrode three-phase furnace. In this case the hearth forms the third phase connection. This construction can only be used in basic furnaces as siliceous materials are never conducting. On the other hand, basic hearth materials become conducting at high temperatures.

Most modern furnaces are of the three-electrode type with removable roofs for rapid charging. The electrodes are suspended and balanced for easy control, and the motion is usually hydraulic. Mechanical screw and pinion elevating gear is very rarely used nowadays.

In the acid process the hearth is siliceous, and the oxidisable elements are removed by reactions similar to the converter and open hearth. In the basic process the hearth is usually of dolomite, and a heavy lime slag is carried. Phosphorus is removed in the oxidising period, after which follows the unique feature of the basic electric process, the reducing slag.

It is usual to remove the oxidising slag before starting the reducing period, but occasionally a one-slag process is worked. The reducing slag is made up from lime, carbon (as crushed coke, coal, graphite, etc.), fluorspar and powdered ferro-silicon. During this period the sulphur is removed into the slag as calcium sulphide, although some may pass into the atmosphere. The reactions are complex, but the necessary conditions are readily recognised by the characteristic slag, which is white on cooling and evolves acetylene when wetted.

Other melting processes such as rotary furnaces, pulverised fuel furnaces and oil furnaces are coming into use, but the greatest output at

FIG. 11.—TYPICAL STEEL CASTING WITH RUNNER AND RISERS.

present is by one of the processes referred to above.

Refractories

The selection of suitable refractories is a difficult problem for the steelfounder. Table II shows the softening point of the commoner materials from which it will be seen that these are only just above the temperature of the steel.

TABLE II.—" *Softening Point* " *of Refractories.*

Fireclay : 1,650 to 1,750 deg. C.	Max. safe working temperature 1,545 deg. C.
Silica : 1,600 to 1,790 deg. C.	
Ganister : 1,545 to 1,650 deg. C.	
Dolomite : 1,600 to 1,700 deg. C.	

In addition it must be borne in mind that the figures given are ideal values, and in all probability commercial materials fall below these figures.

Pouring Practice

The difficulties of pouring are caused by the very high temperature and the very short freezing range of the metal. In addition, the slag is not easy to control. Acid slags are usually viscous and hard and basic slags very fluid and run easily with the metal.

Plain ladles can be used with acid steel if the lining is thick and adequately preheated. It is usual to form a bridge of slag at the lip through which the metal is poured. This bridge may be formed by the addition of sand or by using a fireclay brick. Plain ladles are not successful with basic steel as the slag cannot be controlled.

FIG. 12.—TYPICAL STEEL CASTING WITH RUNNER AND RISERS.

Teapot ladles are used successfully if the spout is large enough and if pouring from the ladle is frequent or continuous. Otherwise the teapot is not very successful as the spout tends to freeze up.

The bottom pour ladle is in most general use, the metal being poured through the nozzle at the bottom of the ladle which is opened and closed by a refractory plug. Fig. 6 shows the mechanism of the operating gear and in the background can be seen a ladle inverted for preheating. Fig. 7 shows the construction of the plug or stopper. It is usual that the actual stopper end should be made of graphite whilst the sleeves are of fireclay supported on a steel rod. It is important that these should be free to expand during heating.

Shanks are also used for pouring small castings in conjunction with a large ladle, but for this very hot steel is essential.

Moulding and Core Practice

This is governed by the very high temperature and considerable shrinkage and contraction of the metal. Table III shows the shrinkage characteristics of a typical 0.35 per cent. carbon steel. Special provisions must be made to resist the high temperature, and for feeding. In addition, the mould and core must be readily collapsible to allow the 7.2 per cent. of solid contraction to take place.

Four methods of moulding are in common use, green sand, dry sand, oil sand and compo. Table IV shows some of the properties of these materials. No coal dust or similar matter is used in steel sands and permeabilities are consequently much higher. It is common to use a much coarser sand in the steelfoundry than the ironfoundry. Compo is a specialised form of moulding material developed especially for use with large castings. It consists of a very strong mixture of refractory materials such as crushed firebrick, silica sand, carbon, old crucibles, etc., bonded with fireclay. With the recent advance in the technique of sand moulding, compo is falling in disuse, except for large castings. Fig. 8 shows ideal cooling and freezing conditions in parallel and tapered sided ingots. It is assumed that the metal freezes in a continuously thickening envelope from the outside towards the centre and that the head of metal falls by gravity. If these conditions prevail the parallel feeder head would be ideal but the conditions shown in the centre illustration more frequently prevail.

Fig. 9 shows the section of a "keel" type test-block from which it is seen how the pipe is formed in the centre of the section. This casting was made with a covered head which has caused a bridge to form over the pipe. In the case of open heads, feeding compounds are frequently employed. These usually operate, either by lowering the melting point of the metal in the head by carbon absorption or by the formation of an insulating layer which prevents cooling of the top surface of the feeder. Most of these feeding compounds are made from powdered carbon, aluminium and calcium silicide, but chopped chaff or straw has been used very successfully, especially on large headers. Figs. 10 to 14 show a number of castings with the gates and headers in position. These show clearly the large amount of feeder metal which is necessary to ensure soundness.

TABLE III.—*Shrinkage and Contraction.*

0.35 per cent. C steel, cast 100 deg. C. above freezing point. (Contraction expressed as per cent. of final volume.)

	Liquid cooling 100 deg. C. to freezing point.	Change from liquid to solid.	Solid cooling from freezing point to room temperature.
	0.85 per cent.	3.20 per cent.	7.20 per cent.
Relative volumes	111.25 →	→ 110.40 ↓ 107.20 →	→ 100.00

Normal contraction allowance for mild steel = $\frac{3}{16}$ in. to $\frac{1}{4}$ in. per ft. = 4.68 per cent. to 6.24 per cent. (of final volume).

Normal contraction allowance for grey cast iron = $\frac{1}{10}$ in. to $\frac{1}{8}$ in. per ft. = 2.50 per cent. to 3.12 per cent.

Fettling

The trimming of steel castings is a very expensive series of operations. Sandblasting is essential owing to the close approach of the steel to the softening point of the refractories, and high pressure with shot is now generally used. Sometimes sandblasting is carried out before fettling begins but in some cases it is usual to heat-treat the castings first. Modern practice tends to clean the castings before fettling and again after final heat-treatment. The removal of the headers presents a problem, all types of saw and mechanical cutting are in use for this but the acetylene torch is most frequently employed. This is costly to run but the rate of cutting is very fast. Fig. 15 shows the header being cut off a pump-end casting. Other operations such as chipping, grinding,

TABLE IV.—*Moulding Sand Properties.*

Type of sand.	Moisture content Per cent.	Green compression strength, lb. per sq. in.	Dry compression strength, lb. per sq. in.	Green Perm. No.	Dry Perm. No.
Green facing sand ..	3.0/3.5	6.8/7.2	—	150/250	—
Dry facing sand ..	4.5/5.5	5.5/6.5	50/150	120/170	150/250
Compo	7.0/9.0	6.0/9.0	100/200	—	—

peening, etc., are similar to iron practice and are governed chiefly by the size of the casting. Pneumatic hammers are in universal use, as are

FIG. 13.—TYPICAL STEEL CASTING WITH RUNNER AND RISERS.

high-speed bakelite-bonded wheels. Swing wheels are very widely employed but are expensive in upkeep.

Welding

The repair of surface defects is often necessary where sand has fused or where some foreign matter in the moulding materials has melted or blown. Also, in spite of the most extensive provision for feeding, it is sometimes necessary to repair cavities in bosses and heavy sections. Hot tears can sometimes be made good but, more generally, torn or cracked castings are scrapped because it is difficult to know the extent of the defect. All the usual welding processes are in use, oxy-acetylene, direct arc and carbon arc, and the choice is often a matter of personal preference, but the modern tendency is towards the use of covered electrodes only.

Heat-Treatment

Heat-treatment is carried out in all types of furnaces—coal, pulverised coal, gas, oil and electrical heating. The objects are: (1) To remove stresses in the casting caused during cooling in the mould and during subsequent operations, and (2) to obtain maximum properties in the metal itself. Table V shows the temperatures usually employed for carbon steel castings.

For stress-relieving the most important thing is to ensure slow cooling. For annealing, normalising and quenching, it is important to be sure

FIG. 14.—TYPICAL STEEL CASTING SHOWING METHOD OF RUNNING.

that the desired temperature is obtained throughout the furnace and that the castings are soaked for the correct period.

The eutectoid region of the iron-iron carbide equilibrium diagram in Fig. 16 shows clearly why these temperatures are used. Table VI shows typical results from steels made to meet the first two grades of B.S.S. 592-1940. These

TABLE V.—*Heat-Treatment of Steel Castings.*

Stress relieving.—Castings heated to 740 to 760 deg. C. and cooled slowly.

Full Anneal.—Castings heated to 880 to 950 deg. C., soaked for a suitable period, and cooled slowly.

Normalising.—Castings heated to 880 to 950 deg. C., soaked for a suitable period, and cooled in air.

Air Quench and Temper.—Castings heated to 850 to 920 deg. C., soaked for a suitable period and cooled quickly in air. Reheated to 500 to 780 deg. C. and cooled (usually slowly).

TABLE VI.—*Laboratory Test Report of Properties and Composition.*

Test No.	A. 3074	C. 10552
Original dimensions—		
Diam., in.	0.564	0.505
Area, sq. in.	0.25	0.20
Distance between gauge points, in.	2	2
Yield point, tons per sq. in.	19.68	25.25
Max. stress, tons per sq. in.	31.40	44.60
Elong. 2 in., per cent.	36	26
Red. of area, per cent.	52.30	32.00
Bend	1 in. × ¾ in. 130 deg. unbroken.	1 in. × ¾ in., 90 deg. unbroken.
Izod impact, ft.-lbs.	45	28
Analysis— Per cent.		
C	0.21	0.44
Si	0.26	0.30
Mn	0.89	1.12
S	0.015	0.027
P	0.019	0.012

figures are from electric furnace steel which has been normalised. A somewhat modified heat-treatment would be necessary in the case of converter or open-hearth steels which contain slightly higher sulphur and phosphorus contents. The properties shown here can be considerably modified in all types of steel by suitable heat-treatment.

Acknowledgments

The author wishes to acknowledge the assistance given to him by Mr. T. W. Ruffle and Mr. C. E. Rayner in preparing the illustrations. Without their help it would not have been possible to give this Paper.

Fig. 15.—Cutting Header off Pump-End Casting.

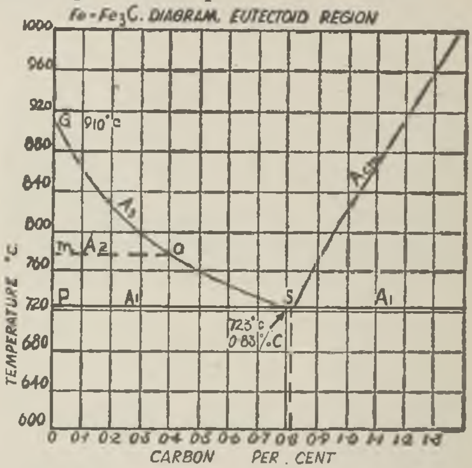


Fig. 16.—Iron/Iron Carbide Eutectoid Diagram.

Principles and Practice of Core Blowing

By H. H. JONES

The making of cores by blowing the sand into the corebox under air pressure, is an art that has been developed in the last decade. South African foundrymen have been quick to appreciate the advantages of the method, and already most of the larger foundries are using core-blowing machines, some having as many as three, five, even six machines at work. The science, however, is very new, and no text-books are available on the subject. Consequently, practical knowledge of core blowing has been confined to those who have actually worked directly with core-blowing machines in the foundry. The pneumatic core-blowing machine is intended for producing small and medium size cores in quantities, and is primarily a production machine. Given a sufficient demand for any particular core, equipment can be developed to a very high degree and a tremendous rate of output achieved, with a corresponding reduction in cost per core.

In South Africa, several types of core are being blown in quantity, and the rate of production in some of these cases does not compare unfavourably with results obtained overseas. However, as nearly all the foundries are of the jobbing type, cores are usually required in rather small quantities, and this entails frequent changing of coreboxes. Nevertheless, many core blowers are being successfully employed in South Africa on, at any rate, semi-jobbing work, and methods have been devised to adapt the machines to this class of work. Some of these methods are decidedly ingenious. A number of marked advantages result from producing cores by the blowing method.

Rapid Production

The most obvious gain is speed. This is influenced very considerably by various factors, including shape, size, and number of cores required, and also the degree of efficiency of the corebox and other equipment in use. In some cases the output will be forty or fifty times as high as with hand work. In others, the advantage may not be nearly so great. Each core must receive individual consideration, and it must always be decided whether a saving in the ultimate cost of production can be made by blowing the core.

Almost as important as speed, however, is the improvement in quality of the core. Blown cores will be more uniform in structure, lighter in weight and higher in strength than those produced by other methods. They will be formed more perfectly, have a higher degree of permeability, and, due to their smoother skins, will impart a better finish to the castings. A characteristic of a blown core is that the finer sand grains arrange themselves at the outside of the core with the larger grains in the centre. Consequently the skin will be of maximum smoothness and the core will have maximum permeability.

Less Venting and Reinforcing

Due to this openness, the cores do not require as many gas vents. However, on large chunky cores it is sometimes desirable to use vent rods. These present no difficulty, for they may be built into the corebox in such a manner that they can be withdrawn after the core has been blown. Alternatively, after blowing, a wire can be inserted through a print, and withdrawn, leaving a vent hole in the core.

The nature of the blowing operation makes it possible, quickly and uniformly, to fill corebox cavities having unusual or intricate contours that would be difficult, or impossible, to ram by hand. Since the filling is uniform, hard and soft spots are eliminated, and the core is of maximum strength; thus, reinforcing wires and rods will not be required to the extent necessary in a hand-rammed core. Usually it is possible to design coreboxes so they can be blown through a core print, or so that a core print will extend through the wall of the box to permit any necessary nails or rods to be inserted before the corebox is drawn. Openings in the top, bottom or sides of the corebox will, of course, be automatically sealed off during the blow, by the machine itself.

If wires are found to be desirable in certain small or simple cores, it is possible to place the formed wire in the corebox cavity, and the whipping action of the sand will pick up and embed the wire in the body of the core. On more difficult jobs the wire can be bedded in a handful of sand before blowing; or the rods can be supported in the core prints. In extreme cases posts can be built in the lower half of the box to support the rods, but there will be a corresponding opening in the finished core, which will have to be filled and patched after drying. In the past, not all South African foundries have made use of the great advantages of oil sand for cores.

