

2566/III
LXX

714
P. 99/LXXX

THE JOURNAL OF THE INSTITUTE OF Metals



WITH THE BULLETIN
AND METALLURGICAL ABSTRACTS

Principal Contents:

SYMPOSIUM ON THE CONTROL OF QUALITY IN THE PRODUCTION
OF WROUGHT NON-FERROUS METALS AND ALLOYS.
I.—THE CONTROL OF QUALITY IN MELTING AND CASTING

- 1448. The Principles of Technical Control in Metallurgical Manufac-
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- 1449. The Control of Quality in the Production of Brass Ingots and
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Rolling Slabs and Extrusion Billets. *C. W. Roberts and B. Walters* 365
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for Hot Working. *R. G. Wilkinson and S. B. Hirst* 393

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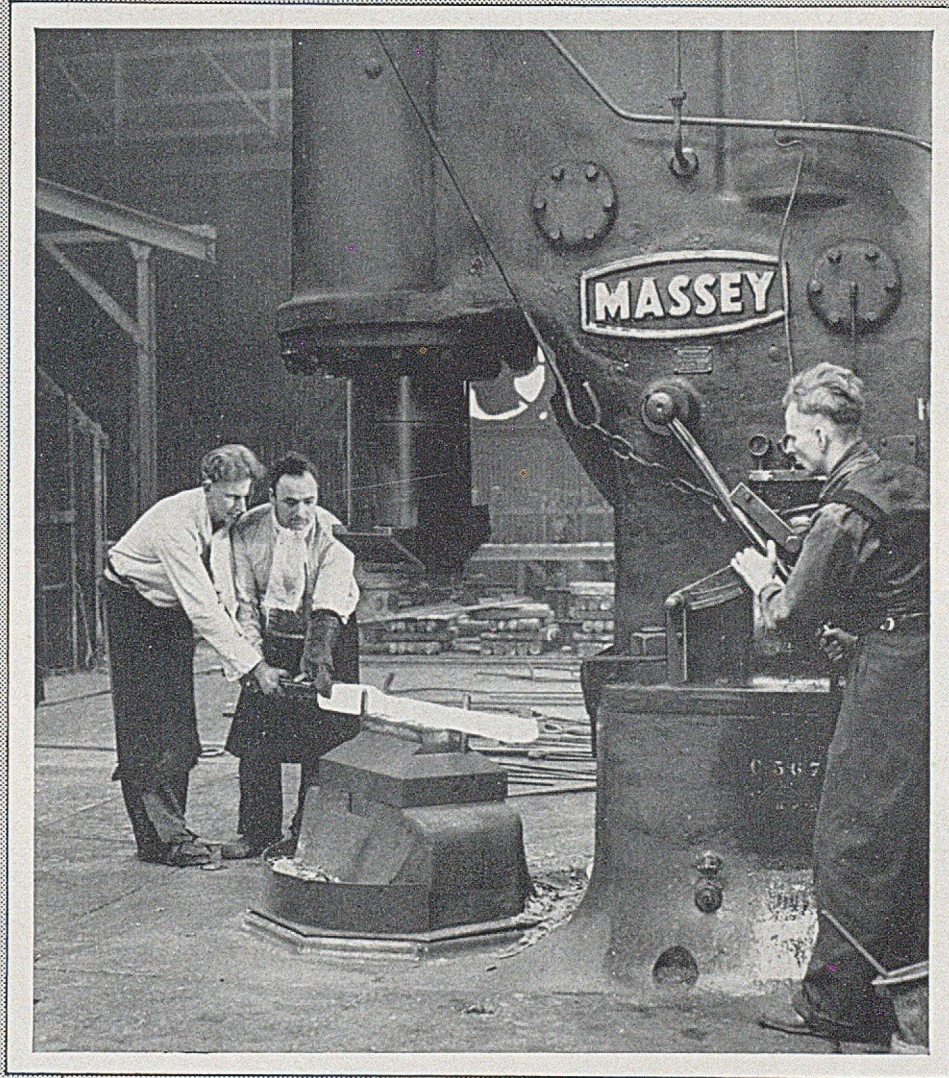
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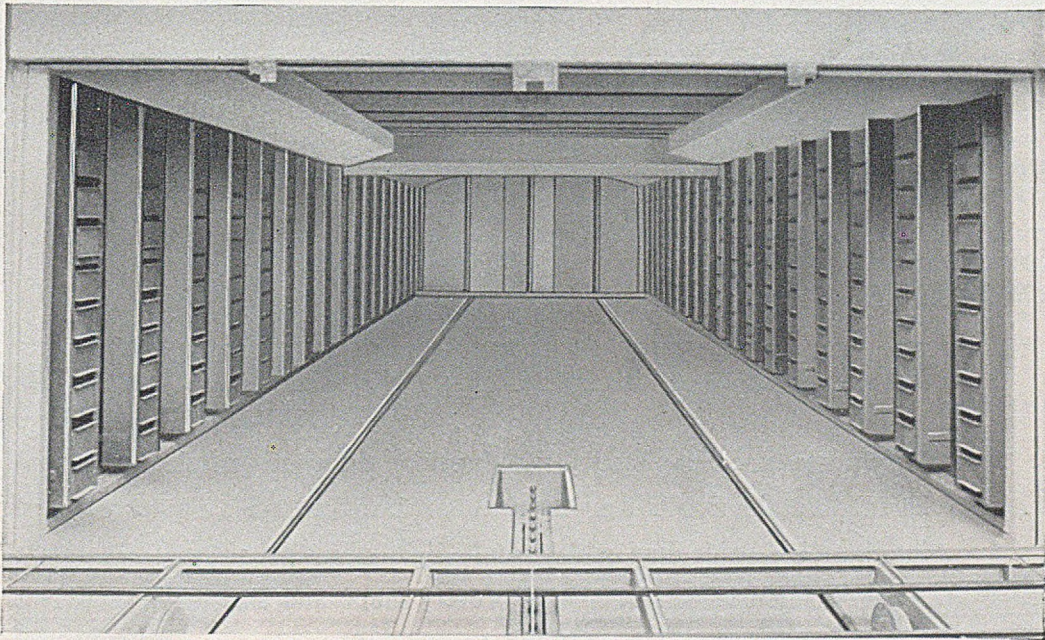
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Illustrated is an ageing oven, supplied to a prominent aircraft manufacturing concern, to take up to 24 feet long light alloy sections and working on the batch principle of operation. The sections are truck-loaded into the oven, the truck running on rails. A centre door, half-way along the chamber, enables the oven to be split into two 12 foot sections, each section having independent temperature control, thus saving electricity costs by using only half the capacity of the unit.

Each half of the oven is provided with its own external heater battery and large volume circulating fan. From the view of the chamber will be seen the series of heater ducts mounted on each side wall. The fans are of the centrifugal type with the impellor shaft mounted in ring oiled bearings, the inner bearing being watercooled. The total rating is 150 kW. Two sets of switchgear and oil circuit breakers are mounted on the outside wall of the oven casing. Each section of the unit is equipped with its own independent dial-type indicating controller.