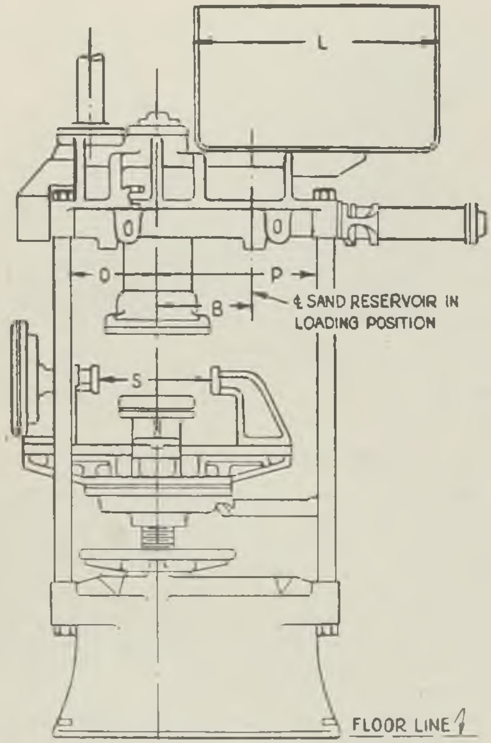


Fig. 1.—Typical Design of Core-Blowing Machine.

Oil-Sand

A core blower has often been the means of introducing oil-sand cores into a foundry, yet at the same time greatly reducing the overall cost per core. Oil-sand cores have great strength when dried, and exceptional permeability; they virtually eliminate the need for nails, wires, rods, irons or vents, except for certain large cores; and the cores can be kept in stock for months without their drying out or absorbing moisture. Incidentally this latter feature aids materially in making a core blower payable in a jobbing foundry because oil-sand cores can be blown in quantities and kept on the shelf ready for use. This enables the core maker to plan out his day's work and, to a large extent, keep ahead instead of working from hand to mouth, as it were, and having to keep moulders waiting for cores.

To blow cores successfully, one must have the machine, compressed air, suitable sand, strong coreboxes, properly designed and vented; the necessary drying plates or carriers, a bench, a core oven, and some shelves for storing the finished cores.

Machines

The main essentials of a core-blowing machine are a sand reservoir with blow plate; some means of filling the sand reservoir and sealing it; and a system of horizontal and vertical clamps to hold the corebox during the blow operations.

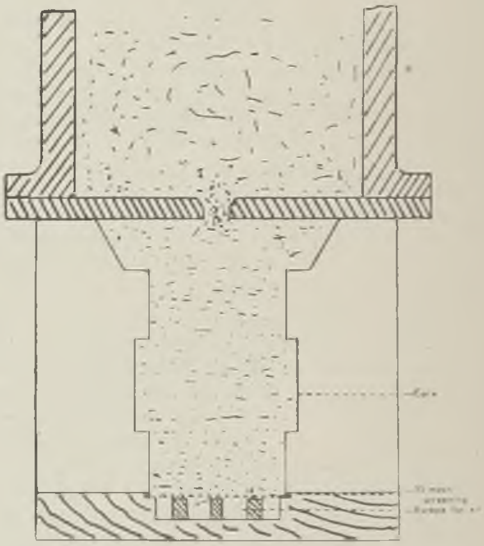


Fig. 2.—Arrangement of Vented Board Acting as Floor and capable of Venting Many Different Types of Core.

Machines of several different designs are manufactured. The machine shown in Fig. 1 has a sand reservoir which travels back and forth from the filling position to the blowing position, on a carriage fitted with rollers running on rails in the upper structure of the frame. In the filling position, the throat of the sand reservoir is open to receive sand by gravity from the hopper. Operating a small hand-lever causes the reservoir to move under power to the blow position directly over the corebox, when blow holes, drilled in the blow plate, will correspond with blow holes in the corebox. When the foot pedal is depressed, the machine automatically goes through the following cycle of operations:—

The machine table and corebox are raised by the vertical clamp diaphragm, thus forcing the sand reservoir to rise also, and form a seal against a rubber sealing ring in the head of the machine. An automatic safety valve then makes contact, and admits air behind the main blow diaphragm, which lifts off its seat, permitting the compressed air to enter the sand reservoir. This forces the sand into the corebox. The pressure is then automatically exhausted, leaving the corebox filled. The whole operation occupies about 6 secs., no matter whether the core be small or large; or whether one core is blown at a time or several dozen.

With this type of machine a free-flowing sand must be used. If the sand is not flowable, craters will form over each blowhole, and air, only, will enter the corebox. Some core blowers incorporate an electrically-driven impeller in the sand reservoir, which permits the use of stronger sands by reducing the tendency to clog. One design employs a valve over the blowhole, which closes after each blow, thus retaining the air-pressure in the reservoir, the object being to reduce air consumption. The disadvantage of these latter types is that the machine has to be stopped, the pressure exhausted, and a cover removed after every few blows, in order to replenish the sand reservoir; and the blow area in the blow plate is strictly limited, so that it is frequently uneconomical to blow small cores (like screen cores) on machines of this design, since only one or two can be blown at a time.

Sands

The question of the sand to be used depends on the size and shape of the core and the type of metal being poured. Many kinds of sand are being employed on the Reef, from ordinary dump sand mixed with about $2\frac{1}{2}$ per cent. of raw linseed oil, to quite strong mixtures containing percentages of red sand, yellow sand, bentonite, molasses, core gum, or other proprietary binders. The core sand should be thoroughly mixed, preferably in a machine, which will do the job far better and with a reduced percentage of core oil. The sand should be placed in the mill first, the dry binder, if any, added, and after a short time, the core oil. After mixing for several minutes, water may be added to bring the mixture to the desired moisture content, and the mixer run for several minutes longer. Over-mixing should be avoided.

Coreboxes

No matter how excellent a core-blowing machine may be, it cannot blow perfect cores unless the corebox is satisfactory. Coreboxes must be properly designed, with suitable blowholes, correctly located, for the entry of the stream of sand and air, and adequate vents for the air to escape.

For high production the best results are obtained from first-class metal coreboxes having well-fitted joints throughout, and sufficient land at the parting joint and around the blowholes to ensure a good, tight seal. The outside surfaces of the box should be squared, and all opposite clamping surfaces machined parallel so that the box will clamp squarely in the machine. The boxes should be of cast iron, aluminium, or other metal, or of hard wood, depending on cost, weight, rate of wear, and amount of machining entailed. If necessary, aluminium or wooden boxes can be fitted with steel bushes or inserts at the places most subject to wear. Hard wood coreboxes have given

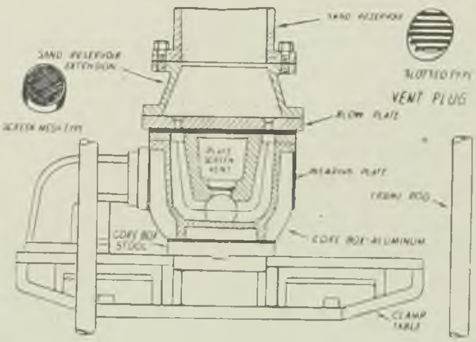


FIG. 3.—TYPICAL SCREEN VENTED COREBOX.

very good results in many South African foundries, especially where the number of cores required at any one time is fairly small. Some wooden boxes have been in frequent use for as long as three or four years; they are now somewhat battered and scarred. The cores they now make have flash on them that has to be cut off with a trowel. During all this time the attitude has been that the cores were being made much more cheaply than could be done by hand, and therefore the position was satisfactory; but a certain amount of touching-up and finishing-off was always required, due to defects in the coreboxes, and undoubtedly much time would have been saved if first-class metal boxes had been made initially. If at all possible, the equipment should be such that the trowel is never needed, and can be dispensed with. Many of the cores at present used in this country have a flat surface and can be drawn on to a flat plate. Others, such as hand-grenade cores, require driers or carriers, which must be cast or pressed to shape, and are an essential part of the blowing equipment.

However, it is necessary to strike the best compromise, and such ever-present troubles as congestion in the patternshop, lack of time for experimental work, etc., have to be taken into account. The great point is that even under somewhat unfavourable conditions, the core blower can often effect substantial economies.

In this connection, prospective purchasers of core blowers, after inspecting existing installations in other foundries, have been heard to remark: " They're not getting a quarter of the work they should off that machine. Wait until we get ours going! "

Their own subsequent efforts are not always any better!

Blowholes

Except in the case of simple, straightforward cores, such as bushing cores, screen cores, etc., each new job will require individual consideration, and often the best arrangement of blowholes and vents will be determined only by actual trial. The blowholes should be from $\frac{1}{16}$ in. to about $\frac{3}{4}$ in. dia., depending on the nature of the sand and size of core. They should be located where they will do most good, and kept as few in number as possible. The object is to inject the sand into the main body of the core and induce it to flow into any pockets or narrow passages by having additional blowholes opposite these points. The blowholes in the machine blow plate should be countersunk to permit the sand to enter them more readily. The blow plate of the machine must be drilled with blowholes to correspond with those in the corebox.

In a jobbing coreshop, with its miscellaneous short-run jobs, means have had to be worked out to avoid frequent changing of the blow plate. Various schemes have been adopted such as standardising the spacing of blowholes in the coreboxes as far as possible, or arranging that a corebox blanks off unwanted blowholes while utilising others. Where this cannot be arranged, the unwanted holes can be plugged. This plugging should be done so as to form an airtight seal, because air leaking through can cause a lot of mysterious trouble if it gets into the corebox; it will carry no sand with it, and will merely add to the volume of air to be exhausted through the venting system of the box.

A very effective idea for jobbing work is to cut a slot in the blow plate, probably a shorter slot crossing it at right angles. Adaptor plates of, say, $\frac{1}{16}$ in. steel plate, with suitable holes drilled in them, are then placed on top of the corebox at each blow. By this means, blowholes are made available in any part of the slot area. The addition of a couple of extra blowholes, strategically located, plugged when not in use, can almost eliminate the need for changing the blow plate. Many variations of such schemes can be worked out to suit local conditions. For instance, the adaptor plates just mentioned can be attached to the machine blow plate, with countersunk screws or by sliding into fittings, etc. The whole question is one of reaching compromise that will give the best all-round results in saving time and money.

Technique of Blowing

The corebox cavity is filled by introducing sand suspended in a stream of air under pressure. To obtain a hard, solid core, it is necessary to let the air escape back to atmosphere, yet retain the sand in the corebox. This is done by providing vents that will allow the air to flow away, but will resist the passage of the sand grains, thus trapping the sand and filling the core.

The stream of sand and air enters the box at high velocity. Upon passing from the restricted openings of the blowholes, there is an immediate expansive action of the blow stream to fill the cavity in the corebox. This action approaches an explosive condition, causing the sand grains to rebound from the point of contact with the inside walls of the box and to exert a general whipping action. Upon being released to the low pressure of the corebox, it is assumed that there is an initial drop in velocity of the blow stream, with the result that the sand grains find permanent rest. The core cavity fills first directly under the blowholes. Then, as the corebox fills, and the available room for the passage of air becomes progressively less, the velocity of the blow stream increases again, with the sand grains tending to follow the direction of the air stream in which they are partially suspended. As the natural flow of the air stream is toward atmosphere, the vents should be placed in those portions of the core farthest from the blowholes and least likely to fill easily.

The air is used only as a vehicle for conveying the sand. Therefore, this air, plus the air contained by the corebox cavity originally, must be released. If it is not released, the box will contain both sand and compressed air, at the conclusion of the blow, and when the machine exhausts the core will suffer from soft spots and holes. Vents of many different sizes and types can be used. It is sometimes possible to blow small simple cores with no venting other than the natural leakage at the parting line of the corebox and at the face contacting the blow plate. Where slight venting is called for, a series of very shallow grooves can be cut in either or both of these surfaces.

This method can be improved as shown in Fig. 2. Here, shallow grooves or slots run outwards part-way across the joint, then communicate with holes drilled through to atmosphere, at an angle. These holes can be joined together by a channel and the system must be able to bleed air quickly from the grooves or slots. This scheme can be adapted in many ways to suit different coreboxes; but direct outlets to the atmosphere should be discouraged. At least one abrupt change of direction should be introduced to retard the velocity of the venting stream, this materially reducing the cutting action which tends to enlarge the vents.

Venting Data

The size of vent employed is governed by the average grain size of the core sand in use; the vents should always resist the passage of the sand grains. If they do not, sand will stream out and leave a hollow place in the core. Vent plugs for coreboxes are available commercially. They are manufactured in diameters of $\frac{3}{16}$ in. to $\frac{3}{4}$ in., and some are of a type that can be machined to conform with the contour

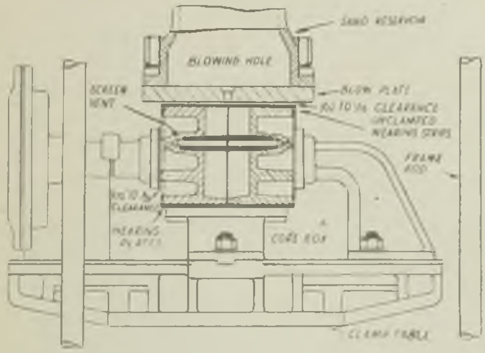


Fig. 4.—Typical Screen Vented Corebox.

of the corebox cavity. These vents are most useful and there are few venting troubles that cannot be overcome with their aid. They are applied quite simply, by pressing them into holes drilled in the wall of the corebox, a shoulder being left in the hole to save the vent plug from being forced out by the air pressure.

Pieces of fine mesh cloth can also prove most useful for venting. They are made to form part of the floor or walls of the corebox and should be backed and faced with thin plate plentifully perforated. When blowing a number of cores at a time in a long box, open at both top and bottom, a useful method is to make up a board, faced with this fine mesh screen cloth, and cut away to provide a free escape for the released air. This vented board acts as a floor for every core in the box, and will serve to vent many different coreboxes very efficiently, as is shown in Figs. 3 to 6. In mass-production core blowing, it is sometimes possible to provide suitable vents in the actual blow plate of the machine itself. This saves having to vent each corebox where several are in use at a time.

Limiting Conditions

Core-blowing machines are available in various sizes based on (*a*) the size of corebox they will accommodate; and (*b*) the weight of core they can blow. The size of box accommodated is governed by the size of the blow plate, machine table, and clamps. Apart from these mechanical limitations it is noteworthy that if a corebox has a greater area than the opposing clamp diaphragm (say in the case of blowing an impeller core), the pressure tending to force the box open will be greater than the pressure tending to keep it closed. The result will be that the box will gape open, and sand will blow violently in all directions.

However, if latches be fitted to the box itself, to hold it together, this limitation is overcome. In the case of boxes that are split horizontally, the side clamps are not required and can be removed from the machine if desired; much

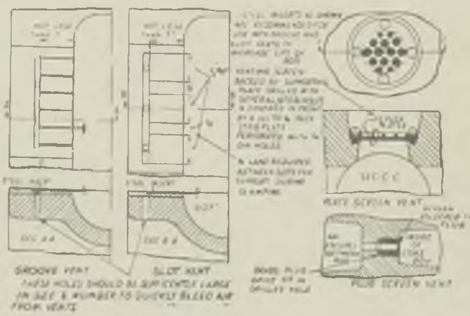


Fig. 5.—Various Types of Corebox Vents in Common Use.

wider coreboxes can then be accommodated. The weight of core that can be blown at one operation is usually a little over one-third of the weight of sand in the reservoir. Thus, if the reservoir contains, say, 120 lb. of sand, the heaviest core that could be satisfactorily blown would weigh between 40 and 50 lb. in the green state.

In a jobbing coreshop, a core blower capable of blowing cores of about the size mentioned will be able to produce a great variety and quantity or cores. A smaller machine would be less useful for jobbing because of its more limited capacity.

Auxiliary Plant

Various developments of the standard core blower as described above are available. One type incorporates a built-in pattern-draw feature, either pneumatically or hydraulically controlled, which is ideal for certain work. Another development is a fully automatic operating valve which aids continuous high-speed production by timing every phase of the blow cycle to the most efficient speed for the one particular job. It is not suitable for jobbing work.

Other "extras" are automatic core sand feeders and elevators, corebox drawing machines; and conveyor loops or turntables, etc., which assist in handling the coreboxes. A simple, but very useful device for use when drawing coreboxes is a vertical plate mounted at the corner of the bench, and fitted with a vibrator controlled by a knee valve. This device greatly facilitates the draw operation, and saves the usual destructive rapping of the box with some handy piece of iron!

The air pressure required to operate a core blower satisfactorily is from 100 to 120 lb. per sq. in. The air consumption varies according to pressure, size of machine, and core being

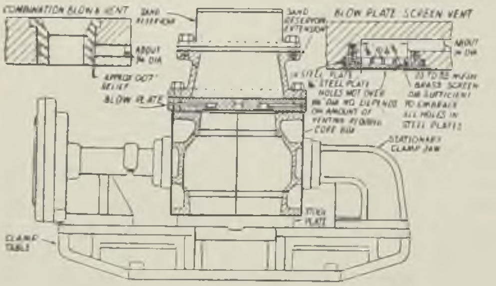


Fig. 6.—Blow Plate Venting.

blown, from about $2\frac{1}{2}$ to 12 cub. ft. per blow, about 6 to 8 cub. ft. being the average. Although this consumption is not great, the volume of air is used almost instantaneously, and to avoid a sudden drop in pressure a receiver of several cub. ft. capacity must be installed near the machine, and connected to it by means of piping not smaller in diameter than the intake pipe size on the machine, usually $2\frac{1}{2}$ in. or 3 in. Provision must be made for draining off the water which is bound to condense in the receiver.

A good core blower has few wearing parts and proves very reliable in service. It should be kept clean and in proper adjustment, and any wear attended to before it begins to multiply. If this is done and sand is not allowed to accumulate and harden on the wearing surface, maintenance costs will be low. The actual operation of a core blower is very simple indeed. The patternmaker, however, finds plenty of scope for all his ingenuity in working out ever more efficient designs for his coreboxes, as experience teaches him more and more of the principles and practice of core blowing.

In conclusion, it is possible to state that almost any core can be blown, provided it is not too big to go in the machine. Unusual or difficult cores may take a good deal of time and patience before they are mastered, but the results are worth the trouble.

DISCUSSION

Mr. D. Lion-Cachet, who opened the discussion, said he had listened with very great interest to Mr. Jones' address. The only criticism he had to make was that the lecture was belated. He recalled his first experience with a core blower. Only one little pamphlet was sent with the machine. This stated that an astonishing number of cores could be made in an incredibly short time. The machine was duly installed, and was always referred to as "she" because at first it was very difficult to know beforehand what would happen. A corebox was duly made in wood by one of the best patternmakers, who made a very accurate job. The first attempts proved entirely unsuccessful, however, because the necessity for venting had not been realised. Eventually, a job was undertaken for which an old corebox split at the back was used, and an excellent core was produced. Even then it was not realised that this result was due to the use of a split corebox. After considerable experiment they tried using fairly coarse sand and oil only. They then found that they could produce a a core, but they could not carry it away. If the oil was sufficiently wet to carry it away the machine wouldn't blow, and *vice versa.* At last it was discovered that they had to get rid of the air. Ultimately they found the machine very satisfactory.

He agreed with Mr. Jones that storage of the oil sand cores made core-blowing machines suitable for a jobbing foundry, but if a machine was worked to the full capacity for which it was designed, the store would have to be as big as the foundry itself. It was due mainly to war conditions that these machines were coming into their own, but he felt that this development was beneficial and that there should be a very good future for core-blowing machines. The trouble was overcome by installing a receiver with a water drain. He thought it was an excellent thing to have lectures on core-blowing machines, because of the importance of these machines to the war effort.

Mr. H. S. Ward endorsed Mr. Lion-Cachet's remarks, and said that in his case the Paper was particularly interesting because his firm were experiencing their teething troubles with a core blower, and he could see that it took some time to obtain really satisfactory operation. He asked what binder was generally recognised as giving the best results. Were the composition binders, generally speaking, more satisfactory than oil, molasses, dextrin, etc.?

Mr. H. H. Jones suggested that some members with experience of blowing cores might care to give their views.

Mr. Boyder thought that the troubles experienced had been due very largely to regarding the machines from the point of view of "she," and tackling problems individually instead of passing on experiences for the benefit of other foundries. In the case of one of the first foundries in South Africa to instal a core-blowing machine, production was brought to perfection after months of experiment. It took five men to keep the machine going. In his opinion the question of moisture in the sand was one on which the experiences of foundries should be pooled. Different foundries used different mixtures. In one establishment a dozen mixtures were tried, but the cores were not successful because of insufficient pressure. They started with a pressure of 110, but after other machines had come into operation the pressure fell to 75 lb. per sq. in. One subject the Institute should tackle was the variation of sand in South Africa.

Mr. H. Holdsworth said he had to deal with a type of core which was made in large quantities. An oil-bonded sand was used, the cores being made in rows of five and removed on to a plate until there were approximately 200 cores on the plate. It was hoped that with the machine they would be able to run up the cores in the usual way, remove the box, and transfer the cores to the plate. Was it a practical proposition, he asked, to remove by hand, cores blown on a machine?

Mr. D. Lion-Cachet said this could undoubtedly be done without the use of any fancy carriers, if they persevered.

Mr. H. S. Ward explained that the machine referred to had only been in operation for a couple of days. The pressure was satisfactory, but so far they had not yet succeeded in finding a mixture which would flow and at the same time would produce a strong core.

Author's Reply

Mr. H. H. Jones, in replying to the points raised, said he was not there to defend the blower, but only to describe it. He hadn't previously thought of blowers as being feminine in nature. However, he reminded the meeting that only the brave deserve the fair, and the reward was worth the seeking. Mr. Lion-Cachet had mentioned the necessity for dry air. It was certainly necessary that condensed water should be drained off. As regards the various binders, it was unfortunate that Mr. Ward's experience had been so short. He believed that if the meeting had been a month later there would have been a different story to tell. It was very rarely that a South African foundry got good results immediately from a blower which had just been installed. It was first of all necessary to get to know the machine. Within two or three weeks, however, beautiful cores were usually being blown with complete regularity.

In many foundries blown cores were being picked up; with a suitable corebox, however, there was no need to pick up cores, as the cores could be produced in good formation ready for the oven. Where a proportion of the cores produced were faulty the trouble was generally due to venting. Instead of venting to the atmosphere the corebox might be venting from one cavity to another, and this would not occur if the venting of each cavity was separately carried out. Variations in performance were usually traceable to variation in the sand or pressure, and in some cases it was actually advisable to dry the sand right out before starting to prepare it, so that the exact water content might be known. Every core should be studied, and in the jobbing foundry every range of cores should be considered on its own merits with a view to discovering whether any saving in the ultimate cost of production might be effected. That blowers were giving satisfaction seemed clearly indicated by the fact that a number of foundries which started with one blower, now had several in use.

Mr. D. Lion-Cachet said that core-blowing machines were becoming fashionable, not as clothes were fashionable, but rather in the manner of motor-cars, refrigerators or radios. Once motor-cars went at about 25 miles an hour and frequently broke down, but the performance of the modern car was vastly different. Core-blowing machines were already blowing from 1,200 to 2,000 cores per hour, and he looked forward to the day when 10,000 an hour would be blown. He certainly thought that in South Africa core blowing would advance at the same pace as in any country overseas, particularly if local foundries were prepared to learn from the experience gained overseas.

Moulding a Bend Pipe Breeches Piece

By J. H. WEST

The finished casting, a bend pipe breeches piece as shown in Fig. 1, is a very unusual shaped casting and therefore required a little more forethought than is customary. After some discussion between the manager, foreman, patternmaker and foreman moulder it was decided, for various reasons, to make the job as follows:—

First, the patterns, or tackle—as one of the members once remarked: "Through the layman's eyes it would look like a bundle of firewood"—had to be made. This tackle consisted of the items shown in Figs. 2, 3, 4 and 5, Fig. 2 being the strickle; Fig. 3 the joint frame; Fig. 4 the plywood template; Fig. 5 body and core strickles; and Fig. 6 the template and strickles for core iron.

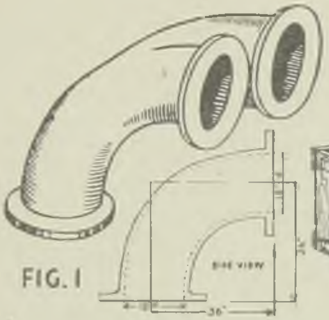


FIG. 1

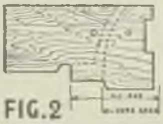


FIG. 2

FIG. 3

With this tackle to hand, the moulder then proceeded to strickle out an impression of the core print, flange, joint and bed of the single-flanged end of the pipe, using the strickle shown in Fig. 2. This work was done at the bottom of a pit, which was the depth of the overall height of the job, when standing on the single flange (Fig. 7).

The strickle was then removed and the 2-in. diameter spindle left in position, and the job thus far was blackened and dried.

The moulder's next procedure was to lay a cast-iron plate as shown in Fig. 8 on to the back half of the bed. This plate, which the moulder made in an open sand bed with the aid of the strickle shown in Fig. 2, came close up to and half-way round the joint. The moulder then filled the remaining half of the bed, flange and print with sand, thus forming a new bed level. The joint frame (as shown in Fig. 3) to which is attached the bottom halves of the two top flanges, was then placed on top of the new sand bed and located by passing the 2-in. hole in the tie strip over the spindle and keeping the flanges parallel with the centre line, which the iron plate formed on the bed.

After the frame was stacked and the tie strip removed, it was rammed up with sand and strickled off, thus forming a block of sand with the curved surface being the actual joint and centre line of the pipe along the line X-Y (Fig. 7). The plywood template (Fig. 4), which was cut 1 in. larger than the outside of the pipe, was laid on the curved surface of the sand block and being plywood was easily bent over the curve and held down flat against the sand by long nails driven into the sand.

Core strickle, item A (Fig. 5) was now used to scrape out a dummy corebox (Fig. 9) with the plywood template acting as a guide, and as there was no further use for the strickle shown in Fig. 2, it was cut off to core size and used for scraping away the sand through the flange and clearing the core print at the bottom.

The core iron was made in the following way:—Two moulds were made in an open sand bed using the template shown in Fig. 6. Into these moulds, $\frac{3}{8}$-in. diameter wrought-iron rods were pushed perpendicularly with half the length of the rods projecting above the floor level. The result was that after casting metal into the mould one had two castings with rods projecting through each side, and the idea was that if any of the rods projected too far out they could be bent, cut off or twisted into any shape required.

Now, the strickle in Fig. 6 was used to strike out a mould in an open sand bed, and the two irons already existing were set up on end in the mould by the patternmaker. Thus, when metal was cast into the mould, it set round the end of the two irons and formed a complete core iron with two horns and a disc, which was the exact size of the core print at the bottom end of the mould (Fig. 10).

The core iron was now placed in the dummy corebox with the disc seating well in the core-print. The core was made in the usual manner

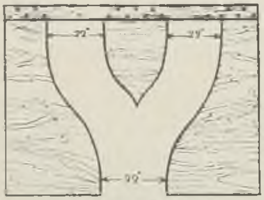


FIG. 4

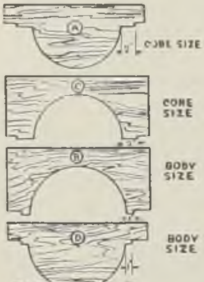


FIG. 5

by ramming sand into the half dummy box and moulding up for the top half and strickling off with body strickle B (Fig. 5), thus forming a sand pattern for the top half of the job. Then two wooden top-half flanges, which clipped over the body and met the bottom halves already embedded, were placed in position, and the sand beyond these flanges was scraped away to core size to form a sand print, thus making a perfect sand pattern for the top half of the job.

The moulder then proceeded to mould this top half by placing bricks and loam on the cast-iron carrying plate and working up to a little over half way, so as not to go over balancing point. Then an ordinary flat moulding box to which was attached a grid was placed over the job on the floor level and stacked round the edge of the pit. The grid which was made in the usual manner hung down over the pattern. It was then an easy matter to ram up the remaining half of the job with only the grid and the centre portion of the box filled with sand.

The top half of the mould was then taken away in two pieces. The moulding box was lifted in the usual way and the remaining portion was lifted by hanging the bottom cast-iron plate at three points, lugs being provided for this purpose. With the top half of the sand pattern exposed, the next operation was to strickle it off to core size and then lift out the whole core by simply hanging it at three points, namely, the projecting horns and an eye bolt screwed into the bottom core plate. This eye bolt was easily found by cutting away a small hole in the core and patching up afterwards.