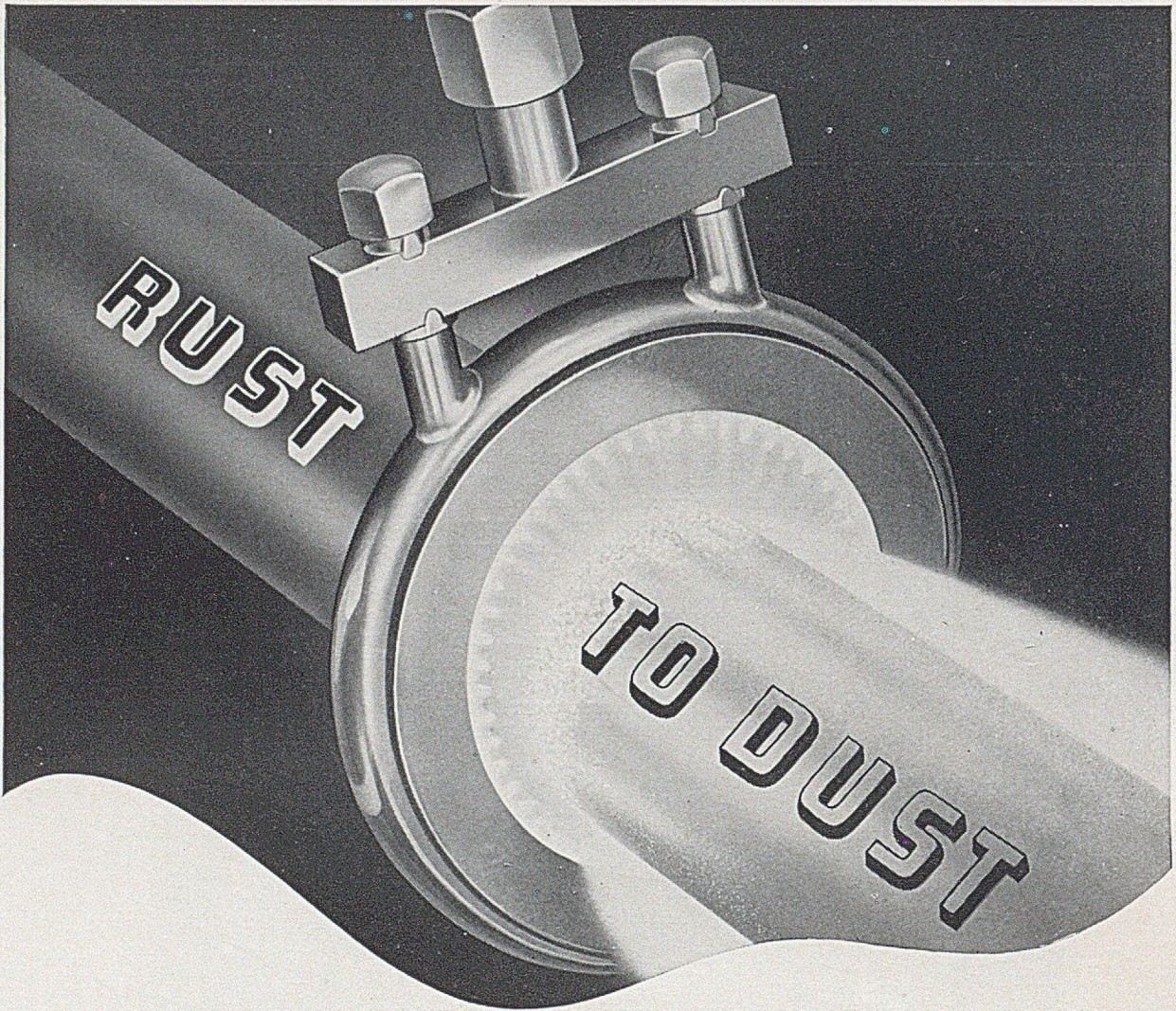
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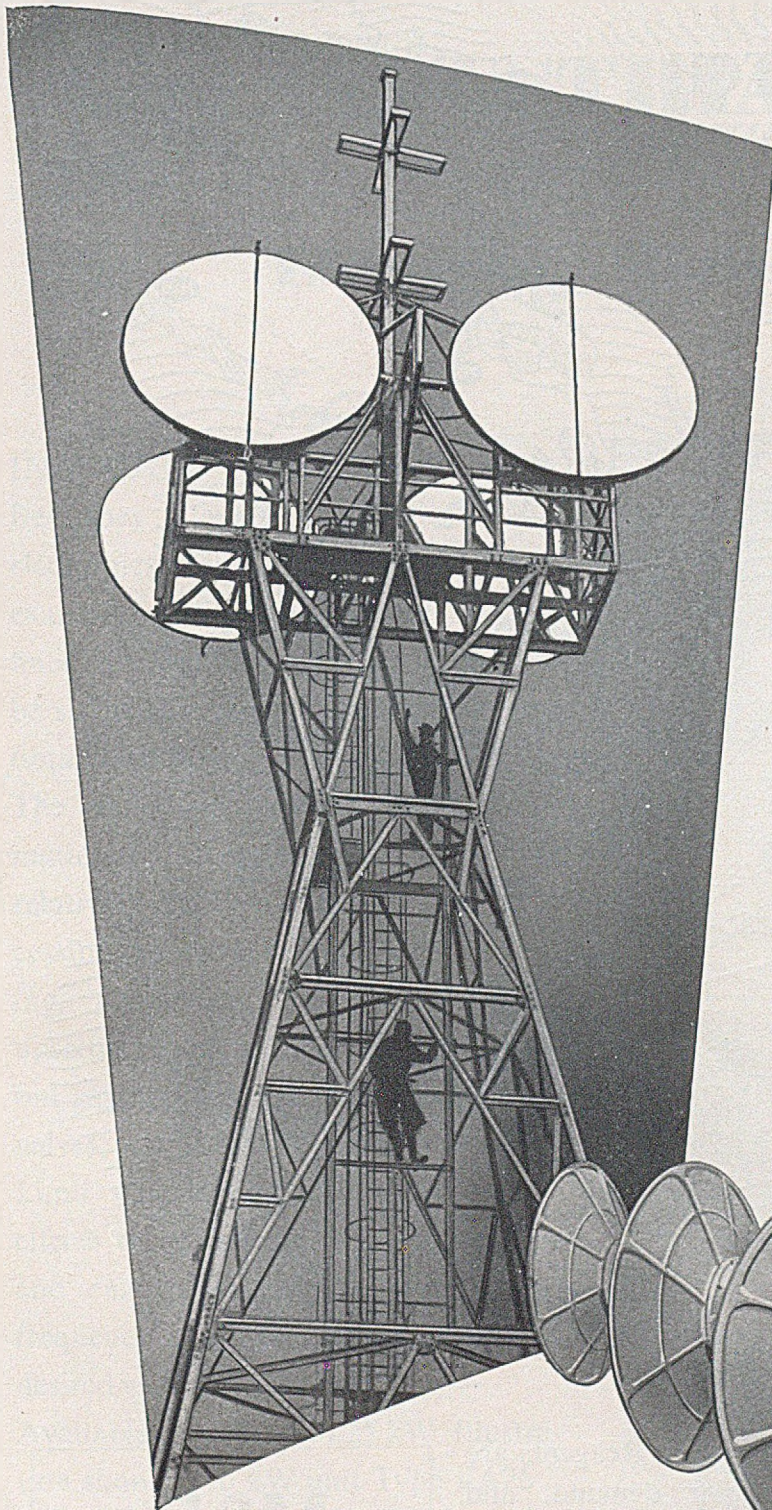
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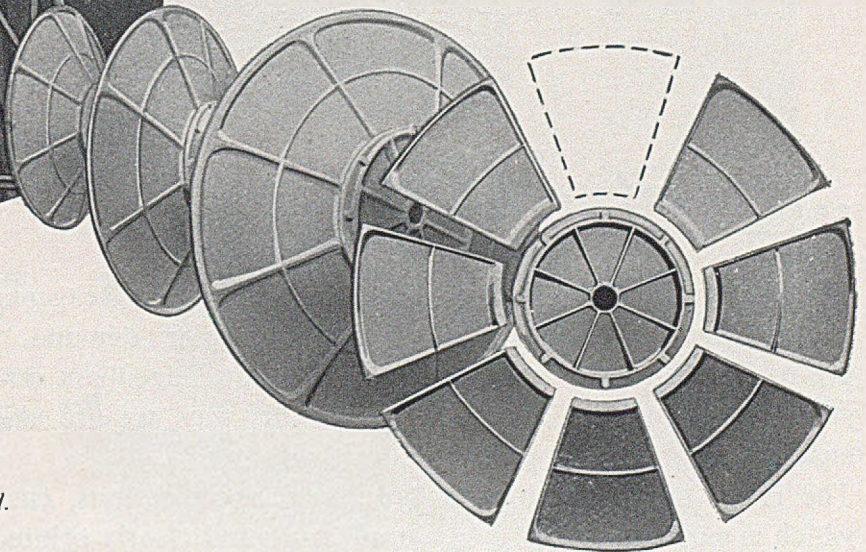


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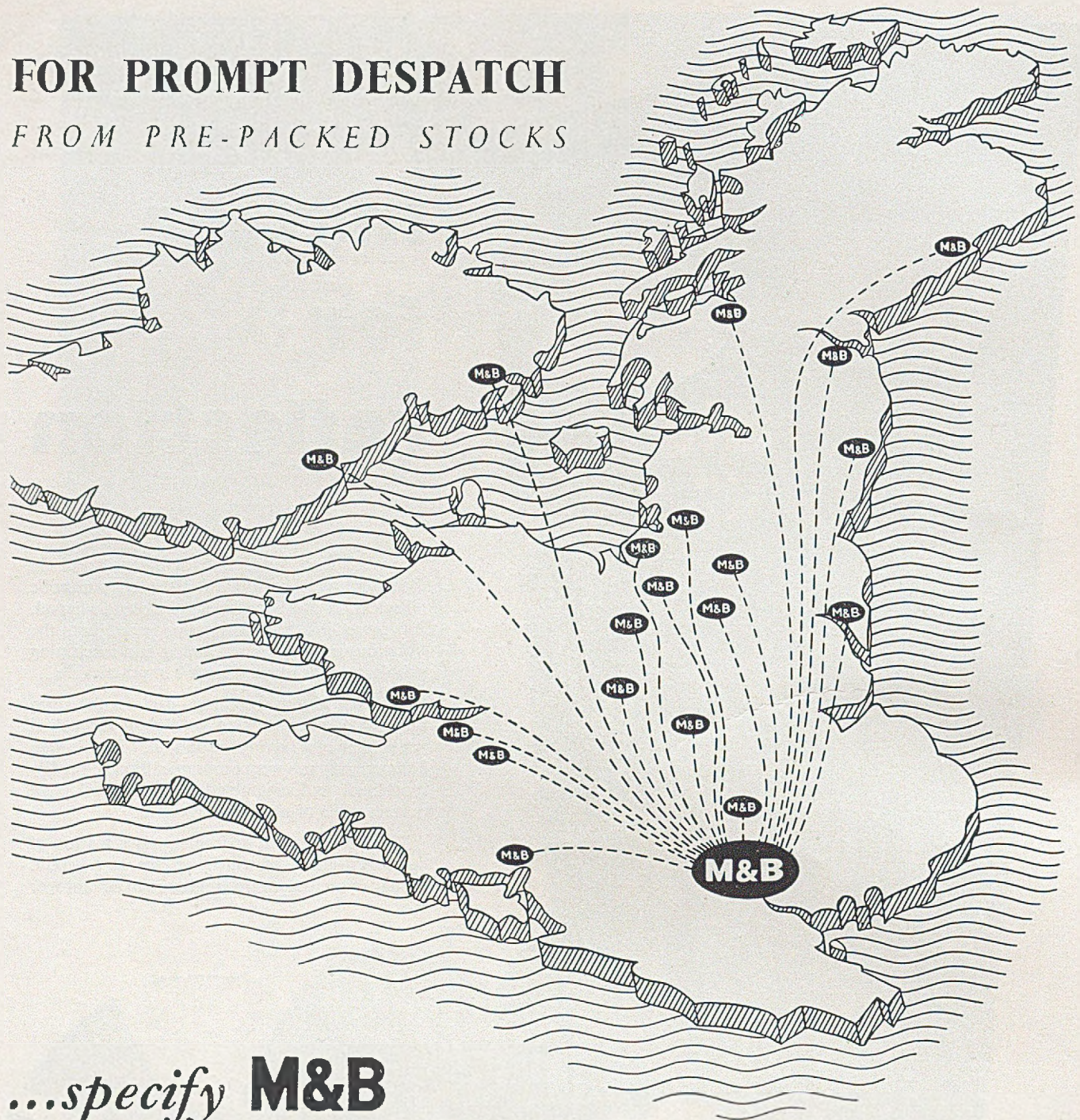
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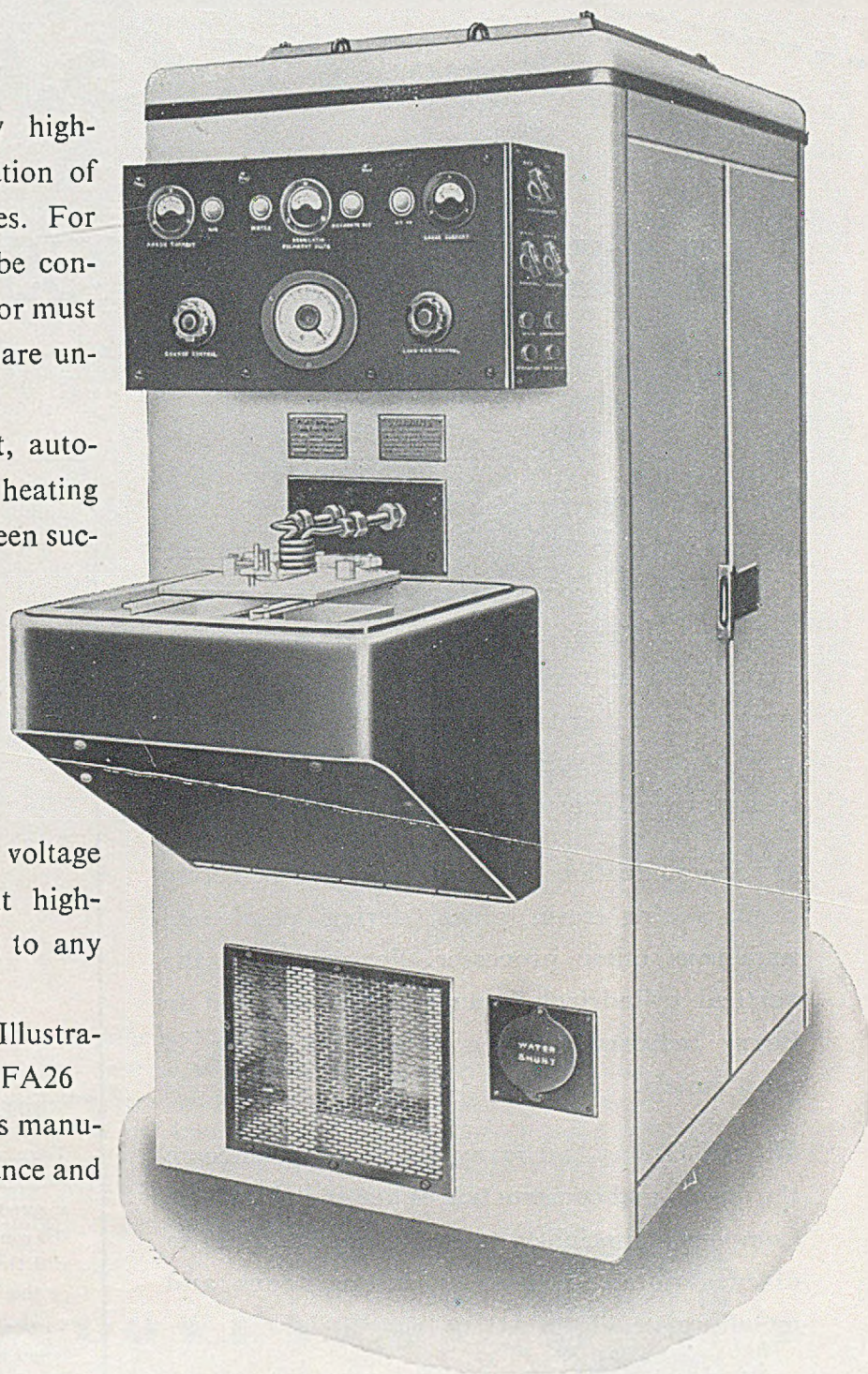
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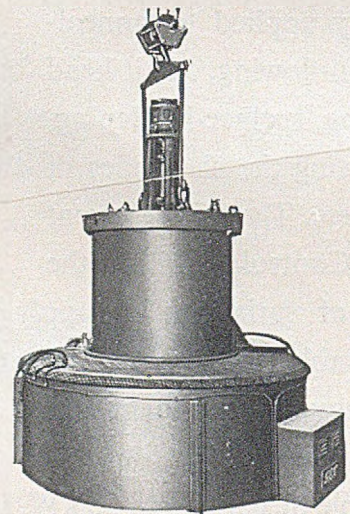
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● Bold thinking about bigger production demands new methods of heat treatment. G.E.C. electric process heating ensures maximum output and true economy. The many heating equipments in its range are clean, safe, simple to operate, and heat rapidly to constant correct and controlled temperature. Its versatility is being proved every day.