It only remained now to strickle the thickness of metal out of the dummy corebox, drawing out the wooden flanges, and scraping away the sand in the bottom flange, and one had the mould for the bottom half of the job. The core and then the two top portions were replaced, the pit rammed up with sand, and the job was ready for casting.

DISCUSSION

A Member pointed out that it often occurred that the cross-sectional area of two outlets or inlets had to be the same size as the main body of the pipe. Supposing that the two branches were, say, 10 in. and the main body of the pipe 16 in., what would Mr. West suggest?

Mr. West agreed that the casting described in his Paper had a peculiar shape. It was unusual for the two branches to be the same size. He thought that difficulties caused by differences in size might be overcome by striking out the two branch pieces in the ordinary way and adopting a larger strickle for the bottom position. Before cutting out the actual thickness, small bosses could be embedded in order to ensure an even thickness of metal throughout.

Mr. W. J. Petersen wondered how many patterns could be found along the Reef which had been used once and would never be used again. It occurred to him that, if sufficient thought were more commonly given to the job, a surprising number of patterns could be avoided. In cases where there was only " one off " consideration might be given to the possibility of finding a short cut and saving the expense of a pattern.

Economics of Patternmaking

Mr. H. J. Bragg said that, in his opinion, there was a tendency on the Reef to think too much of the expense of making patterns. He recalled a particular job which had been made about nine years ago from a rickety old skeleton pattern that took 56 hrs. to mould. The job weighed perhaps 1,500 to 1,800 lbs. A few months ago he had an inquiry for four similar castings. The pattern was still in existence and had been used a number of times by different firms. His company tendered for the job and was successful, whereupon he decided to make a pattern. It took him about 50 hrs. to make the pattern. With it he produced castings in 20 hrs. instead of 56, and the pattern was there for all time. In the production of the second casting the cost of the pattern was recovered, and much better castings were produced. He felt that there was a tendency to cut out the pattern at the expense of the foundry and the quality of the article.

Mr. D. Lion-Cachet was inclined to endorse Mr. Bragg's remarks. He pointed out that even when a right and left were needed, the patternmaker frequently made only one pattern, which was changed over from right to left as required. He believed that by making both a right-hand and a left-hand pattern considerable money could be saved.

On another point which Mr. Bragg had made, Mr. Lion-Cachet agreed that, when casting in steel, it was particularly necessary for a full pattern to be provided, because the moulder could then ram the sand harder. Moreover, in the steel foundry the carving ability of the moulder could not be relied upon to the same extent. He took the opportunity of congratulating Mr. West on what had been the best explained Paper he had heard for a long time. The method adopted was most ingenious.

Replying to Mr. Bragg, Mr. West said he was of opinion that the day when patterns were not considered sufficiently was past. Competition was very keen, and every manager had to decide whether it paid him better to run an efficient patternshop or to rely on cheap patterns. Foundrymen were beginning to realise the significance of a good pattern when there were a large number of castings to be made, and were ready to go to considerable expense in order to obtain a perfect pattern.

" Good-Looking " Castings

Mr. A. H. Guy said that Mr. West had raised an interesting question, but he did not agree that good-looking castings gave a foundry a good name. They had to persuade their customers to appreciate good castings and quality metal. At present there were no specifications, and there was no incentive to turn out a good-looking casting rather than one which merely served its purpose. If customers could be persuaded to appreciate the difficulties of foundrymen, much would be accomplished. Patternmaking was a big item in the expenses of an engineering shop on the Rand, and was out of all proportion to what it ought to be. However, with the limited market available, they had to please their customers.

Mr. Bragg said that he had been misunderstood. What he had in mind was that a cheaper and more efficient article could be produced with a good pattern.

Mr. J. Tonge recalled that two or three years ago he had made a special plea for closer co-operation between engineers and foundrymen. His experience in the production of steel castings was that a rugged casting, if sawn up, proved to be a better casting than one which pleased the eye. He considered that customers should be brought to know what to expect from a steel casting and what from an iron casting. In regard to Mr. Bragg's contention that a good pattern was cheaper than a skeleton pattern, he agreed that in jobs which were repeated a number of times, the cost of a good pattern was repaid over and over again. At the same time, ingenuity was required when a job came along which was only one off.

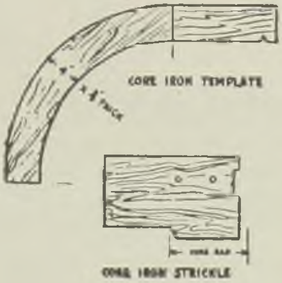


FIG. 6

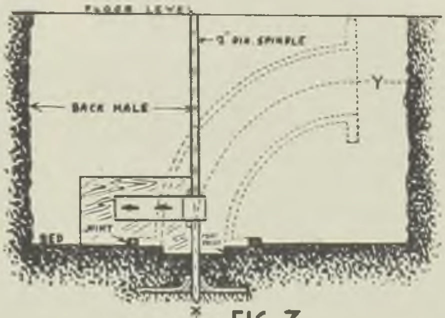


FIG. 7

FIG. 8

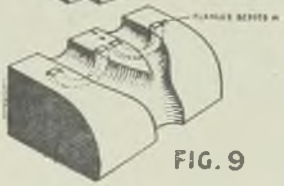


FIG. 9

FIG. 10

Co-operation between Departments

A Member was of opinion that, though much was said about co-operation, very little was done to bring it about. This led Mr. Holdsworth to state that from his own experience he could say that co-operation saved considerable money, as well as many headaches in the foundry after the job was finished. Mr. Cartwright considered that it was practically impossible to produce articles on a competitive basis without co-operation between departments.

Mr. West considered that consultation should not be between the patternmaker and the moulder only, but also between the patternmaker and the foreman fitter. Many hours could be saved in the machine shop if the patternmaker had a full understanding of the job.

Mr. Lion-Cachet thought there must be general agreement that much money could be saved by co-operation between departments. There was also a need for closer co-operation with customers. Personally, he was very much in favour of castings used by the mines being changed, because it was only by changing existing designs that progress could be made. To his mind, it was right that a single engineer on a reduction works should have the power to alter a casting because it was out of the workshops that new ideas and improvements usually came.

A change in a particular pattern might cost a foundry a few pounds, but might result in an improvement of great value to the mining industry. It was difficult to draw any line as to the extent to which alterations should be made. Many of the improvements which had been brought about on the mines during the past few years had been due to individual workers.

Sometimes the speaker had the impression that a moulder could not read a drawing quite so easily as a machine-shop foreman. The individual moulder should endeavour to familiarise himself more with drawings in order to give the patternshop that service which was so essential.

Technical Education

Mr. Holdsworth considered that the system of technical education was not altogether satisfactory. He thought the Institute should force those higher up to give every youngster a good education. It was necessary for every man in every department of the engineering industry to be able to read a drawing.

Mr. J. M. Stones disagreed with Mr. Holdsworth. He pointed out that at the Technical College every youngster was taught drawing, which was compulsory. The facilities were there, but he felt that the youngsters themselves had no time for them. How many moulders were able to explain how they wanted a pattern made? He was also of opinion that every manager should study patternmaking.

Mr. Tonge endorsed the remarks of Mr. Stones, and declared that no blame could be attached to the technical colleges, which were as fine as those overseas. The trouble sometimes was with the apprentices themselves. The majority of foundrymen felt that the lads did not seek always to benefit from the facilities as their fathers had done.

Mr. West was of opinion that a shop foreman could have a valuable influence on the apprentices, particularly if he singled out one or two of the most promising for particular attention. He should chat to the lads about their schooling and encourage them to use their brains.

Mr. Lion-Cachet made the point that when most members began their careers, there were neither motor bicycles nor cinemas. Nevertheless, he felt that the modern boy grew up as good a man as his father.

Mr. Holdsworth recalled that in Britain the patternmaker could frequently be seen going round the castings at lunch time, to see how his patterns were faring.

Mr. Bragg thought a moulder should not be expected to be so proficient at reading drawings as an apprentice fitter or turner who was working from drawings all the time.

The Psychological Aspect

Mr. T. Nimmo Dewar felt that psychology had to be considered. There was also a tendency to adopt the same pessimistic attitude towards the youth of to-day as our fathers did to us. It was possible that the young people of to-day might develop a line of thought which in future years would have unusual effects. Psychology was an integral portion of industry to-day. Moulding, in common with other industries, required intelligence and without men of ability the progress of the past few years could not have been accomplished. South Africa's industrial effort would have been considered impossible a few years ago, and he thought the industry should remember that it had got the workmen it deserved. If apprentices were treated fairly, difficulties were swept aside and the lads would not be found lacking.

South African Branch

Paper No. 748

Planning Research in Foundry Work

By Dr. J. K. MARAIS

Physical, chemical or metallurgical analysis is comparatively simple where it is possible to analyse and investigate one property at a time. As the number of different reactions increase, analysis becomes more involved. For this reason practical research on foundry work could be divided into two categories:—

(1) Physical, chemical and metallurgical analysis of the various materials used in foundry work, such as composition of metals, characteristics of moulding sands, drying processes, etc.

(2) The applicational research by which the results of the investigations mentioned in (1) are translated into actual moulding and casting technique.

The usual way of conducting research work of a highly technical nature is to study one small phase of a phenomenon at a time. This is not directly possible in foundry problems. For this reason very little co-ordinating research work has been done in foundry problems. In most other branches of technology, operations and processes are in series, whereas in foundry work processes and operations converge to a parallel final operation—the actual casting. To illustrate this statement, compare the production of a machined element with the production of a cast element.

The actual manufacture by machining takes place comparatively slowly, a little at a time. The process can very often be stopped at any moment. Inter-process inspection and testing are possible. Mistakes made in one operation can very often be corrected in a subsequent operation. Briefly, manufacture by machining takes place by means of a series of events which are chronologically disconnected, thereby making it possible to experiment and investigate each event on its own. By this method the number of variables affecting the final result, although large in number, can be studied separately, or a few at a time.

In foundry work the position is entirely different. Here a great number of variables enter into the final operation simultaneously or practically simultaneously. This makes it almost impossible to study each variable on its own. Disconnected research on isolated properties of foundry materials only becomes of value when the practical interpretation of results is established by actual practical investigation and analysis of final results.

Therefore, from the nature of foundry work it must be deduced that the most fertile avenue of research will be investigations which culminate in the final casting process in which all possible variables are taken into consideration. The logical procedure is to adopt a process of elimination, although the practical method has been reduced to scientific guess work and practical experience. The chief difficulty in foundry work is that the final results are functions of too many variables, and a diagram showing the main direct and indirect variable factors influencing the results of a cast is set out in Fig. 1.

The degrees in which the control of the above-mentioned factors are in the hands of the moulder depend on the size of the foundry and the organisation of supervisional control. As the size of the foundry increases and depending on the degree of mechanisation, the control of more and more of these factors is taken over by specialists. For example, the selection of moulding and core sands, their mixing and preparation form a specialised work which is gradually being taken away from the moulder and handed over to a separate department. The same applies to the metal used in casting. Such factors as cooling, skimming, rate of pouring, casting temperature, feeding, chills, facing, venting, reinforcement and support, hardness of ramming, shape, runners and risers, still fall under the control of the moulder and the shop foreman. Where moulding machines are introduced, some additional control is transferred to the machine.

Moulding Materials

In planning research on moulding practice the first factor to be considered is the moulding materials. In South Africa very little has been done in this connection. The reason why so little has been made public of the results obtained on investigations into moulding materials, is because results obtained at one foundry where local sand is used cannot be of direct applicational value at another foundry where the local supply of foundry sand is of a totally different character. Also because the bases on which sands are selected and prepared differ widely. A few foundries are equipped with proper sand testing apparatus. Whether this apparatus is used to the full extent is still doubtful.

If, instead of giving a formula for a sand mixture by stating that so much floor sand plus so much red sand and so much white sand are to be mixed, it would be of far more general importance if certain properties are referred to, as for example: Green strength permeability, moisture content, firmness, etc. Results could then be expressed in international standards which will be of greater value.

The investigation of a few factors will be discussed in more detail. Discussion, criticism and suggestions to plan this type of investigation so as to be of more practical national importance and assistance in solving some problems are invited.

analysis. Data regarding drying time are very scanty and although the exact drying time for any particular mould or core in any particular oven could be determined very easily by experiment, this type of investigation does not supply all the necessary information required for the design of efficient and economic drying ovens.

In order to plan a series of experiments which will furnish information on the drying of moulding sands as well as design data for drying ovens, certain suggestions are put forward which with the criticism and advice of those present might be used as a basis of investigation.

The factors influencing the drying time of moulds and cores can be summed up as follows:—

The Mould.—(*a*) Moisture in moulding sand; (*b*) thickness of sand in mould; (*c*) area of exposed mould surface; and (*d*) thermal conductivity of moulding sand.

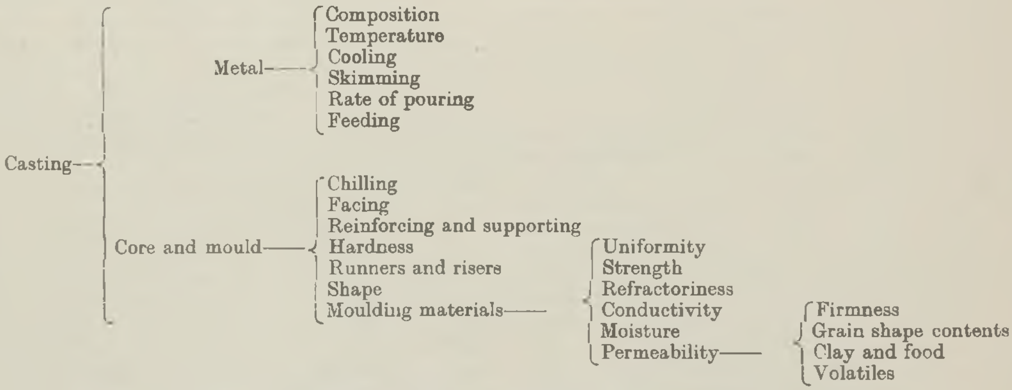


Fig. 1.—Diagram Showing the Main Direct and Indirect Variables Influencing the Result of a Cast.

Mould Drying

The technique of drying moulds and cores has an important bearing on the final results obtained in foundry work and economics. Economics is mentioned as a fair proportion of the capital invested in foundry equipment is represented by drying equipment. The time of drying not only affects total throughput of a given oven, but leaves its mark on the fuel bill. Various fuels are in regular use. Their relative merits are not too well understood by most foundrymen, although practical experience has taught them some of the important characteristics to be avoided.

The following fuels are in common use in various countries of the industrial world: (1) Coal (*a*) long flame bituminous and (*b*) anthracite; (2) coke; (3) wood; (4) producer gas from coal and coke; (5) coke oven gas; and (6) blast furnace gas. The properties of these fuels are given in Table I. The drying of cores and moulds does not lend itself to mathematical

The Drying Gases.—(*a*) Temperature of gases; (*b*) degree of saturation of the gases; and (*c*) gas velocity and turbulence in drying oven atmosphere.

The apparatus set up for investigating some of these variables was given and discussed. The outcome of tests carried out on the lines discussed will be read as a Paper at some future date.

DISCUSSION

The President (Mr. W. J. Petersen), opening the discussion, expressed the appreciation of the meeting, and hoped that at a later date they would have an opportunity of hearing the fuller Paper.

In view of the importance attached to the drying of cores, Dr. Marais was asked to explain what action took place in green-sand castings. Dr. Marais admitted that it was a subject on which he could only theorise, but by showing the scantiness of their knowledge, theorising should stimulate an interest in practical investigation. Illustrating his explanation by diagrams, he pointed out that in green-sand castings the presence of a certain amount of water lent an artificial permeability to the mould which was not encountered in dry sand. He added that, as water has the highest specific heat of all known substances, the steam generated in the damp sand near the casting is condensed and cooled by the moisture in the sand farther in the mould. This considerably reduces the volume of gas to be vented, and gives an artificial permeability to the mould.

The pressure set up by the generation of gas and steam in the mould a short distance away from the face of the casting makes the tensile strength of the moulding material play quite an important part. This is not yet fully understood and will require investigation, especially in connection with scale formation.

Moisture Content

Mr. Cartwright congratulated Dr. Marais on his Paper, which opened up a very wide field for future study. An interesting point had been made in connection with the large number of experiments conducted on cores which, after drying, were allowed to stand. Since moisture always travelled from the centre, the cores in the experiment would have to remain constant in weight for a considerable period after drying took place. Was this the case?

Dr. Marais stated in reply that if the moisture balance on the outside was kept the same, "flattening out" of the moisture curve was eventually obtained, but in ordinary practice a downward bend always resulted near the exposed face owing to the escape of a certain amount of moisture.

Mr. Cartwright then asked whether there was any marked difference in the water depending on the permeability of the sand, or whether the travelling of moisture was "contagious." In other words, did moisture travel from one particle to another?

Dr. Marais replied that moisture spread mainly in the open spaces between the particles due to diffusion and capillary action. This could be determined very accurately by experiment.

Mr. J. Tonge said that, in drying a mould, he could assume from his practical knowledge that the main concern was to dry the core sufficiently to prevent reaction taking place until the metal had set, after which neither diffusion nor permeability could cause very much damage to the casting. Though raising this practical point, he was very grateful to Dr. Marais for his experiments, and suggested that individual members could do something in their own works that would help him in the production of a more practical Paper at a future date. Some very successful castings had been made, and this was a step towards what Dr. Marais visualised.

A further point raised by Mr. Cartwright was that the general custom in foundries was to

Table I.—*Properties of Common Fuels.*

Solid fuels.	C	H	O	N	Ash	Moisture	Products of combustion.	
							Partial pressure.	Dew point.
							Lb. per sq. in.	Deg. F.
Bituminous coal	75.6	4.8	5.8	1.5	10.0	2.3	0.466	78
Anthracite ..	80.2	2.7	2.4	0.9	11.4	2.4	0.272	62
Coke	82.9	—	—	—	13.8	3.8	0.078	29
Wood	45.9	6.0	38.5	—	0.5	9.1	0.91	99

Gaseous fuels.	CO_2	O_2	CO	H_2	N_2	CH_4	C_2H_4	Products of combustion.	
								Partial pressure.	Dew point.
								Lb. per sq. in.	Deg. F.
Coke-oven gas ..	3.4	0.3	7.5	52.3	3.4	29.1	4.0	2.2	129.3
Blast-furnace gas	11.0	—	27.0	2.0	60.0	—	—	0.82	95.0
Producer gas .. (without steam injection)	3.0	—	29.0	6.0	60.5	1.5	—	0.32	67.0

have a constant heat and vary the drying times rather than to dry the moulds for a constant period and vary the heats. His own experience was that a temperature of 250 deg. C. was satisfactory, but in some cases 300 deg. C., or even 350 deg. C., would not be too high if the temperature was raised slowly.

Mr. Tonge agreed that an increase in temperature seemed desirable, but emphasised that foundries were invariably working against time and consequently there was always danger of cracking the moulds and disturbing the surface.

Effects of Ramming

Replying to Mr. Holdsworth, Dr. Marais said that he had carried out a few tests on ramming. By increasing the amount of ramming-force, hardness could definitely be increased. A greater number of light strokes secured a more uniform hardness throughout the core. His tests had been carried out on various mixtures of floor sands, red sands and green sands, and both natural and artificial binders had been used. He had not used oil sands because of the difficulties involved in handling.

Asked whether the binding compounds volatilised completely, Dr. Marais stated that there were two types of binding agents and that the clay or colloidal type and the oil type reacted differently. In the case of the former very little gas was driven off.

Mr. H. S. Ward inquired whether Dr. Marais had carried out tests on cores made with various artificial binders. He had often heard that cores made with these binders after a long period of storage had to be redried. Had the moisture actually come from outside, due to absorption by the bond? Alternately, was the time factor responsible? It was possible that dampness attributed to atmospheric moisture was due in many cases to the fact that the mould had been improperly dried initially.

Dr. Marais said that his results had been obtained mainly with clay binders, and that he had not yet completely investigated artificial binders. There was a possibility that a hygroscopic type of binder might draw a certain amount of moisture from the air.

Natural Binders

Mr. Cartwright wondered whether the problem should not be tackled from the point of view of natural binders. He had often seen moulders trying to get a better result by using more red and less yellow. Yet a fortnight later they would go back to their original mixture, and very much the same results would be obtained.

Dr. Marais said that in determining the clay content of a used red sand indications of the existence of two different types of clays were found. On shaking up the sand with a caustic soda solution, the clay was brought into suspension. As the amount of caustic soda in the solution is reduced by syphoning off and adding fresh water, a stage is reached at which part of the clay precipitates in a flocculent mass; when adding more caustic soda to the solution proper suspension again takes place.

Mr. Cartwright asked whether hydrogen was responsible for the presence of blow-holes which were not due to faulty venting. Particular difficulty was often experienced when casting in steel with a high chromium content. Was this due to hydrogen, and if so was the release of hydrogen caused by water in the ladle or, according to a more recent hypothesis, to electrolysis? He wondered whether other members had encountered the blow-holes he had referred to in low chromium steel.

Dr. Marais said that it was found by experience that hydrogen was one of the most persistent contaminating elements in steel. It had actually been traced to humidity in the air, which during the operation of blast furnaces entered as hydrogen into the iron. This hydrogen persisted right through the steel-making process.

Chromium Heat-Resisting Cast Irons*

DISCUSSION OF PAPER No. 706

Vote of Thanks

MR. E. J. L. HOWARD, proposing a vote of thanks to Mr. Tucker for his Paper, said that it was one which was particularly interesting to the foundry industry in view of the higher temperatures and pressures which were being used throughout the world. He was in full agreement with the author that sufficient publicity had not been given to chromium additions to cast iron. When further development had taken place in that direction it would be found that they were quite as good as any other alloy additions, particularly for resisting corrosion and abrasion. It had been pointed out in the Paper that too much stress should not be laid upon what might be termed laboratory tests. The materials could only be judged adequately by long-service conditions.

MR. J. E. COOKE seconded the vote of thanks. The statement at the end of the Paper where it was pointed out that the usefulness of the chromium heat-resisting cast iron must be with regard to its length of service was in marked contrast to what very often happened when tests were relative to very little of anything except themselves.

MR. TUCKER, in responding, said it had given him great pleasure to come to Manchester and read his Paper.

DISCUSSION

Substitute Additions

MR. E. LONGDEN paid tribute to the quality of Mr. Tucker's Paper. The author had not merely done an immense amount of complicated research work, but had succeeded also in presenting its results in an easily understandable form. The effort in compounding metals to resist corrosion, heat and abrasion seemed to be always centring on the production of the maximum amount of carbide or carbides of various kinds. In the forefront was chromium.

Had Mr. Tucker made any comparison of ratios? For instance, manganese was used for the purpose. Was the ratio or percentage of manganese to chromium of such an order that a high percentage of manganese would create undue brittleness and impair the effectiveness of the properties required?

Again, the introduction of nickel for the purpose of improving the strength of the metal at the various temperatures mentioned brought to mind the usefulness of copper in place of the nickel. From the point of view of the expense of nickel the possibility of dissolving high-temperature melting alloys in cast iron was worth emphasising. In all changes in metals the question of time and temperature must be considered, together with the acceleration of the dissolving of the added element, and whether the speed of the operation could be accelerated by increasing the temperature.

MR. TUCKER replied that when he originally decided to read a Paper he thought he had not sufficient information to prepare a Paper entirely upon heat-resistance, so he decided to include the subjects of corrosion resistance and abrasion. However, when he looked at his notes, he found, having regard to all the activities with which one was associated in wartime, that he could not prepare a longer Paper, so in the end he confined himself to heat-resistance.

The question of carbides was important, because in 30 per cent. chromium iron carbides were definitely 50 per cent. of the microstructure, but with the lower heat-resisting cast irons it was better to get a carbide network; otherwise, if there was more carbide than was sufficient to form just a network, the initial rate of growth—not the final rate of growth—was extremely great, and cracking or distortion might result.

Manganese Ineffective

With regard to manganese, he must say that he did not favour its use because it was so ineffective in result. It certainly formed a carbide, but such carbides were not stable to heat, breaking down at about the same rate as iron carbide. Chromium carbide, on the other hand, was stable, and therefore could be expected to impart strength or growth resistance at high temperature.

Again, he had never used manganese of more than 1.5 per cent., and even that tended to make the graphite too coarse for adequate growth resistance. Therefore, he had never had sufficient manganese in iron to cause excessive

* Lancashire Branch Discussion of Mr. R. C. Tucker's Paper: see Proceedings Vol. XXXIII, p. 11.

brittleness. In the case of low-chromium cast irons, he had never had more than sufficient manganese to neutralise the sulphur content. Weight for weight, manganese was definitely less effective than chromium.

Scale Reduction by Copper Additions

The influence of nickel and copper on strength was very interesting. He had recently read of some tests on the addition of copper to chromium cast irons. In an American publication, issued by the Battelle Memorial Institute, it was stated that the introduction of 1 or 2 per cent. of copper gave excellent growth resistance. He had had an inquiry for castings from America which had led him to look into the matter. He had found excellent resistance to scaling at 850 deg. C., the results having been completed that week. The difference between the plain chromium cast iron and the same cast iron with the addition of 1 or 2 per cent. of copper was that the 1 per cent. of copper had no influence, while 2 per cent. reduced the scaling by 90 per cent. of the amount of scale obtained with chromium iron at 850 deg. C. in 700 hours.

With regard to the influence of copper on strength, present-day knowledge of the materials at high temperature was practically nil, and therefore he could not deal with the point. The influence of the copper on growth was practically negligible.

Stress Relief

Mr. E. J. L. Howard asked if Mr. Tucker had carried out any heat-treatment with high-chromium cast irons in order to relieve stresses. He would like to endorse Mr. Longden's remarks concerning the addition of copper. It might not have much effect on the resistance to growth or to scaling, but it certainly had an effect on the resistance to abrasion. The addition of 1 to 2 per cent. of copper to a 30 per cent. chromium cast iron made a vast difference. He was speaking of the high-chromium irons melted in a crucible. Did Mr. Tucker have any difficulty with regard to fluidity? It had been found that the addition of ferro-titanium improved the running properties. When speaking of resistance to high temperatures, one must also consider resistance to corrosion, *viz.*, atmospheric corrosion through gases such as were encountered in the foundry industry. This remark applied particularly to sulphur gases. What was the resistance of the high-chromium cast irons compared with the austenitic type of iron?

Effect of Copper on Abrasion

Mr. Tucker said that Mr. Howard had raised two interesting points. He had no knowledge of the effect of copper on abrasion with 30 per cent. chromium. The only extra element addition he had made with 30 per cent. chromes was that of nickel. It was to be imagined, from the effect of the nickel on the cast iron, that the effect of the copper would be of a similar order, but whether it would be of the same magnitude he could not say. Definitely, the addition of 1 per cent. nickel made a considerable difference to the abrasion resistance.

Abrasion had very often been associated with corrosion. As most corrosion-resisting metals depended upon the existence of an oxide film, if one started to wear off the film with an entrained sand there was an entirely different effect. This was where the chromium and manganese steels differed. Really it was the other way round, because manganese steel only wore thin if it was battered about; it did not wear thin against a relatively slight action like a sandblast or a sand entrained in water A white iron, or any chilled cast iron, was hard intrinsically and would stand up to batter without getting any harder, yet it would resist slight abrasions such as those caused by sand or by a pump water. It would also resist corrosion as well as austenitic steel.

Deoxidisers

With regard to fluidity, he thought ferro-titanium must be added as a deoxidiser, though he had not used it. He had used other deoxidisers, for when melting in certain refractories, deoxidisers were needed. He had recently carried out tests without a deoxidiser over periods to ascertain whether the same properties were obtained. He got just as good fluid soundness in the castings as with the deoxidiser, so he had stopped using the deoxidiser. If he had to make castings in a refractory-lined rotary furnace, he would certainly use a deoxidiser. Had Mr. Howard used ferro-zirconium?

Mr. Howard replied in the negative.

Mr. Tucker suggested that for grain refinement it was efficacious.

Mr. C. Cooper asked what Mr. Tucker considered to be the maximum temperature for which low-chromium irons were suitable, say, in a flue damper. Sometimes customers made such an inquiry. How long would the casting stand in a temperature of 700 deg. C. in continuous service?

Mr. Tucker replied that obviously life would depend upon temperature. Low-chromium cast irons would stand for indefinite periods at 600 deg. C.

Mr. Cooper asked what would be the maximum temperature.