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● G.E.C. has had many years' experience in the design and construction of heating plant. The Company's specialists welcome opportunities to discuss potential uses with engineers and metallurgists.

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G.E.C.

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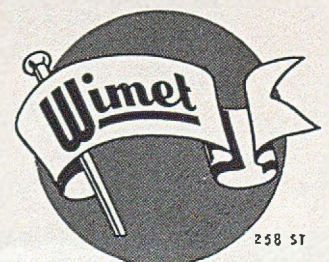
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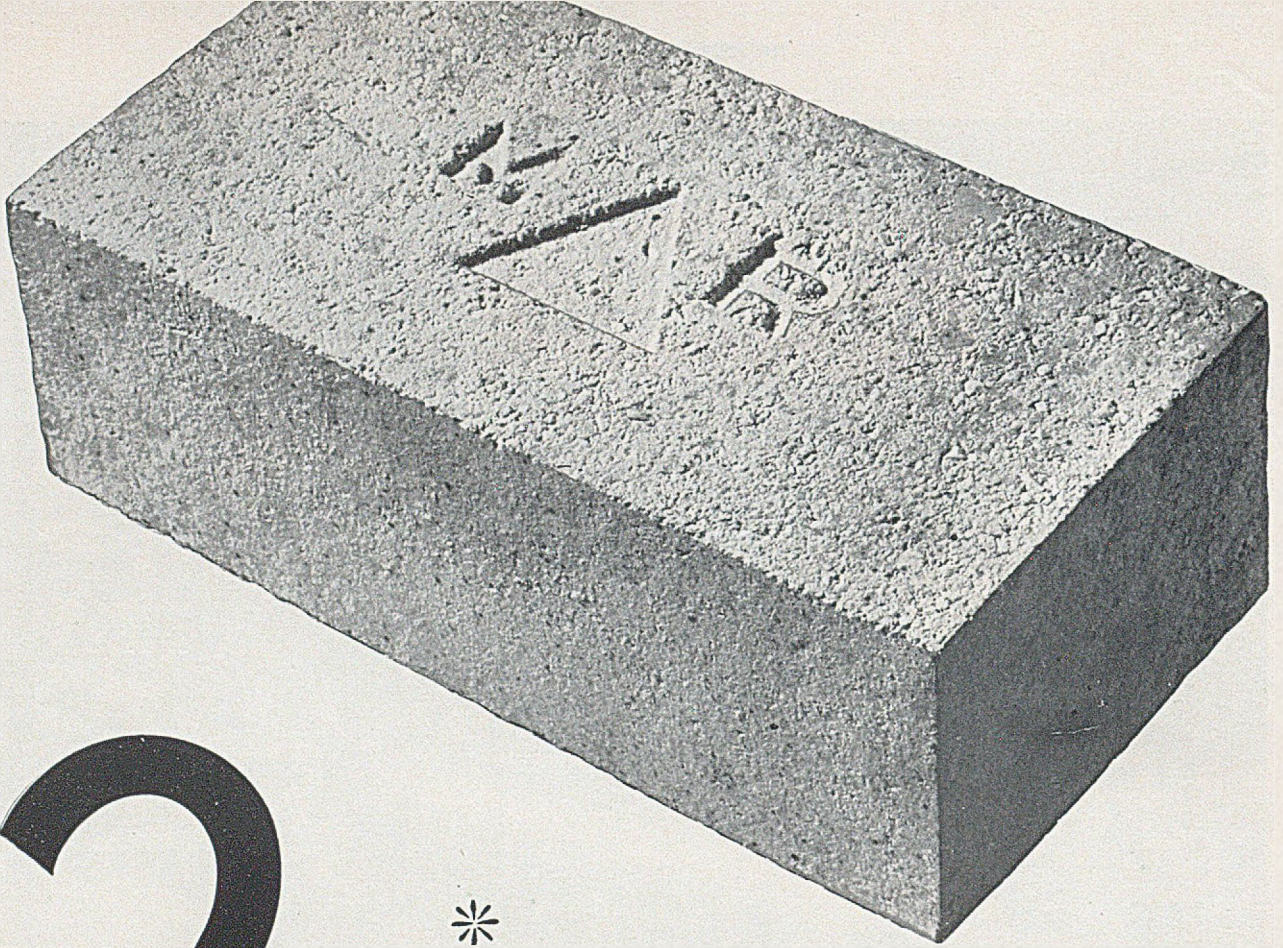
★ **PATTERN
FOR PROSPERITY**

★ The rapid development of aircraft design and the ever more complex equipment which is today becoming commonplace, are making constantly greater demands upon production. Planes are taking more man-hours to build, yet output must be increased. In no other industry, therefore, is the importance of carbide tooling more fully appreciated. Large scale production in the shortest possible time means Wimet tooling to aircraft engineers, because Wimet is usually the answer to the problems they encounter in expanding the output from machine tools.

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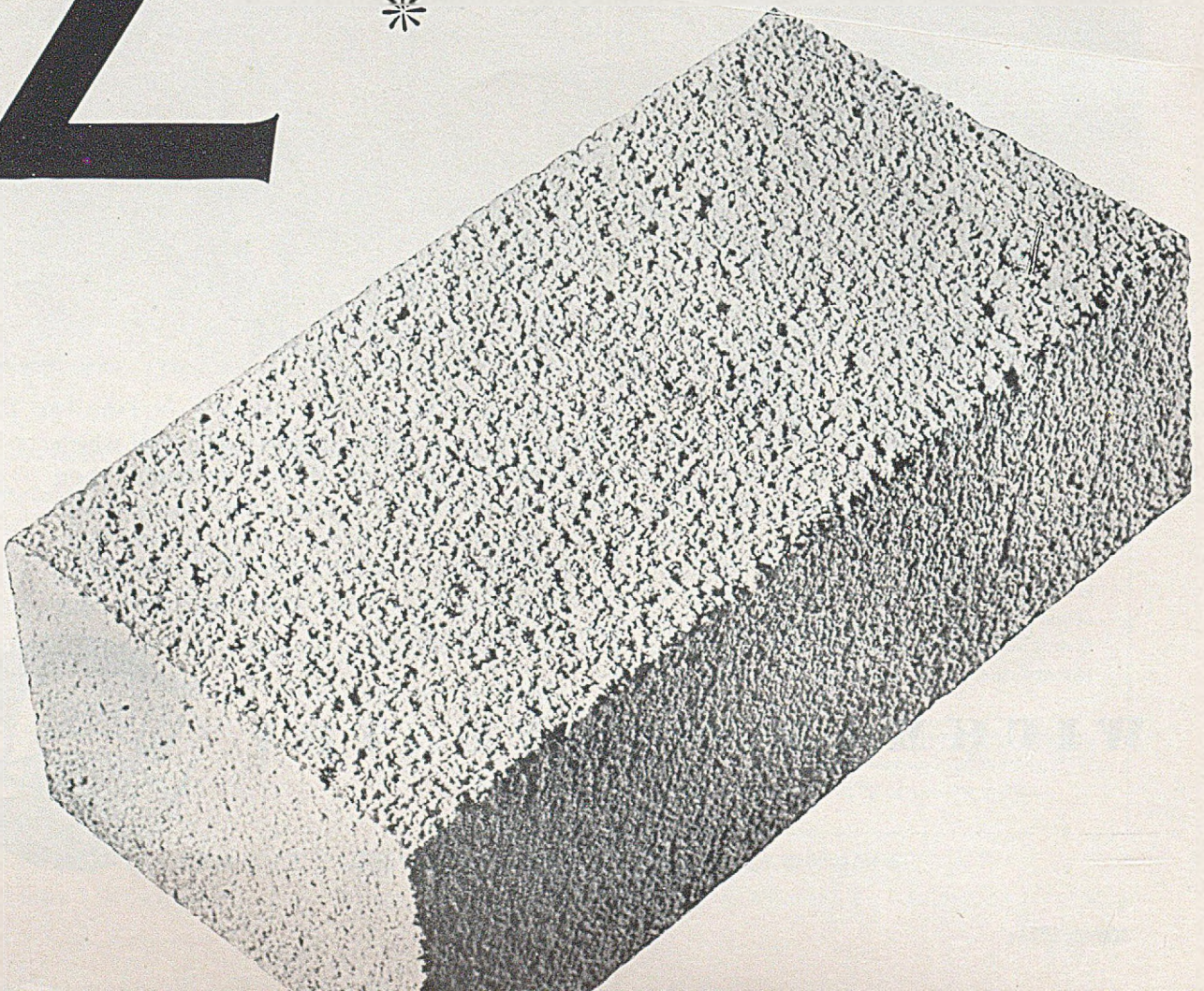
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refractories which may well change the

*



* THE MORGAN M.R.1

—a brick that carries the ordinary high quality firebrick into entirely new fields of usefulness. It can be used, for example, at temperatures as high as 1600°C—far beyond the capacity of other refractories of similar alumina content. In fact, with these bricks, this standard of comparison is no longer valid. They can be judged only on performance and in that they are comparable only with special purpose refractories having a very high alumina content indeed.