Mr. Tucker suggested 800 deg. C. He would not like to guarantee them for six months, but he would expect a life of approximately six months to a year. It all depended upon what happened in shut-down periods. Very often, in such flues, sulphur-containing gas was present, and if at any time there was a dew-point temperature, sulphuric acid would form. This acid would do more damage in half an hour than the whole of the heat would do in many weeks. The effect was the same as with mild steel, and it was very rapid. Great care must be taken to see that no corrosion was taking place during shut-downs.

Aluminium Additions

Mr. Cooper remarked that Mr. Tucker had stated he had cast chromium irons at a very high temperature. In dealing with fluidity in the case of the needle casts, had he tried the addition of a small quantity of aluminium in order to increase the fluidity? This being the case, were there any bad after-effects? Occasionally, when iron was stiff, he added aluminium, but he had not sufficient knowledge of the after-effects to know what had happened.

Mr. Tucker replied that, in the case of the needle air heaters, if the iron was stiff enough to cause trouble, it could not be remedied. The iron must be melted properly. No amount of aluminium would cure it sufficiently to run the needles. If the iron came out oxidised, or the pit bed had got low, and the iron was not up to standard, there was no cure for lack of fluidity. No ladle addition would increase the hardness of the iron.

He had solved the difficulty by the addition of "Chromex," which was exothermic. The iron was tapped on to it, and by the time 1 to 1.5 per cent. of chromium was added, the iron was exceedingly hot. All that was necessary was to skim the pot and the iron would run smoothly

The "Chromex" material contained ferro-silicon. The exothermic reaction was between sodium nitrate and the ferro-silicon. He had heard of the addition of aluminium to dull iron. It worked all right in certain classes of common iron that did not require to have excessive fluidity.

Mr. Cooper inquired what was the effect of aluminium on heat-resistance.

Mr. Tucker said that if the aluminium had done any good, the iron must be combined within aluminium. It was bound to be less heat-resisting than if it was a sand casting. He could not say any more than that. He had never added aluminium to the particular iron he was dealing with, but he added it to low-chromium irons, and it had not improved matters.

Mr. A. Sutcliffe asked if he understood Mr. Tucker aright to say that he poured castings at 1,500 deg. C., as this was something new to him?

Mr. Tucker said it was not done out of a cupola, but was a crucible melt.

Mr. Sutcliffe said he sometimes made fire-bars very cheaply because customers would not pay any more for them. How would it be possible for him to continue doing so if he used chromium iron? The fire-bars weighed anything from 8 to 28 lbs. at a price averaging 22s. per cwt. What length of life would Mr. Tucker expect them to have, and would he place the blame on the fire-beater or upon the air space in the bars if they did not last sufficiently long?

Hammer Blocks

He had made castings for puddling and billet-heating furnaces up to five or six tons and two or three hammer blocks. Did Mr. Tucker think his metal would do away with cracks on a hammer block of 5 tons' weight? He did not think it was a commercial proposition to make the runners and the doors referred to by Mr. Tucker at the price of common castings.

Mr. Tucker said that Mr. Sutcliffe really wanted him to give another lecture, but he must refrain from doing so. Chromium was the cheapest alloying addition known apart from the four elements usually present. Half per cent. of chromium could be added to any mixture at a cost of approximately 4d. to 6d. per cwt. It was possible to reduce the cost of the mixture by 6d. per cwt. by the judicious use of a higher silicon pig-iron and steel scrap, finishing with a mixture which would last a great deal longer with a great deal more heat-resisting service.

The hammer block proposition left him cold, because he would like to see what type of cracks were produced. Were they due to the billets being cold or to the blows from the hammer? If they were due to crushing from the billets then chromium would be of assistance. If they were due to the beating of the hammer chromium would be of some assistance, but care would have to be exercised, otherwise there would be cracking. Such irons must be very closely controlled. To add any chromium, and to do any good, one would run dangerously near the point where cracking might ensue.

Cracking of Fire-Bars

With regard to fire-bars, there were no two days' work alike in any one plant as a rule, and there were no plants alike from the point of view of fire-bar castings. Anybody who quibbled about fire-bars which were bought at a suggested price of nothing per ton was just idiotic, because the conditions were far from uniform. The conditions in the end fire-bars and those in the fire-bars in the middle of the row were quite different. Men cleaned their ashes in different manners. All he could say was that careful experiments carried out at large power stations before the introduction of mechanical stokers showed that a small amount of chromium incorporated in the metal, say 3 per cent., gave about 10 per cent. extra life. The addition of steel to a mix of about 10 per cent. would just about account for the extra cost of the chromium and also gave a similar increase. So there might be an increase in life by using steel or chromium, but there must be no attempt to go too far in either direction, otherwise the fire-bars would crack. One could not just throw in something from a ladle

Mr. Longden remarked that Mr. Tucker, in his reference to the addition of steel, mentioned it was necessary to introduce steel in order to reduce the graphite size. That would be graphite with reference to fire-bars. He would like to add that really there was more harm done by the fire than any adoption of added elements. It was really a matter of keeping the bars clean and trying to keep the combustion from the fire-bar itself; namely, lift it off the fire-bar. In the case of a forced-draft fire there was less liability for it to be burnt than in the case of an ordinary fire blast.

Creep Tests

Mr. A. Phillips said that the following statement appeared in the Paper:—"It is intended finally to determine the influence of phosphorus, nickel, molybdenum and tungsten on the creep of cast iron." Had Mr. Tucker done anything with regard to the question of creep in cast iron? There was no doubt that this was a time when the replacement of steel castings could be effected by cast iron if the full properties of certain cast irons could be accurately ascertained. To replace a steel casting by cast iron, first of all the engineer would want to know the tensile strength. Attempts had been made to effect an improvement in tensile strength by the addition of, say, nickel or certain other alloys. Then it was found, on comparing with the creep in steel, that nickel was not one of the best elements to effect a favourable creep test. Again, it had been found that molybdenum steel gave good creep results, but this metal was very difficult and very expensive to introduce in the case of cast iron. It was very difficult to reach the high tensile strength which was necessary. Had Mr. Tucker any information on the creep test as effected by the addition of chromium? If so, how did he combine it to obtain a good high-strength alloy cast iron, and at the same time maintain a cast iron which had good creep properties? Speaking from the point of view of the man in the street, looking at some of the tests, one might say that the chief thing about them was that there was rapid growth in the initial stages of the product in service. Was it not possible, and was it not beneficial, to normalise or heat-treat the castings before they were machined in order to obtain better service in use?

Another point about heat-resisting cast irons which did not appear to be clear was that in certain industries cast iron was subjected to contact with superheated steam. In another industry there would be contact by flame. The temperature was obtained by different methods. If one sought heat-resisting cast iron and temperature-resisting cast iron, and could look into the literature for a specification or a certain chemical composition—a certain heat-resistance and a certain composition for temperature-resistance—would Mr. Tucker be prepared to state his view about its applicability?

Influence of Molybdenum

Mr. Tucker was surprised to hear that molybdenum did not give tensile strength to cast iron. Did Mr. Phillips mean low-temperature or high-temperature strength? He (the speaker) found molybdenum was much better than nickel for good tensile strength. He did not use it in heat-resisting cast iron because it was so expensive. He did not know very much about its heat-resistance. He knew that molybdenum steels were the best heat-resisting steels; but he had a feeling at the back of his mind that if he gave a sufficient heat-resistance it would be like selling platinum instead of castings on account of the price.

With regard to the preliminary results obtained by means of the cantilever test, chromium did not seem to give an increase in creep resistance. This was disappointing; but that was his view having regard to the few tests he had made.

Heat-Treatment

Mr. Phillips was quite right in his idea of normalising before treatment. It would cut out a good deal of growth, but it must not just be a steel-normalising process. There was a special normalising process which would cut out the majority of the steel without, should he say, oxidising the castings too much. This method had been adopted for some low-temperature carbonisation retorts. He could not really tell, from a practical point of view, how much effect there was on the original ones. It was going to be very difficult to tell, because in two years the first few castings grew $\frac{1}{4}$ in. It was hoped by a pre-normalising treatment to make it $\frac{1}{16}$ in. or less in two years. He did not know whether success would be secured or not.

Mr. Phillips' last point was interesting, but one about which the speaker could not say very much owing to lack of knowledge. It was with regard to temperature-resistance and heat-resistance. Heat-resisting tests were still very desultory, and he was alone in the world in his particular foundry in doing the tests. He had very many other jobs to do, so that he was getting on very slowly. There were many people who were doing much more fundamental work nowadays, so that probably some day Mr. Phillips' idea would be realised. Perhaps by that time cast iron would not be used.

MR. E. LONGDEN said that, with respect to the amount of chromium necessary to introduce to an alloy, there appeared to be two aspects of heat-resistance. In one case there was a comparatively uniform temperature—a moderate uniform temperature—over a long period, and a kind of thermal shock on rapid heating and possibly rapid cooling. Could Mr. Tucker offer any suggestion as to what percentage of chromium should be used?

MR. TUCKER said that in the first case, where there was a uniform temperature, slow heating and cooling, he would suggest adding sufficient chromium to give the excess carbide over the pearlite. In other words, there should be a carbide network. In the second case he would invariably add hematite. He would not add chromium to an ingot mould even if he was asked to do so.

Needle Castings

MR. HAROLD HAYNES congratulated Mr. Tucker on being able to make needle castings. He had understood that the Germans were the only people who could make them, and it was gratifying to hear that Mr. Tucker's firm could do so. What was the best method of casting them—in green sand or dry sand? Also, did Mr. Tucker get short runs in the little spindles or fine needles? Did he run them in spray runners, or run them from the end and cast them using three or four shanks in order to ensure success?

With regard to adding chromium, would there be the same results in casting from green sand or dry sand?

MR. TUCKER said that the 3 per cent. chromium and 2 per cent. silicon castings, of which the maximum needle temperature was 850 deg. C., were always cast in green sand and with an oil-sand core. The 30 per cent. chrome was very interesting. When they started making them they adopted steel-foundry practice, and cast them by dry sand with an oil-sand core. Then he thought that he had a crucible furnace at hand, giving 100 deg. heat more than was needed, and so it was used. Unless there was a question of changing of a pattern or of convenience, they had not made one cast in dry sand since. They were all cast in green sand, with a spray runner in the side all the way along.

Mr. Tucker illustrated the method by means of an illustration upon the blackboard.

The use of the exothermic mixture "Chromex" (he continued) obviated the misrunning of any needle even at the ends.

Gating and Feeding of High-Duty Alloys

DISCUSSION OF PAPER No. 708

American Co-operation

Mr. Vincent Delport (Past-President of the International Committee of Foundry Technical Associations and European Representative of the American Foundrymen's Association) opened the discussion. Although he had not been specifically commissioned by the A.F.A. to represent them officially, he was quite certain that they would wish him to take advantage of the opportunity to extend to the members their most cordial greetings, to express sincere wishes for the continued success of the Institute despite the difficult conditions under which it was labouring, and, above all, to assure members of their heartfelt sympathy for the ordeal through which all were passing to a greater or less degree, and their admiration for the manner in which the British were facing the trial.

Industrial Collaboration

Turning to the Paper under consideration, Mr. Delport said he did not propose to discuss its technical aspects, but he would like to take it as a text for a few thoughts of general interest to the foundry industry, and he would attempt briefly to sum up the Paper in order to start an exchange of views by the West Riding members. In their introductory paragraphs, the authors had brought to light a certain aspect of the necessary collaboration between metallurgist and foundrymen. Among the activities of the metallurgist was the constant quest for better castings, not only by using special alloys that gave better resistance to wear, heat and abrasion, but also improved castings made from ordinary iron—more homogeneous castings and fewer wasters; in general, more regular and more economical production.

The authors were quite aware of the fact that progress along the lines indicated brought about added difficulties in foundry practice and technique. The operation of a foundry equipped for modern production required a considerable amount of technical knowledge, skill and organisation, and there was going to be more direct contact between the metallurgist in his laboratory and the foundry manager and moulders and melters; and that was all for the good. In connection with this question of collaboration between the research worker and the practician, Mr. Delport quoted a passage from the address which the late Lord Rutherford, that great New Zealander, delivered when he became President of the British Association in 1923: "If the fundamental researches of the workers in pure science supply the foundations on which the applications are surely built, the successful practical application in turn quickens and extends the interest of the investigator in the fundamental problem, while the development of new methods and appliances required for technical purposes often provides the investigator with the means of attacking still more difficult questions."

The results described in the Paper from America were due to such collaboration. The time had gone when the so-called "practical man" looked upon the metallurgist as a man solely concerned with science and theory, and far removed from the problems that had to be confronted on the cupola platform or at the moulding station. It was now recognised that without the patient research work of the metallurgist the foundry industry would not have reached the position of prestige that it had now attained, nor would the iron foundry be able successfully to compete against other forms of fabrication in order to satisfy modern engineering requirements. On the other hand it was evident that all the work done by metallurgists would be of no avail if foundrymen had not, themselves, improved their methods and made the necessary efforts to keep informed of continuous developments. In this connection mention should be made of the facilities afforded to-day for the distribution of specialised foundry knowledge, and of the opportunities given for the interchange of knowledge by such organisations as the Institute.

Improved Feeding Methods

The methods of feeding described were, no doubt, not unfamiliar to most members, but perhaps they were not used over here to a very great extent. The authors had made a specialised study of the subject and had successfully translated the results of their experiments into practice. They now published the results so that all might benefit from them. This was eminently a practical Paper, while being the result of much research work. There were

* West Riding of Yorkshire Branch Discussion of the 1940 A.F.A Exchange Paper; see Proc. Vol. XXXIII, p. 45.

probably many points that members would wish to discuss. They might find, for instance, that head feeding was not the best method in every case, because of the different nature of moulding sands—or it was possible that some members were satisfied with the method in use. The authors themselves stated that direct feeding-head pouring was not uniformly applicable to all designs. At all events, he had no doubt that the authors would gladly answer all questions, even though their replies would have to be in writing, and that members would benefit from their own mutual exchange of remarks.

The Branch-President (Mr. H. A. MacColl) thanked Mr. Delport for his opening remarks. He thought that the methods advocated in the Paper were to a considerable extent what was normal practice in steel founding, in which direct feeding gave very satisfactory results. It did, however, make for substantially increased cost, and that was a factor which must be taken into consideration.

Top Feeding No Panacea

Mr. F. K. Neath, B.Sc., felt the Paper was a development of a long-standing "feud" between the advocates of top-pouring and those of low-level practice. There was much to be said in favour of top pouring, which gave metal set at the bottom almost before one had finished pouring. The feeders were filled with fresh, hot metal and the body itself had already done some feeding to the lower portions. The whole principle was a logical development of much that had been argued about in the Institute's meetings and performed in this country.

In the end the authors quite clearly and frankly admitted they did not advocate top pouring for every casting. They admitted that it would not always answer, and they actually showed, in Fig. 14, a "waster" as a result of the wrong method of moulding a Monel centrifuge casting. Moreover, Fig. 16 was an excellent piece of work showing the way they overcame the trouble by the use of denseners and side pouring. They had had the pluck to show their failures as well as their successes, and members should congratulate them. There were some metals mentioned in this Paper which admittedly were not used much in this country, but the general principles were the same, as all metals required feeding.

Mr. A. S. Worcester said that, whilst the Paper related particularly to high-duty alloys, all its principles were applicable to producing castings from ordinary common grey iron, and it was an excellent and valuable contribution. Members' minds were carried back to the time of the Papers by Ronceray on top running or strainer running to deflect thought into the right direction. The West Yorkshire Branch, especially Mr. S. Carter (Past-President) had done more work in this direction than he had encountered in other districts, with much success. It was a fact that if a casting was cast up with a fairly long, straight runner, there was, as a consequence, a certain amount of turbulence in the metal, and it must impinge on the sand, especially if it was not blacked. Thus there was much to be said for this method of strainer running.

Wide Application

Mr. S. Carter said the departure from ordinary practice to meet the calls of high-duty irons was obviously necessitated by the difficulties encountered in liquid shrinkage in metals of a short freezing range. Whilst the practice illustrated by the Paper confined itself to these high-duty alloys, he considered that the methods employed had a wide field of application in the sphere of ordinary grey iron, although, as pointed out by the authors, application must necessarily be limited to dry-sand moulding on account of the fragility of the small neck end of the bottle-shaped riser.

The absence of dimensions on the illustrations did not assist in the proper appreciation of the value of the methods employed, and it would be very interesting to know, amongst other things, the thickness of the strainer cores used for passing the 2 tons of metal into the bushing illustrated in Fig. 8. In a long experience of strainer cores and their application, he would not care to employ a core $1\frac{1}{2}$ in. thick, in oil sand, for the particular casting in question, owing to the tendency for fusion when the bonding agency disintegrated. This casting commended itself to the speaker as a fine illustration of the achievements claimed by the authors for the methods employed, and contrasted very favourably with English practice, which would have used an extension of the casting as a feeder head to be cut off in machining and returned to the foundry—all at considerable expense.

Sphere of Application

The application of this system for large compact masses of iron appeared to be a very fruitful proposition, and could be well recommended for the bosses of large gear blanks, flywheels, couplings and the like. The nature of the metal used in making the valve body in Fig. 9 was not stated, but the necessity for using this method of running and feeding was not apparent. Such a casting, emerging from a mould in England, would be considered a freak, and he believed he was right in stating that 90 per cent. of British founders would attempt to produce these castings satisfactorily by means of denseners in preference to the obviously expensive and elaborate heads employed by the authors in this case.

The authors mentioned the feeding rod in describing methods used for compensating liquid shrinkage, and a personal opinion was that any method which could eliminate this most inconsistent and unsatisfactory process from a foundry merited recommendation. It was almost true to say that as many castings had been spoiled by the rod as had been saved, and in their departure from hidebound foundry practice the authors were to be congratulated on their calculated and scientific approach to one of founding's worst difficulties. Mr. Carter amplified his observations by some blackboard illustrations of his own work, as mentioned by Mr. Worcester.

Gear Blanks

Mr. F. Oldershaw, referring to a gear blank sketch which Mr. Carter suggested as the type of job that would yield a satisfactory result by the top running method, said he would be inclined to run that particular job in the bottom, with a small runner and two risers at the top. There was a great deal in the way of handling the feeding, and much depended on who carried out the work, and the care or otherwise put into it. The object was to keep the neck of the riser open and let hot metal sink into the casting. With a hard iron one could not cast with what was known as "cold" metal. There must be enough fluidity after the metal had left the mould to allow it to feed back. Answering a remark by the President, Mr. Oldershaw said he had tried steam feeding, but he regarded it as more trouble than it was worth.

Mr. Carter, giving several other blackboard illustrations of jobs he had tackled much on the lines suggested in the American Paper, remarked that one of the points that did not seem to have been raised was that of running through an oil-sand core.

Mr. Neath said a point to remember, also, was that the metals used in this Paper were not the ordinary common irons.

A Member asked whether, when casting a small job and skimming the metal, a strainer core was advisable.

Mr. Carter said that such was the case, as one could ensure the elimination of slag and dirt.

Mr. Neath endorsed Mr. Carter's plea for a strainer core as a means of ensuring the greatest possible cleanliness of the metal.

Mr. S. W. Wise suggested that the strainer core would retard the flow of metal. He drew on the blackboard a strainer core as operated by himself in regular practice for a 3-cwt. job, using sea sand. He agreed, in answer to questions, that if any difficulty were experienced he would turn from sea sand to ordinary foundry sand. Mr. Wise's illustration showed two circles of holes, the places for passing the metal being $\frac{1}{8}$ in. diameter less at each stage.

Use of Strainer Core

Mr. G. Illingworth stated that this was the first occasion he had seen the metal introduced on to the top of the strainer core in the way illustrated by Mr. Wise. The authors of the Paper gave the size of the head to the moulder and the core was made to fit into the top of the riser. (Mr. Illingworth illustrated his point on the blackboard.) The strainer core was level with the top of the moulding box and they introduced a pouring box. The pouring box being rammed up, the authors introduced a "pinch" effect, but there was no actual direct pressure on top of the strainer core.

Mr. Wise said that about 1912 he used a strainer runner which he thought was a wonderful discovery such as nobody had made before—until he saw an article in the technical Press by a man who had made a strainer runner thirty years previously!

The Branch-President suggested that the meeting might take one or other of the examples in the Paper and say whether they agreed or, if not, what they would do themselves. Let them take, for instance, the coil-wire annealing pot illustrated in Fig. 5 and showing the gating arrangements. The authors had used four large heads on the ribs with a strainer core on those. What alternative methods had members to offer if they did not agree with that? Successful castings, presumably, were being made by their own methods. What advantage was there in taking up this other way with its slight complications? If members were to change methods they must obviously have some expectation of definite advantage. Did this method offer such an advantage over their existing practice as to justify the change?

Answering Mr. Carter's comment that discussion was handicapped by the absence of dimensions, Mr. MacColl said he would suppose this particular item was possibly five to six feet high, perhaps 30 in. dia. and 1 in. thick.

Mr. Carter said that in his opinion, for that particular job, the authors' method would have no great advantage over normal district practice.

Mr. Neath said Diesel-engine founders in the North-East used a header such as was shown in Fig. 5, but from their experience they would bottom-pour it. They would make it a continuous header, and he did not think there was much difference between the authors' practice and that of the Diesel-engine makers in this country.

Mr. Illingworth felt it was a little unfortunate that the Paper did not give analyses of the irons used, thereby leaving discussion without any true conception of shrinkage.

Mr. Delport, referring to the desire for dimensions and analyses, felt it would be a good thing to ask these questions of the authors themselves and await the answers in writing. The members would appreciate, of course, that this might take some little time. As regard the question as to advantages of the system, an outline of advantages was given in the Paper under the heading "Advantages Obtainable by Direct Riser Pouring." The advantages, as suggested by the authors, were set out in four definite points there. The point was, Mr. Delport would suppose, whether members of the Institute agreed with the advantages as suggested by the authors, or had other ideas of their own against them.

Mr. Worcester, proposing a vote of thanks to Mr. Delport for his visit and opening the discussion, paid tribute to him for travelling from London to speak on a Paper which was not actually his own work.

Mr. Oldershaw seconded, and Mr. Wise warmly supported the proposal.

Mr. Delport, replying, said he had greatly enjoyed his visit. They might not, during the evening, have kept discussion to strict arguments on all the points in the Paper, but the value of a Paper, after all, was very largely in the opportunities it created for opening up other aspects on the kindred subjects. He would, nevertheless, welcome any written comments or questions which members may individually care to send for the attention of the authors.

Phosphor Bronze Castings of Heavy Section*

DISCUSSION OF PAPER No. 724.

Vote of Thanks

Upon the motion of MR. E. LONGDEN (Manchester) a hearty vote of thanks was accorded to the author for his Paper. Mr. Longden stated that he entirely agreed with all that the author had said in connection with the methods of making very large bronze castings. Doubtless, during the course of the discussion, there would be some opportunity to dot the i's and cross the t's of what had been said.

MR. A. SUTCLIFFE, SENR. (Bolton), seconding the vote of thanks, referred to the pillar which had been chilled all over, and an illustration of which had been shown upon the screen. Would it be suitable for making a spun casting, because it appeared likely that the chills would densen it.

The vote of thanks was carried unanimously by acclamation.

Limitations of Spinning

MR. A. HOPWOOD, in acknowledging, also answered Mr. Sutcliffe's question concerning the use of chills. There was a saying that there was nothing new under the sun, and he had no desire to infer that any of the ideas presented to the Paper should be regarded as new. What he wanted to point out was that the Paper was the assembling of practical experience tending towards the successful production of a casting. Chills never were intended to be the be-all and end-all of successful foundry practice, but nevertheless they could not easily be replaced.

With regard to the spinning of the wheel which had been referred to, the bore of the one shown on the screen was about 4 in. dia. A machine cut of $\frac{1}{8}$ in. would reduce it to $3\frac{3}{4}$ in., and it could be visualised what an excessive speed would be necessary in order to get the bore completely solid. He did not insist that it could not be done, but coupled with that suggestion was the consideration of the expense of the metal bowl which it would be necessary to mount on to a machine. He thought the total number which were made were all to replace worn-out castings, and as far as he could remember not more than half-a-dozen were produced. Therefore, it did not appear to be an economic proposition.

MR. KILBURN SCOTT (London), referring to a bronze casting which was more dense at one end than the other, said that this would be difficult if it was made as a spun casting. He remembered Mr. Joseph Whitley, of Leeds, who achieved such results round about the year 1870, or about the time that Cleopatra's Needle was brought to this country, an action in which Mr. Whitley was personally interested. Cylinder bronze castings for paper-making machines had been made practically ever since then, and Mr. Whitley thought the casting would be a much better one if it was spun. The place where the greatest density was required was clearly on the periphery where the teeth were. Instead of making them in $\frac{3}{16}$ in. lengths, a long one would be spun, and parted by machining; thus there would be no head. He noted that the lecturer had stated there was only a 2-in. head. This surprised him because the head on a sealing gate was very much larger. Was any silicon used in the castings as was the case with steel, in order to eliminate the gases and to keep the metal liquid?

Degasifying by Atmosphere Control

MR. HOPWOOD, answering Mr. Kilburn Scott's last question first, said silicon was not used, though it was used in non-ferrous metals in some cases for the reduction of oxides. With regard to the degasifying of non-ferrous metals, there were certain fluxes on the market which were said to degasify bronze, after which it was necessary to deoxidise. These fluxes had a certain scope for use, but possibly the best way to degasify bronze was to keep the furnace atmosphere in a suitable state by maintaining slightly oxidising conditions. It had been proved more or less, but experiments were still being carried on, that the gases causing trouble in non-ferrous metals were definitely reducing gases. Hydrogen was a source of trouble in copper in the melting period; that is, when it was first put into the pot. As it became hotter, it absorbed hydrogen from the gases before it melted; during melting, and whilst superheating, it absorbed them to a still greater extent.

The question of gas, to his mind, resolved itself more or less into a question of furnace atmospheres. If an oil-fired furnace was used, the necessary steps could easily be taken. The melting of the metal could take place under a reducing atmosphere which would give almost the same temperature. The metal did not melt quite so quickly, but the castings made from it

* Lancashire Branch Discussion of Mr. A. Hopwood's Paper; see Proc. Vol. XXXIII, p. 203.

would be very porous; whereas by melting in a reducing atmosphere, and then when the metal was molten changing over to an oxidising atmosphere, the gas pick-up could be nullified to a great extent, for it seemed to reduce the amount of gas picked up.

The fluxes on the market were oxidising mixtures which were stirred into the metal, or plunged to the bottom of the melt, and the melt was oxidised in the same way as in a furnace carrying an oxidising atmosphere. Then it was necessary to reduce the oxides created by the oxidising mixture by the use of a deoxidiser and by having a correct atmosphere when finishing.

Advantage of Spun Castings

He had had a fair amount of experience with regard to the spinning of phosphor bronze wheels. Mr. Kilburn Scott was perfectly correct in what he had stated. There was nothing to surpass a spun casting; a 22-lb. casting made "sand-cast" would weigh 24 lbs. when spun-cast. From this the densening effect of spinning was evident. These 22-lb. wheels were machined to very fine limits and inducing an extra 2 lbs. per casting, would enable one to appreciate the value of spinning over ordinary methods.

However, a large number of castings were necessary in order to make spinning an economic proposition, unless, of course, the type was a very simple one. He had spun one-off castings by adopting a machine specially lending itself to this purpose; but it was more or less a combination of the two processes of using loose chills and sand built into a spinning machine. The mould was made in the machine with the chills in position, dried, and then closed down. The machine was spun and the metal fed into it. This had been done for odd wheels.

With regard to the question of the nut, a horizontal machine would be required initially. He doubted very much whether it would pay to build up a mould, turn it horizontally on its side, and spin it. Probably the mould could not withstand this treatment. Then there was the difficulty with small bores of getting them sound. The difficulty with both the horizontal and vertical machines was in producing small diameters. It could be done with a bush, because there was very little difference between the outside and inside diameters. With a large outside diameter and a very small bore, it was a different problem altogether.

Mr. E. Longden (Manchester) also referred to spinning. The minimum peripheral speed required to give the requisite density was approximately 1,400 ft. per min., though in his opinion 1,500 ft. per min. was a safe spinning speed. In the case of a small diameter it could be imagined at what a terrific speed the mould must be spun; added to which there must be considered the economic factor of the small orders. These considerations exceeded the economic possibility of the case in regard to any attempt to spin. The lecturer had pointed out in the case of a spiral gear that it had to pass the inspection, but in addition it had also to have a life, which if not attained resulted in a complaint.