How is it done? The answer is in the way they are made: in the selection and purification of the clay; in the unusually hard burning and careful grading of the grog; above all in the very high temperature of the final firing. The manufacturing process is a continuous one—which in itself makes for uniformity—and it is carried out under rigorous quality control.

All this costs money—but consider what its results mean in practice. Remarkable rigidity up to 1600°C; an after-contraction at this temperature of only 1% (The usual temperature for measuring after-contraction is 1410°C); negligible after-contraction below 1600°C. The bricks are close textured and strong, their resistance to abrasion is high; and they have unusually good resistance to both thermal and physical spalling.

Bricks of this type, although not previously manufactured in this country or in Europe, have been in use for some years in the U.S.A. where they have decisively proved their economy in terms of reduced furnace maintenance.

TYPICAL PROPERTIES OF M.R.1			
Approximate Chemical Analysis			Physical Characteristics
Silica	(SiO ₂)	52-53%	Refractoriness ... Cone 35 (1770°C)
Alumina	(Al ₂ O ₃)	43-44%	Refractoriness under load (25 lb./sq.in.):
Iron Oxide	(Fe ₂ O ₃)	less than 1%	Commencement of subsidence 1600°C:
Titanium Oxide	(TiO ₂)	less than 1%	10% subsidence 1700°C
Magnesia	(MgO)	} less than 2%	Bulk density ... 132 - 157 lb./cu.ft.
Lime	(CaO)		After-contraction (2 hrs. 1600°C)
Potash	(K ₂ O)		less than 1.0%
Soda	(Na ₂ O)		Thermal expansion ... 4.5 x 10 ⁻⁶ per °C.

whole conception of furnace maintenance and efficiency

* THE MORGAN LOW STORAGE REFRACTORY M.I.28—a brick that can double furnace output.

It is a hot-face insulating refractory which can be used at furnace (or interface) temperatures up to 2800°F (1538°C).

At these temperatures it has a lower conductivity than any other type of refractory; and therefore provides a greater reduction in the convection and radiation losses from the outside of the furnace. But that is less than half the story: even more important is the reduction in heat storage. The M.I.28 is little more than a third of the weight of an ordinary refractory; consequently only a third of the heat is required to raise the whole of it to the same temperature. But, with the same furnace temperature, the average temperature of an M.I.28 is much lower (owing to its lower conductivity) and this still further reduces the heat it takes up. With the same heat input, therefore, furnaces built from M.I.28 bricks heat up rapidly: on batch furnaces this can amount to a doubling of the furnace output—to say nothing of the saving in fuel. Low conductivity also has a bearing on the effective strength of the brick. For, even when working at high face temperatures, the greater part of the brick is relatively cool. Not only this but their light weight reduces the load on the lower courses and, incidentally, the weight of the whole furnace structure.

There have been hot-face refractories before. What, then, is new about the M.I.28? In theory nothing. Again it is a matter of the way they are made. Morgans have put the whole of the theory into practice. The plant is entirely new in design and operates under rigorous quality control from the purification of the clay to the final grinding to size.

As in the case of the M.R.1, bricks of this quality have been available for some years in the U.S.A. and the improvements they can make in furnace efficiency have been firmly established.

TYPICAL PROPERTIES OF M.I.28	
Maximum Service Temperature ...	1538°C (2800°F)
Thermal Conductivity:	
Mean Temperature	538°C (1000°F) ... 2.4 B.Th.U./hr. (sq.ft.) (in.) (°F)
(temperature at centre of brick)	816°C (1500°F) ... 2.9 B.Th.U./hr. (sq.ft.) (in.) (°F)
Bulk Density ...	less than 47.5 lb./cubic ft.
Refractoriness ...	1710°C (3110°F)
Modulus of Rupture ...	greater than 120 lb./sq. in.
Heat Capacity Factor ...	0.105
(ratio of heat stored in M.I.28 to heat stored in ordinary firebrick with same hot and cold face temperatures)	

MORGAN

Refractories

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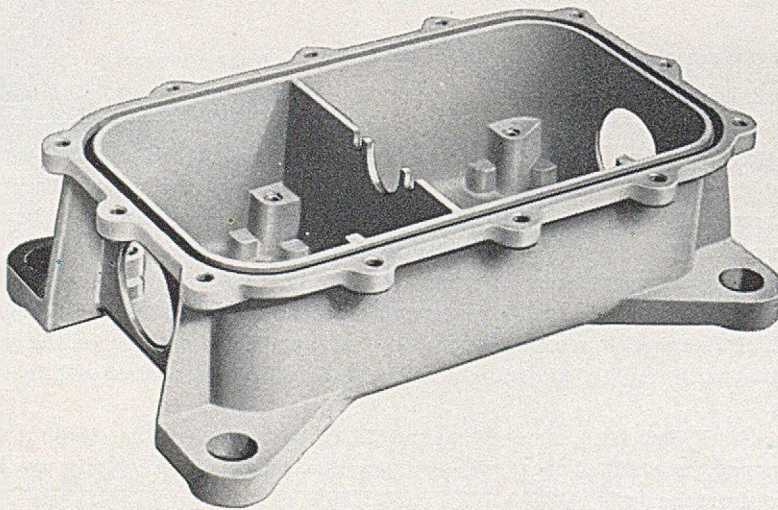
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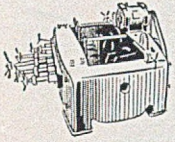
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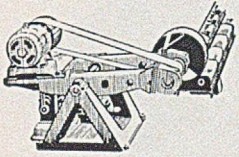
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EQUIPMENT

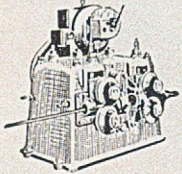
for the Tube Industry



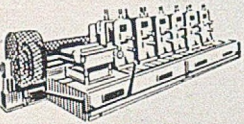
High Speed Tube Straighteners—for ferrous and non-ferrous tube $\frac{1}{4}$ " up to 18" diameter with non-adjustable or adjustable angle driving rolls.



Tube Saws—High Speed Rocking type Saws and Flying Saws.



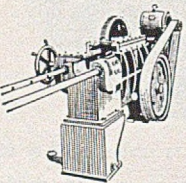
Close Joint Tube Forming Machines in three sizes from $\frac{1}{2}$ " to 5" diameter tube.



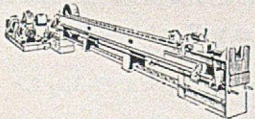
Tube Forming and Welding Equipment—for the production of close joint or welded tube from $\frac{1}{2}$ " to 6" diameter—with Sizing and Cutting-to-length Equipment.



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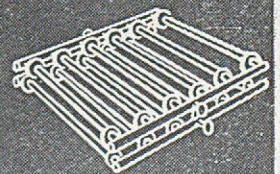
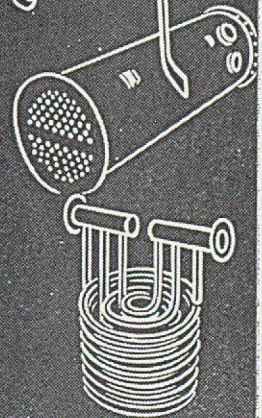
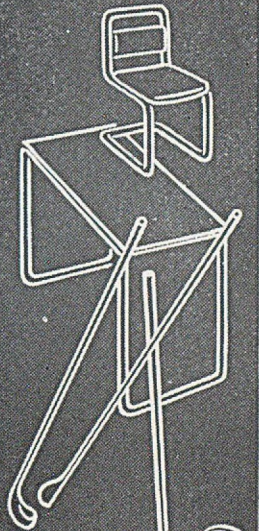
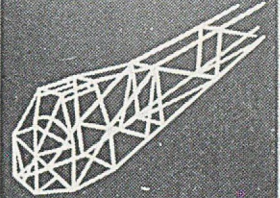


Expanding and Reducing Machines in sizes to handle from $\frac{1}{2}$ " to 6" diameter tube.

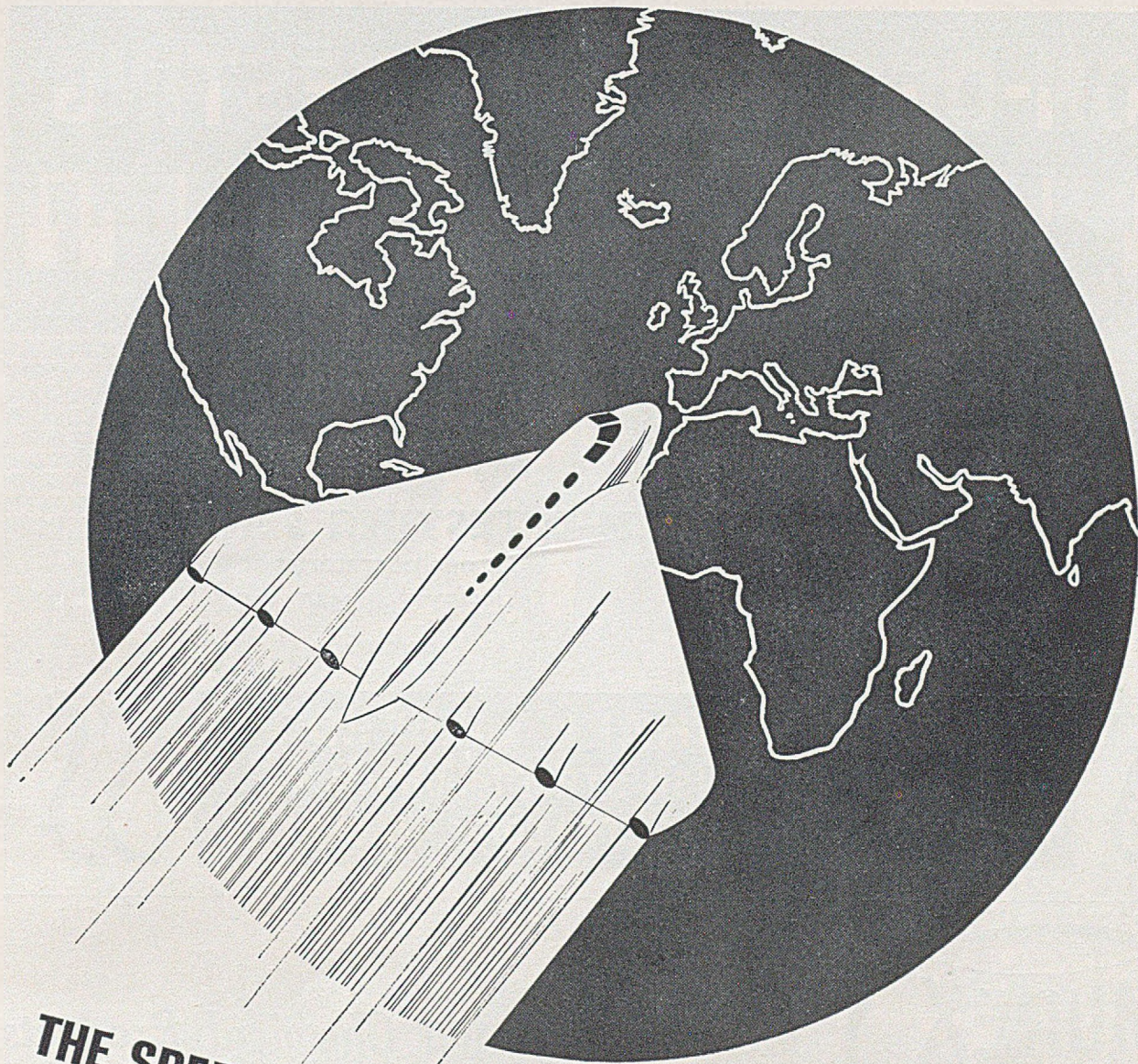


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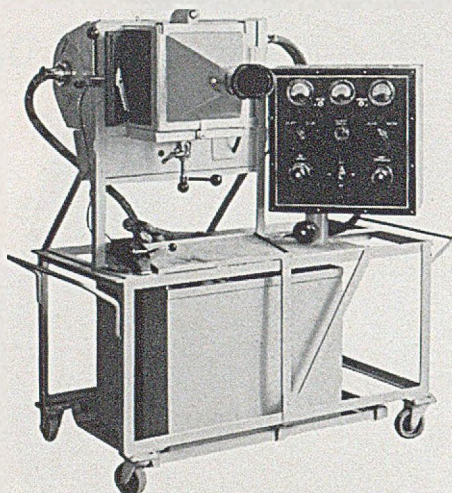
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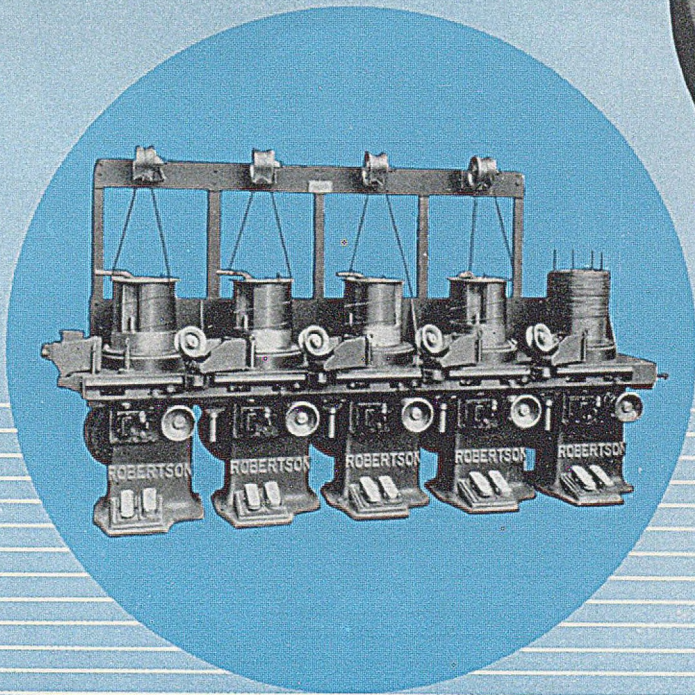
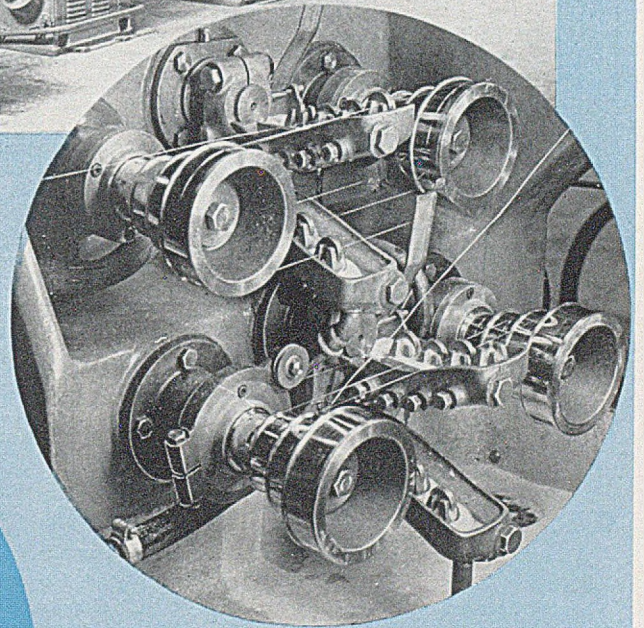
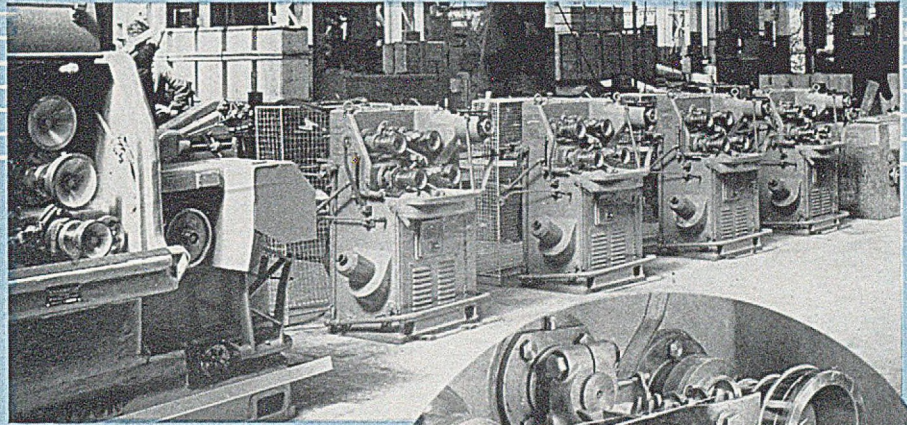
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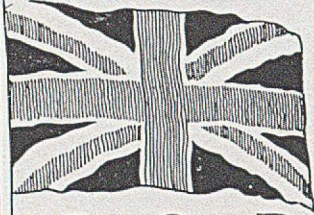
TYPICAL
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of
WIRE
DRAWING
MACHINES



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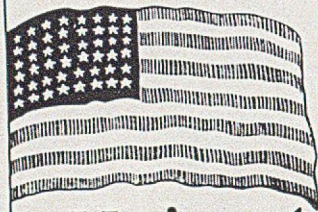


COPPER



1783

in British



History

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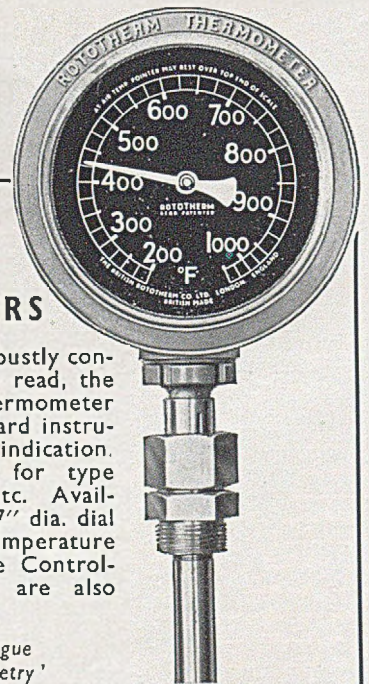
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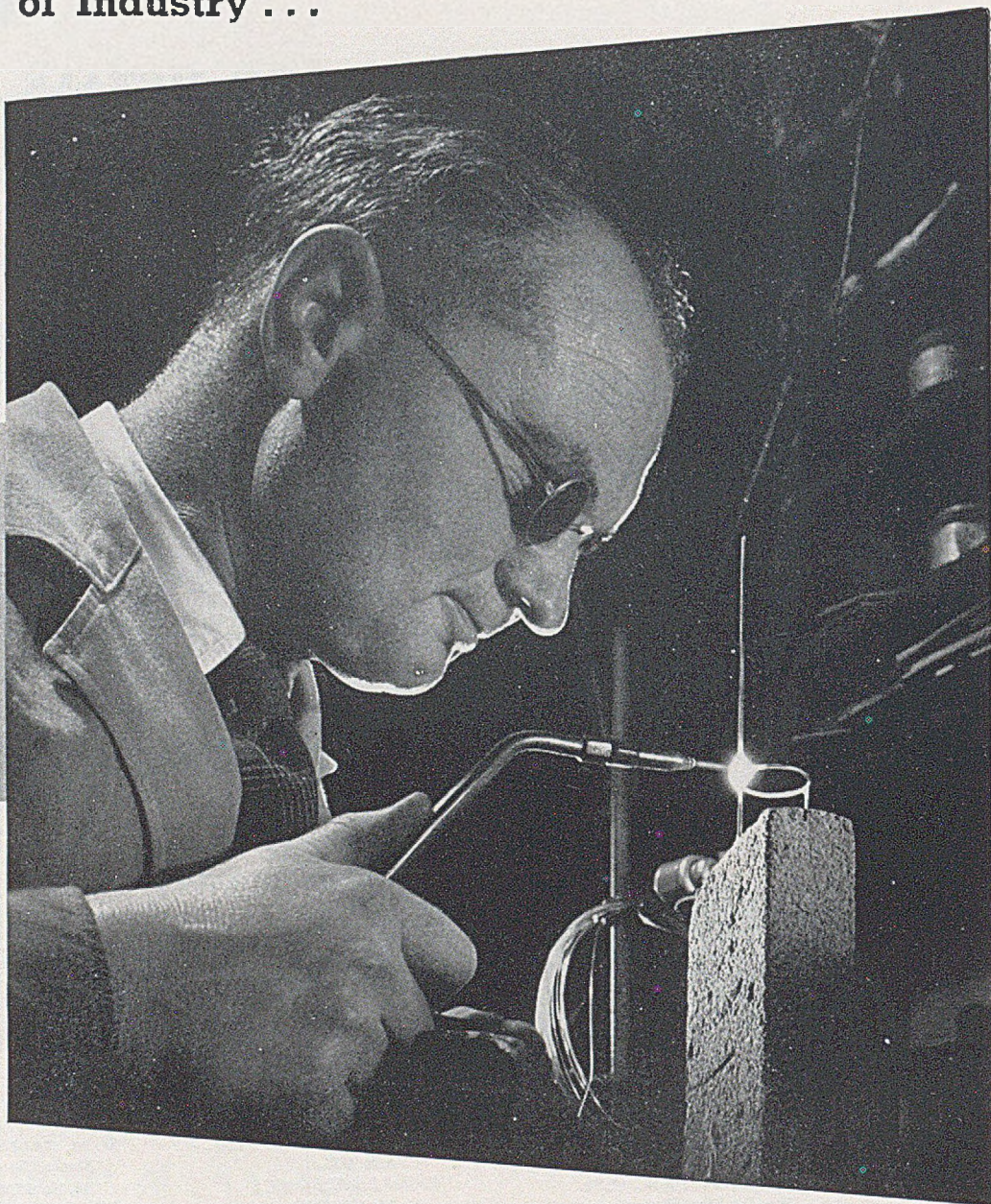
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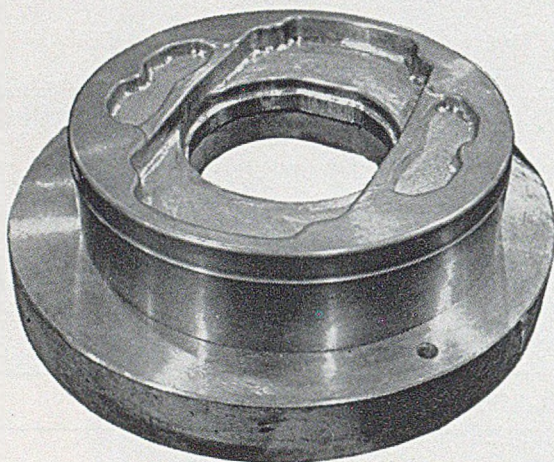
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BULLETIN