Where the Metallurgist Fails

Mr. Sutcliffe, Senr., said the successful production of a non-ferrous casting needed a perfect mould, and in this respect the moulder had done all within his power to accomplish this result, and a mould could be produced which was satisfactory. Why did not the chemist or metallurgist provide a suitable metal, and abandon the attempt at a solution of the problem when the result was faulty? If there were a mishap with the casting the chemist or metallurgist could always find an explanation which exonerated himself. If the customer wanted a gunmetal casting then he must pay for the tin. There was no credit given him if he was being supplied with 8 per cent. instead of 10 per cent. tin. If the product was taken, say, next door for analysis, and then taken somewhere 20 miles away, the analyses would so differ that no fine could be imposed. This should not be forgotten, because it was what had happened!

Ordinary bench sand was now being commonly used for moulding, and he had not experienced difficulty with regard to it. He could produce details for core-making and for sand-facing mixings, but the metal had great tendency for burning on. He particularly desired information concerning corrosion-resisting alloys because many of the castings used in the Lancashire area had to withstand the effects of corrosion, especially those used in the very considerable bleaching industry.

For large non-ferrous castings, a cupola of the type shown in Fig. A had been successfully used. This small cupola had one blast pipe so that the blast would not be too great. A certain amount of large coke was used. The holes numbered 1 and 2 on the sketch were so placed in order that the cupola could be repaired.

Would Mr. Hopwood expect to achieve good or bad results in the metal from such a cupola, and would it be a better proposition than either the rotary or the pot furnace? It was not a new type of cupola, but was in use about 46 years ago. It could be seen that there was no contact with coke when the metal was in the receiver portion.

Sands for Non-Ferrous Practice

Mr. Hopwood remarked that the metallurgist was a very useful man to have about a foundry. The complaint was sometimes voiced that the metallurgist had appropriated to himself all the best jobs of the industry. This was a fallacy, and if the foundryman would only learn more about the metals with which he was dealing no such question would ever arise. Whenever a foundryman dealt with a new alloy, the first thing he should study before making his mould was the properties to be associated with it.

Generally speaking, in the case of non-ferrous foundries, sand had not the same importance that it had in the case of ferrous metals, which involved higher casting temperatures. Thus extreme refractoriness of the sand was not necessary, and therefore the same problems were not experienced. Sand was a porous mixture, carrying spaces between the grains and the binder. Speaking broadly, the gases expanded according to the temperature attained. Therefore the trouble of the evolution of gas from sand had not the same importance. The use of fine sands in non-ferrous foundries could be over-done, though many people favoured them. It was satisfactory for small work such as bench work. In the case of very heavy sectioned castings, where the metal lay not only in contact with it but remained in contact with it in a liquid or semi-plastic state, then a different set of conditions would arise. The gas was still expanding, and was liable to push its way into the pasty mass. Most cast irons are different, inasmuch when the metal comes in contact with the sand, a skin of rapidly solidifying metal forms, which resists to a great extent the tendency of the gases to flow into the solidifying metal. He found that by using a coarse sand for heavy non-ferrous work and using a good blacking mixture was very advantageous for a dry mould. This involved using a coarse green sand, ramming firmly, and making sure that the mould retained its original size throughout the cast. He wished to stress this point because many castings were scrapped through the statement that wrong casting temperature was being used and was responsible for the faulty fracture and red patches, the presence of which was not always attributed to the correct cause. They could be ascribed to the inferior ramming of moulds.

Risers for non-ferrous metal castings was a problem in itself, and more risers should not be put on than were necessary.

Corrosion-Resisting Alloys

The subject of corrosion resistance was bound up with service conditions. It was usually found that the people who required castings to be made with non-corrosion resisting alloy or partly-non-corroding metal stipulated the use of their own mixtures. Such alloys were usually zinc-free. He remembered, when he was an apprentice, making cocks and plugs in phosphor bronze to withstand pressure, and he remembered also the foreman's method of overcoming the difficulty. Several batches were made, but they could not withstand the pressure; not because they were incorrectly fed, but because the alloy was naturally porous. The kind of alloy to be selected, of course, depended upon the liquid or other conditions with which it had to deal.

Available for this purpose were lead-antimony mixtures; phosphor bronze and nickel alloys, all used for different services.

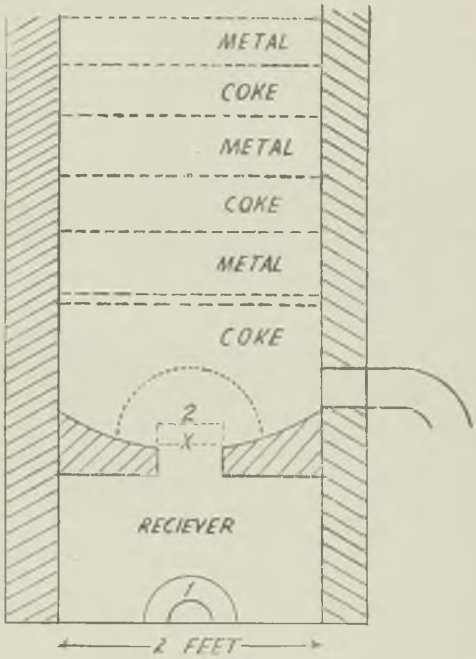


Fig. A.—Cupola utilised for Melting Non-Ferrous Alloys.

Cupola for Non-Ferrous Work Condemned

The melting of non-ferrous metals in cupolas depended upon the particular conditions arising in the furnace used. There were troubles in melting brass in crucibles, and there was added difficulty in melting these alloys in open-flame furnaces. There would be a still greater difficulty in obtaining consistent results by melting in a cupola. It could be done, but he would not like to say he could produce the same results in that type of furnace as could be produced in an open-flame furnace or a crucible furnace. The less non-ferrous metal came into contact with the fuel, or with the gases, the better the type of metal produced. Test bars proved this to be correct. Melting in a cupola furnace could be broadly stated as having the bed coke to retain the charge above the tuyeres, and to charge the coke to replace the coke which was burnt, and so on. The metal was in actual contact with the heat-producing fuel. The condition prevailing in the melting zone was, it might be said, the critical point in the type of metal produced. If there was a heavily oxidising atmosphere in the melting zone, that is, there was a considerable amount of air being blown in, the condition would be an oxidising one, and there would be heavy metallic losses. There would be a considerable amount of oxide formed. If there was a melt of copper alone and an alloy addition later, then the oxide would be dissolved in the copper, and when it came down into the well or collecting chamber it would have to be reduced before adding the mixing. If there was any charging of ready-mixed alloy, which mixture contained such constituents as zinc and phosphorus, which were easily oxidised, then the losses of those constituents would be very considerable. He would not be surprised to learn that all the phosphorus had disappeared. If tin were present in conjunction with zinc, then after the zinc burnt out, or perhaps simultaneously, some of the tin would also be oxidised. The tin oxide would come down with the liquid running into the bottom, and if the castings had to be pressure-tested they would fail to pass inspection.

Mr. Longden said that the question dated back to the old days when there were not sufficient furnaces. Apart from that point, he did not think the matter need now be considered.

Mr. Hopwood thought the difficulty lay in the atmosphere of the furnaces and the oxidising effect, and added that the trouble with copper, or with any non-ferrous metal, would lie in the actual melting zone, and not in the well. Molten copper could be kept in contact with coke, and there would be very little effect as a result, particularly in the case of low-sulphur coke. In fact, there might be an advantage, as any copper oxide produced in the melting zone may be reduced.

Cast Phosphor Bronze Sticks

Mr. E. White (Stretford) raised a point with regard to cast bronze sticks. Could Mr. Hopwood suggest any particular type of tackle, through the use of which it was possible to have a minimum of machining done on the sticks, and at the same time to obtain the Brinell hardness required without excessive machining.

Another rather important point in production was in connection with the large risers used on some of the small brass castings. It seemed, to an ordinary individual who knew very little about the matter, as though there was a great deal of wastage caused thereby. There must be a considerable cost in terms of money. Getting down to fundamentals, when one had to quote definite prices, a clear indication was given that brass founding would decline, and that some metals, such as magnesium, which for small castings could be die-cast, as is the case in the aircraft industry, would become very commonly used, particularly as they required little or no machining. How was it possible to reduce this extravagance? Because, when a moulder made a mould many times, he was not too cautious and did not think about an extra pound or two of metal. It all cost money. In order to achieve the results which were necessary at the present time, a minimum of machining and a maximum of efficiency were desirable.

Mould Dressings

Mr. Hopwood said that normal practice was to chill-cast phosphor bronze sticks. The chills in some cases were full chills carrying a slight taper, but very often they were half chills put together by a male and female joint, and then clamped. This was a very successful method of production; but there was still the difficulty that the chills had to be dressed and cared for in the proper way. The Brinell hardness was far higher than that which the same alloy would give in a sand casting. The production of sticks in sands was a bugbear.

Risers were every brass-founder's trouble. The fettling cost of non-ferrous work was something upon which it was necessary to maintain a constant supervision. Very often the solution of the question crystallised down to the proper shape of a riser. The majority of brass-founders frequently put on a straight cylindrical riser, whereas one with a narrow neck, where it joined the casting, would be more economical in fettling cost and still answer the purpose. When he referred to a taper riser, he meant that a riser of that description was not, in his opinion, a successful proposition, because very often the metal would lie on the face. The size of the necks was a wide question, and depended upon the alloy and the particular conditions and shape of the casting. No one could give particular advice on the matter, but the fettling cost would be considerably decreased through adopting such a riser and narrowing the neck. The reason was that the neck became so hot that it approximated the same temperature as the metal itself, and the sand forming the neck retained the heat.

Reducing Remelting Costs

Mr. White remarked that the point he wished to emphasise was that of reducing the cost of the actual casting by minimising the amount of metal, because it all required remelting. He thought it was a point worth consideration.

Mr. Hopwood, agreeing, said it was a question of the shape of a casting. No one could help very much with regard to the actual problem until they saw the casting and the thickness of the particular section it carried. Many castings had risers which were unnecessary. Much riser work could be eliminated by increasing the amount of head pressure. Even manganese bronze castings could be cast without any risers, but with a high head pressure. Castings of even sections which would normally carry a riser equal to their own weight had been cast successfully in manganese bronze by means of high head pressure.

Running Methods

Mr. H. Haynes (Ashton-under-Lyne) referred to the horizontal runners used on the castings, wherein the section of the casting was larger than the down runner. For instance, one slide showed five gates, apparently of greater section than the down runner. It also occurred to him that for running the castings, two down runners would feed better than one large one, which was liable to cause a swirl and take the scum down into the casting. In the case of another illustration, he noticed there was a 2-in. down runner, and he thought the in-gate was $\frac{1}{2}$ in. or $1\frac{1}{2}$ in. He was speaking as an iron founder and was not particularly experienced with regard to brass founding. The thought had occurred to him, why not have a 1-in. down runner supplying two gates, or to have a 2-in. down runner leading to the four gates?

Mr. Hopwood replied that it should be realised the top bush was a standard piece of tackle, and to utilise it the two down runners were taken on to each side of the casting. The size of the intake of the metal was controlled, and no dirt could get into the casting. It was not, as in the case of molten iron, where the metal was usually at a temperature far in excess of its melting point, but one of controlling the running so that metal was introduced much slower. The non-ferrous metals must be quickly and smoothly delivered to the mould.

Pouring Phosphor Bronze Sticks

Mr. F. Andrews (Oldham) asked, if he desired to cast a stick 4 in. dia. in phosphor bronze, having 9.5 per cent. tin and 0.5 per cent. phosphorus for hardness, using a chill mould, would it be advisable to keep the mould vertical or to tilt it? What would be the best dressing?

He was pleased to find that Mr. Hopwood spoke about gas absorption, because too often much was said about oxidised metal when it was actually a case of gas absorption. The trouble was with gas absorption in most cases, and, owing to the gas not escaping, pin-holes were formed in the casting.

Mould Dressing Details

Mr. Hopwood said that quite often mould dressing was over-done. Many people had used dressings, but he had found that keeping the chills at the correct temperature, and maintaining the correct casting temperature, was much more helpful than the use of any fancy dressing. The material which he did use was an ordinary lubricating oil and plumbago dressing. If it was necessary to stiffen it, the introduction of linseed oil on to a hot mould put a hard face on it. Or, if it was necessary to stiffen an ordinary oil dressing, then resin could be used, or else a thicker oil base like lard oil. A thicker oil than a lubricating oil could be used, and one with a little higher flash point.

He would pour the sticks vertically, because not only did the gas from the mould dressing rise more naturally, forming a cushion between the metal and the side of the chill, but metal running on to the bottom chills was more apt to give trouble. If there was a chill on the bottom more care had to be taken than if the same chill was up the side.

Temperature Control

It was possible to cast phosphor bronze sticks in chills at the same temperature as with an ordinary sand mould. This could always be taken as a reliable guide; if there was available experience of casting in sand moulds, then chill casting could be carried out at the same temperature.

Mr. Andrews asked how Mr. Hopwood ascertained whether the temperature of the metal in the furnace was adequate, and did he take the temperature at the furnace?

Mr. Hopwood said that he used an immersion-type pyrometer after withdrawal. It was usual to melt the metal in the furnace until it was thought to be the correct temperature and then withdraw. He must admit that this was not always the best practice, but it was the method which was carried out, due to the liability of damage to the thermocouples.

Mr. Andrews said, in his experience, temperature was taken in the furnace, because it was not desirable to return the crucible through the metal being insufficiently hot.

Mr. Hopwood replied that if a standard alloy was used, the furnacemen became very adroit at judging temperature; in fact, they became too clever and started casting the jobs without taking any temperature test at all. This often led to trouble.

Mr. Sutcliffe, sen., referring to the bush or stick of approximately 4 in. dia., mentioned by Mr. Andrews, asked whether it would answer to cast as with a chill bowl.

Mr. Andrews pointed out that large quantities were called for.

Mr. Sutcliffe, sen., said the job could be made as if it were a chill bowl. By using two necks—one at the top and one at the bottom—the bottom one having a spinning runner, success could be achieved, for the action of the metal entering the mould would result in a spinning effect directed toward the centre.

NAME INDEX

SUBJECT INDEX

Note 1.—If more than one mention is made of a subject during the course of a Paper and/or its discussion, only the first time of mentioning is indicated in the following index. References to the same subject in other Papers or discussions are indicated by an additional page number. Users of the index are advised, therefore, to examine the whole of a Paper and/or discussion to which attention is directed by the index.

Note 2.—References to non-ferrous alloys will be found under the heading ALLOYS, together with references to alloy cast iron. References to Grey Cast Iron will be found under CAST IRON References to cast irons having high physical properties and not containing alloy additions, will be found under the heading HIGH-DUTY CAST IRONS.