OF THE INSTITUTE OF METALS

VOLUME I

MARCH 1953

PART 19

INSTITUTE NEWS

Discussion on Liquid Metals

As announced in the programme of the Annual General Meeting (January *Bulletin*, pp. 133-135), the Metal Physics Committee is arranging a discussion on "Liquid Metals" on the morning of Thursday, 26 March, at the Park Lane Hotel, Piccadilly, London, W.1.

The Committee desires the discussion to be informal in character, and those taking part are therefore asked not to speak for more than five minutes. Apart from two introductory addresses, the reading of prepared contributions will not be permitted.

Dr. B. R. T. FROST, of the Atomic Energy Research Establishment, Harwell, and Dr. V. KONDIC, of the Industrial Metallurgy Department, Birmingham University, have been invited to open the discussion with introductory surveys of the subject, and synopses of their contributions are being inserted in this issue of the *Journal*.

Election of Members

The following 8 Ordinary Members, 1 Junior Member, and 3 Student Members were elected on 15 January 1953:

As Ordinary Members

- BROWN, Arthur F., M.A., Ph.D., Lecturer, Natural Philosophy Department, University of Edinburgh.
- CHETTIAR, P. S. N. S. Ambalavana, Managing Director, P. S. N. S. Ambalavana Chettiar and Co., Ltd., 260 Angappa Naicken Street, Madras 1, India.
- EISNER, Frederick, Ph.D., Director, Electro-Chemical Research Laboratories, Ltd., 33 Knox Street, London, W.1.
- FAIRHOLME, Ian William Forbes, General Works Manager, Richard Johnson and Nephew, Ltd., Manchester 11.
- FRENAY, Professor Eugène L. J., Professeur de Métallurgie des Métaux autres que le Fer, Université de Liège, Belgium.
- PEARCE, Sidney Cecil, A.R.S.M., B.Sc., A.I.M., Metallurgist, H. J. Enthoven and Sons, Ltd., London, E.C.4.
- PIETSCH, Professor Erich, Direktor, Gmelin-Institut für anorganische Chemie und Grenzgebiete in der Max-Planck-Gesellschaft zur Förderung der Wissenschaften, Altenauer Str. 24, Clausthal-Zellerfeld (Harz), Germany.
- POLAKOWSKI, Natalis Horacy, Dipl.Ing., Ph.D., I.C.I. Research Fellow, University College, Swansea.

As Junior Member

- KIRBY, Patrick Charles, B.Sc., Metallurgist, J. Stone and Co. (Charlton), Ltd., London, S.E.7.

As Student Members

- ATKINSON, Raymond Frederick, Student of Metallurgy, University of Manchester.
- NIELD, Bernard John, B.Met., Research Student, Department of Metallurgy, University of Sheffield.
- SMITH, John Edward Martin, Assistant Foundry Metallurgist, Blackstone and Co., Ltd., Rutland Engineering Works, Stamford, Lincs.

NEW OFFICERS

Below are given some biographical details of members who take office as President, Vice-Presidents, and Ordinary Members of Council at the Annual General Meeting on 24 March.

Professor F. C. Thompson (President)

Frank Charles Thompson was educated at the Sheffield Royal Grammar School and King Edward VII School in the same city. Entering the Metallurgical Department of



the University of Sheffield in 1908, he graduated in 1911, being awarded the Mappin Medal. After spending a year taking further courses in pure science, he obtained a London

NEW OFFICERS

B.Sc. in 1912, and in that year was appointed to Professor Arnold's staff in the University of Sheffield, where he assisted with the teaching of metallography. During the 1914-18 war he served with the R.A.M.C. as an X-ray operator and as a part-time inspector of cupro-nickel for the Ministry of Munitions. For a short time he was with the Mechanical Warfare Department, in charge of specifications for tank armour.

In 1920 he was appointed Sorby Research Fellow and worked in the University of Sheffield on the etching properties of the carbides in alloy steels and the abnormal change points in iron below the carbon change point. After assisting as a part-time lecturer in the Metallurgical Department of the University of Manchester, he was appointed to the Chair of Metallurgy in 1921.

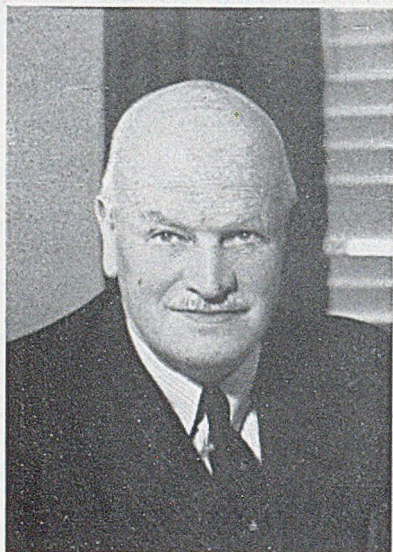
His research interests have centred mainly around problems dealing with stress effects in metals, particularly with the drawing of wire, and, in more recent years, with the measurement of creep and damping capacity. A number of papers on these subjects have been published in the *Journal*. He has served as President of the Institute of Welding.

He was elected a member of the Institute of Metals in 1917, and has served as an Ordinary Member of Council from 1924 to 1931 and again from 1946 to 1950, and as Vice-President from 1950 to 1953.

Major C. J. P. Ball (Vice-President)

Charles James Prior Ball was born in 1893 at Cowes, Isle of Wight, and was educated at Charterhouse and University College, London.

During the 1914/18 War he was commissioned into the Royal Artillery, and took part in the landing at Cape Helles, Gallipoli, on 25 April 1915, with the 15th Brigade, R.H.A. Commanding first "B" Battery R.H.A., and later the 460th Howitzer Battery, he served with this Brigade in all its operations in Sinai, France, Belgium, and the march into



Germany. He was mentioned in Dispatches three times, and awarded the D.S.O. and M.C.

After serving in Germany with the British Army of Occupation and the Military Inter-Allied Commission of Control, he retired from the Army in June 1923 to join F. A. Hughes and Co., Ltd., as Managing Director, where he became

closely identified with the development of the use of magnesium metal, both at home and abroad.

When F. A. Hughes and Co., Ltd., became a fully owned subsidiary of The Distillers Co., Ltd., in 1946, Major Ball was invited to join the Board of that Company, being appointed to the Management Committee in 1948. He is also Chairman and Managing Director of Magnesium Elektron, Ltd., and Chairman of British Resin Products, Ltd., as well as a Director of several other Companies in the D.C.L. Group, and of Sterling Metals, Ltd., Coventry.

Major Ball's main interest in metals is with magnesium, and for the last thirty years he has been working to spread the use of this indigenous material. He is the author of a number of publications on magnesium and its alloys.

Major Ball was elected a Member of the Institute of Metals in 1937, and served as a Member of Council from 1945 to 1949, and as a Vice-President from 1949 to 1952. He was Chairman of the Finance and General Purposes Committee from 1948 to 1952.

He is a Fellow of the Royal Aeronautical Society.

Professor G. V. Raynor (Vice-President)

Geoffrey Vincent Raynor was educated at Nottingham High School and Keble College, Oxford.



At Oxford he obtained a First Class in the Honour School of Natural Science (Chemistry) and qualified for the degree of B.Sc. in 1936. From 1936 to 1944 he carried out research work, mainly on the constitution of copper, magnesium, and aluminium alloys, in the Inorganic Chemistry Laboratory at Oxford, and obtained the degree of D.Phil. early in 1939. He received a Department of Scientific and Industrial Research Senior Research Award in 1938.

In 1944, Dr. Raynor was appointed to an Imperial Chemical Industries Research Fellowship in Metallurgy at Birmingham University and took up his duties there in January 1945. He continued with research on problems related to the constitution of alloys, and was appointed to a Senior Lectureship in Metallurgy in March 1947, and to the Readership in Theoretical Metallurgy in the autumn of the same year. He received a Beilby Memorial Award in 1947, and was awarded the degree of D.Sc. of Oxford University in the following year. His appointment as Professor of Metal Physics at Birmingham University was made in 1949, and he received the Institute's Rosenhain Medal in 1951.

NEW OFFICERS

For the academic year 1951-52, Dr. Raynor was Visiting Professor of Metallurgy at the Institute for the Study of Metals, Chicago University, and lectured there and at other metallurgical centres in the U.S.A. and Canada. He delivered the R. S. Williams Lectures at the Massachusetts Institute of Technology in 1951.

Professor Raynor has published several papers, in collaboration with colleagues and research students, on the theories and properties of alloys, and is the author of "An Introduction to the Electron Theory of Metals" (Institute of Metals Monograph and Report Series No. 4), which is in its second printing.

He is a Fellow of the Royal Institute of Chemistry, a Fellow of the Institute of Physics, an Associate of the Institution of Metallurgists, a Fellow of the Royal Society of Arts, and a Member of the Iron and Steel Institute. He joined the Institute of Metals in 1936, and has served as a Member of Council since 1949. He has also been a member of the Metal Physics Committee and of the Publication Committee.

Mr. W. A. Baker (Ordinary Member of Council)

William Albert Baker joined the staff of the Assay Office, Royal Mint, London, as a student assistant, and graduated in metallurgy at the University of London as an external student in 1934.



Shortly afterwards he went as an investigator to the British Non-Ferrous Metals Research Association, where he was engaged mainly on problems connected with the melting, casting, and welding of non-ferrous metals, on which subjects he has published numerous papers in the Institute's *Journal* and elsewhere. He is now Research Manager of the British Non-Ferrous Metals Research Association.

He is a Member of Council and of several Committees of the Institution of Metallurgists, and represents the Institute of Metals on the Board of Governors of *Acta Metallurgica*.

Mr. J. C. Colquhoun (Ordinary Member of Council)

James Clifton Colquhoun was born in 1893 in Clifton, Arizona, U.S.A., where his father, James Colquhoun, at that time was President of the Scottish-owned Arizona Copper Company, later acquired by the Phelps Dodge Corporation. His education at Trinity College, Glenalmond, and at Caius College, Cambridge, where he was reading for a Natural Science Tripos, was interrupted by World War I.



After that war and a brief spell back in the copper smelters of Arizona, for educational purposes, he studied metallurgy at the Royal School of Mines, London, until offered a position by Sir Cecil L. Budd, K.B.E., then Joint Managing Director of The British Metal Corporation. His business appointments since have been entirely with companies in which The British Metal Corporation held an interest, namely: Messrs. Vivian, Younger and Bond, Ltd., as Director; The Cornish Tin Smelting Co., Ltd., as Director and Local Manager; The Manganese Bronze and Brass Co., Ltd., of which he is the present Chairman and Managing Director; The Green-side Lead Mine on Lake Ullswater, as Director and Chairman for a time during the last war; and Lightalloys, Ltd., of which he is Chairman.

Mr. Colquhoun joined the Institute in 1924.

Mr. E. R. Gadd (Ordinary Member of Council)

Ernest Reginald Gadd was born in 1902 and educated at Rutlish Science School. He entered the Royal Aircraft Establishment, Farnborough, in 1918, and there underwent



PERSONAL NOTES

five years' training in metallurgy. In 1923 he joined the Bristol Aeroplane Co., Ltd., Engine Division, as assistant to the Chief Metallurgist. He succeeded to the post of Chief Metallurgist in 1930 and still holds the position.

During the last war Mr. Gadd served as an Aircraft Industry Representative on the Technical Advisory Committee of the Iron and Steel Control. He is a member of the Society of British Aircraft Constructors' Standing Committee on Materials, and is Deputy Chairman of its Metallic Materials Panel.

Mr. Gadd has been a member of the Institute since 1930, and has served on its Publication Committee for the last three years. He is also a Fellow of the Institution of Metallurgists.

The Hon. John Grimston (Ordinary Member of Council)

John Grimston was born in 1912 and educated at Oundle and Christ Church, Oxford. In 1936 he joined Enfield Zinc Products, Ltd., and in 1938 Enfield Rolling Mills, Ltd., of which he is now Director and General Manager.



During the last war Mr. Grimston served as a pilot in Coastal Command. From 1943 to 1945 and again since 1950, he has represented the St. Albans division of Hertfordshire in Parliament.

Mr. Grimston has been a member of the Executive of the Cold Rolled Brass and Copper Association since 1946 and a member of the Executive of the British Non-Ferrous Metals Federation since 1950. He joined the Institute in 1949.

PERSONAL NOTES

SIR CLIVE BAILLIEU received a barony in the New Year Honours List.

PROFESSOR P. G. BASTIEN has been awarded the V. Noury Prize of the Institut de France for his contributions to metallographic research.

MR. P. BROCK has been awarded the Ph.D. degree of Sheffield University and is now on the staff of the British Non-Ferrous Metals Research Association.

MR. R. D. CARTER has left the Plessey Co., Ltd., to take up an appointment with British Insulated Callender's Cables, Ltd., Shepherd's Bush, London.

MR. G. T. COLEGATE has been transferred from the Shell Petroleum Co., Ltd., to Shell Venezuelan Oil Concessions, Ltd., and has recently left England for Venezuela.

MR. D. K. COUTTS has been appointed Assistant Manager of the Technical Office of The Mond Nickel Co., Ltd., in Bombay.

MR. B. G. DAVIES has been awarded the Ph.D. degree of the University of Wales.

PROFESSOR E. HOUDREMONT has been awarded the honorary degree of Dr.Ing. of the Technische Hochschule, Berlin-Charlottenburg.

DR. D. E. R. HUGHES has left Tube Investments, Ltd., to take an appointment in the G.K.N. Group Research Laboratories, Wolverhampton.

MR. WILLIAM E. KUHN has left Titanium Alloy Manufacturing Co. and is now with The Carborundum Metals Co., Niagara Falls, N.Y.

DR. A. LATIN has left British Insulated Callender's Cables, Ltd., to take up the post of Head of the Department of Metallurgy and Chemistry at the National Coal Board Central Research Department II, Isleworth, Middlesex.

PROFESSOR G. MASING has been made an honorary doctor (Dr.Ing.c.h.) of the Technische Hochschule, Berlin-Charlottenburg.

MR. N. H. MOSELEY has left The Mint Birmingham, Ltd., to take up the position of Metallurgist and Foundry Manager to Albert G. Sims, Ltd., 241 Roden Street, West Melbourne C3, Vic., Australia.

MR. G. MURFITT has been appointed a Director of Metals and Methods, Ltd., Langley, Bucks.

MR. F. R. N. NABARRO has been awarded the degree of D.Sc. of Birmingham University.

MR. L. POWELL has been transferred from the Alkali Division to the Nobel Division of Imperial Chemical Industries, Ltd., to take charge of a newly formed section dealing with materials of construction. His address is now Research Department, Imperial Chemical Industries, Ltd., Nobel Division, Stevenston, Ayrshire.

MR. K. SACHS has left The Mond Nickel Co., Ltd., and joined the staff of the G.K.N. Group Research Laboratory, Wolverhampton.

MR. G. SLATTERY has left the A.E.I. Research Laboratories, Aldermaston, and taken up an appointment as Scientific Officer in the Ministry of Supply, Division of Atomic Energy, Springfields, near Preston.

MR. C. B. SNODGRASS, General Manager of Fusarc, Ltd., Gateshead, has been appointed Director and General Manager of the Company.

MR. J. E. SRAWLEY has recently joined the staff of the British Columbia Research Council, Vancouver.

MR. P. H. TORTISE has left James Booth and Co., Ltd., to take up an appointment as Assistant Works Chemist with Denbro, Ltd., Handsworth, Birmingham.

DR. R. F. TYLECOTE has been appointed a Lecturer in Metallurgy at King's College, Newcastle-upon-Tyne.

LETTER TO THE EDITOR

MR. J. WILKINSON, Director and Chief Metallurgist of The Yorkshire Copper Works, Ltd., has been awarded an honorary M.Sc. degree by Leeds University.

PROFESSOR A. B. WINTERBOTTOM, formerly at the Metallurgisk Institutt, Norges Tekniske Hogskole, Trondheim, has accepted a post in Pakistan under the auspices of U.N.E.S.C.O. and his address is now: Department of Metallurgy, University of Dacca, Dacca, East Pakistan.

Death

The Editor regrets to announce the death of:

SIR JAMES WEIR FRENCH on 14 January, formerly Chairman of Barr and Stroud, Ltd., Glasgow. He had been a member of the Institute since 1939.

LETTER TO THE EDITOR

Stress-Cracking of Copper by Mercury

The view seems to be generally held that whereas stressed brass is susceptible to intercrystalline cracking by mercury, copper is immune. For example, Edmunds¹ states that copper is immune to mercury and ammonia stress-cracking. Robertson² is more positive. He says: "Copper is not susceptible to mercury cracking, because the equilibrium dihedral angle formed at the grain boundaries in contact with mercury is such that penetration is impossible".

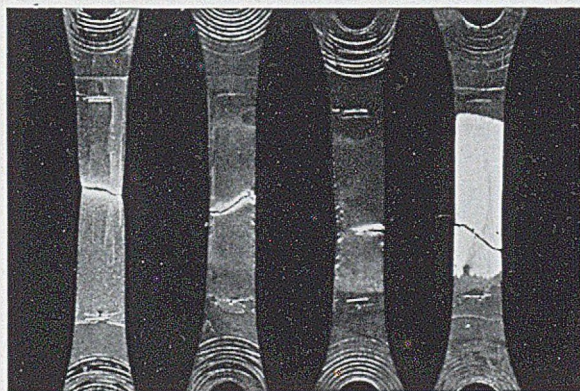


FIG. 1.—Tough-pitch Copper.

Without mercury (a); with mercury, strained at 1000 (b), 40 (c), and 0.2 (d) %/hr.

TABLE I.—Influence of Rate of Strain and Mercury on the Mechanical Properties of Tough-Pitch Copper (Mean Grain Dia. 0.03 mm.).

Rate of Strain, %/hr.	Max. Stress, lb./in. ²	Elongation % on 1 in. (at fracture or cracking)
0.2	28,000	34.5
40	28,600	36
1000	31,500	44
40 (without Hg)	28,800	50

TABLE II.—Influence of Rate of Strain and Mercury on the Mechanical Properties of O.F.H.C. Copper (Mean Grain Dia. 0.10 mm.).

Rate of Strain, %/hr.	Max. Stress, lb./in. ²	Elongation % on 1 in. (at fracture or cracking)
0.2	27,000	20
40	25,400	22
1000	29,000	30
40 (without Hg)	27,600	42

"dry". At the end of the experiment the existence of a second solid phase on the surface was confirmed by X-ray diffraction.

A control test without mercury was carried out at the inter-

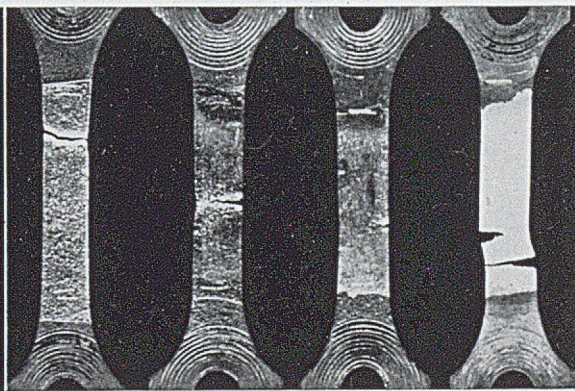


FIG. 2.—O.F.H.C. Copper.

During an investigation of the influence of mercury on 70:30 brass subjected to varying rates of strain, it was decided to carry out some check experiments on copper.

Two types of copper were used: O.F.H.C. and tough pitch. They were subjected to approximately constant rates of tensile strain of 0.2, 40, and 1000%/hr. at room temperature. Mercury was applied to the electropolished surface by rubbing with cotton-wool soaked in a saturated solution of mercuric chloride, followed by washing in water. This produced a film of metallic mercury sufficiently thin to evaporate within 24 hr. Consequently, with the lowest strain rate it was necessary to supplement this by the addition of liquid mercury. Under the slow straining conditions imposed, this added mercury combined with the copper, giving a solid phase. More liquid was added whenever the surface appeared

mediate strain rate on each type of copper. All specimens were annealed after machining to size. The grain-size was measured by counting all grains across the test-piece on two traverses and so obtaining the mean diameter.

The results are shown in Tables I and II, and the test-pieces after fracture are shown in Figs. 1 and 2. The bright appearance of the test-pieces strained at the lowest rate is due to the presence of a mercury-copper solid phase.

Taking the control test as standard, it will be noted that the maximum stress to fracture is not significantly affected by the presence of mercury. The ductility, as measured by elongation, is, however, appreciably lowered, the more so the lower the rate of strain. A check test with O.F.H.C. copper showed that the properties (without mercury) were unaffected by strain rate alone.

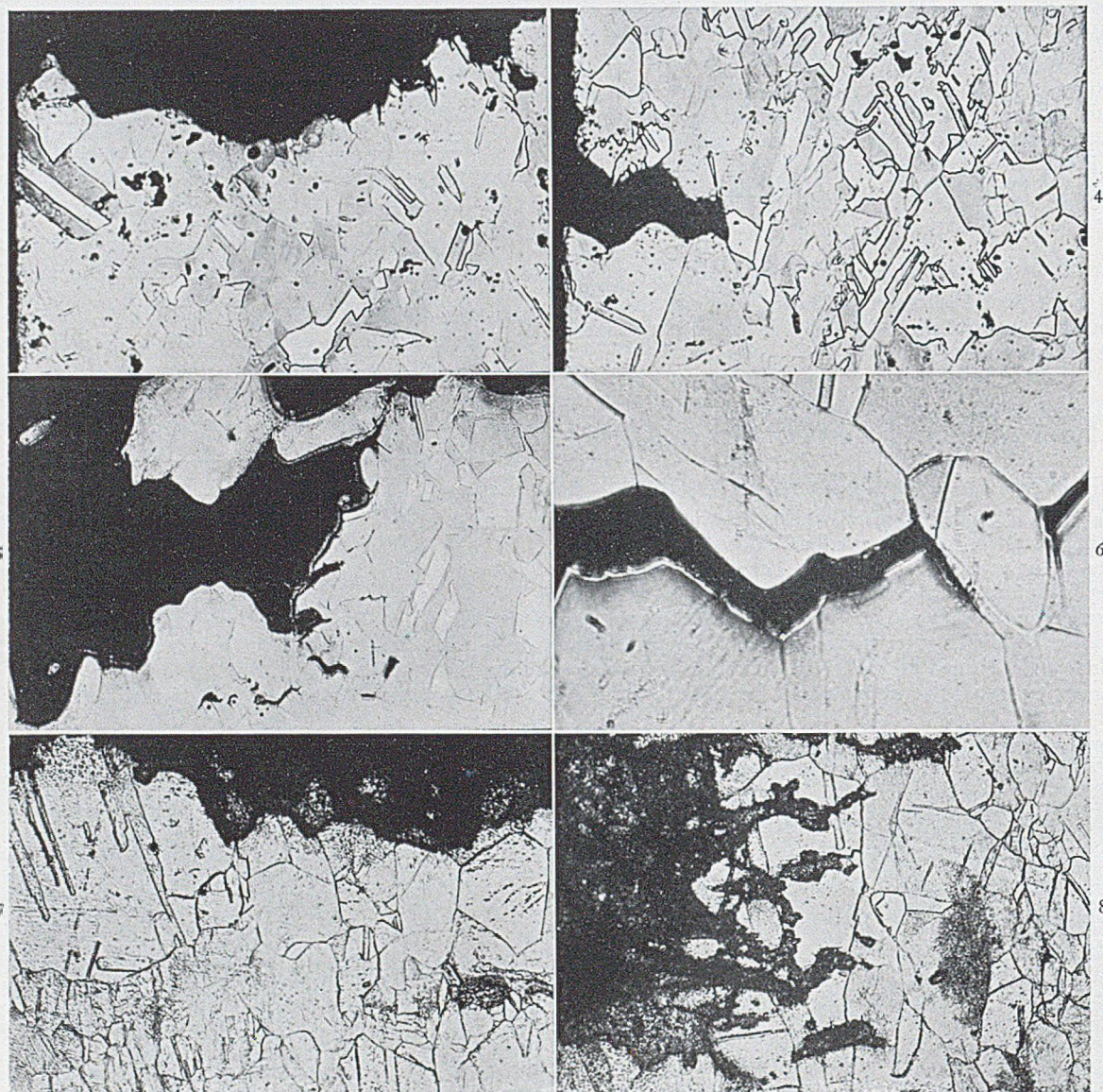


FIG. 3.—Tough-Pitch Copper. Fracture edge after straining at 40%/hr. $\times 200$.
 FIG. 4.—Tough-Pitch Copper. Edge crack in same piece. $\times 200$.
 FIG. 5.—O.F.H.C. Copper. Fracture edge after straining at 40%/hr. $\times 100$.
 FIG. 6.—O.F.H.C. Copper. Same piece, internal crack. $\times 500$.
 FIG. 7.—O.F.H.C. Copper. Fracture edge after straining at 0.2%/hr. $\times 100$.
 FIG. 8.—O.F.H.C. Copper. End of same fracture, showing transcrystalline penetration. $\times 100$.

The lower elongation shown by the O.F.H.C. copper is probably due to the larger grain-size—0.10 mm. as compared with 0.03 mm. for the tough-pitch copper.

Micro-examination showed that all fractures in the presence of mercury were intercrystalline. This feature is illustrated in Figs. 3-8. It will be seen in Fig. 8, which is the end of one of the two main fractures, that transcrystalline attack has also occurred.

In view of these results, the previous views concerning the immunity of copper from mercury stress-cracking must be modified. There is a great difference in the degree of susceptibility of copper as compared with 70:30 brass. It is possible that this difference and the fact that a stress very

close to the breaking stress is needed to cause the effect, is the reason why this observation was not made earlier.

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REFERENCES

1. G. Edmunds, *Symposium on Stress-Corrosion Cracking of Metals*, (A.S.T.M.-A.I.M.E.), 1944, 87.
2. W. D. Robertson, *Trans. Amer. Inst. Min. Met. Eng.*, 1951, 191, 1190.

NEWS OF LOCAL SECTIONS AND ASSOCIATED SOCIETIES

Sheffield Local Section

At a joint meeting of the Section with the Sheffield and North-East Branch of the Institute of Metal Finishing on 12 December, Dr. G. L. J. BAILEY, Deputy Research Manager of the British Non-Ferrous Metals Research Association, gave a lecture on:

The Mechanism of Adhesion of Electrodeposits upon Aluminium

After giving reasons why plating upon aluminium is likely to prove of increasing commercial importance, the lecturer reviewed methods of plating upon aluminium and theories dealing with the adhesion of the deposits. He went on to illustrate the effects of low and high nucleation density upon the adhesion of deposits applied using the immersion zincate method, and showed how optimum adhesion could be obtained.

In the discussion, speakers referred to factors influencing the density of nucleation and affecting the area of intimate contact between the basis metal and the growing crystals of the electrodeposit.

South Wales Local Section

At a meeting of the Section held on 13 January 1953, in the Metallurgical Department of University College, Swansea, at 6.30 p.m., Major P. L. TEED, Deputy Chief of Research and Development, Vickers-Armstrongs, Ltd. (Aircraft Section), Weybridge, delivered a lecture on "Some Metallurgical Problems Imposed by Stratospheric Flight". A synopsis of this lecture will be found on p. 80 of the May 1952, issue of the *Bulletin*.

At a meeting held at University College, Swansea, on 10 February, Dr. B. A. BILBY spoke on:

Dislocations in Crystals

The lecturer said that the slip of crystals during plastic deformation occurred in crystallographic directions on crystallographic planes. The current theory of this process postulated that the slip occurred first in local regions, whose boundaries then moved across the slip plane as the slip spread. These boundaries, separating regions which had slipped from those which had not, were "dislocations".

There were important differences between the properties of dislocation lines which lay parallel to the direction of slip (screw dislocations) and the properties of those which lay perpendicular to the direction of slip (edge dislocations). A dislocation line was the source of an elastic stress field in the lattice; it also had a line tension which tended to make it as short as possible. These properties formed the basis of quantitative theories of the behaviour under stress of crystals containing dislocations. Many results of these theories could be illustrated qualitatively with the aid of a simple model of a crystal lattice into which dislocation lines could be introduced.

The dislocation theory enabled a qualitative account of many of the mechanical properties of metals to be given, and there were several phenomena which were not easily explained without it. Recently direct evidence for the existence of dislocations had arisen from a study of spiral steps on the surfaces

of growing crystals. Similar evidence for local slip had come from studies with the high-speed camera of the development of slip lines.

NEWS OF KINDRED SOCIETIES

Australian Institute of Metals

The 1953 Annual Meeting and Congress of the Australian Institute of Metals will be held in Brisbane from 25 to 29 May. Besides technical sessions, the programme will include visits to various industries in Queensland. Any members of the Institute of Metals who are in Australia at the time are warmly invited to the meeting.

Institution of Mechanical Engineers

The Council of the Institution of Mechanical Engineers is arranging on Friday, 6 March 1953, a one-day Conference, at which a series of papers on Marine Steam Turbines will be presented. The authors of these papers are Dr. T. W. F. Brown and several of his colleagues at the Parsons and Marine Engineering Turbine Research and Development Association, and the papers will review the work which that Association has been and is now doing.

The Conference will take place in the Institution Building at Storey's Gate, London, S.W.1, and there will be three sessions, Morning, Afternoon, and Evening, the last being devoted to a general discussion of the papers presented at the earlier sessions.

Admission to the Conference will be by ticket only. Arrangements are being made for a buffet lunch to be available in the Institution Building, for those who have applied in advance for tickets, the charge being 6s. *od.* per head. Refreshments will be served, without charge, to those attending, at 4.45 p.m.

A cordial invitation has been issued to members of the Institute of Metals to attend. Advance copies of the papers will be available nearer the date of the Conference, and will be forwarded to those persons taking part.

The Physical Society

The Spring Provincial Meeting of the Physical Society will be held in the Department of Physics, The University, Leeds 2, on Monday, Tuesday, and Wednesday, 30, 31 March, and 1 April 1953. The meeting will be on:

Aspects of Solid-State Physics

and will be divided into three sessions: (1) Analysis of Magnetization Curves; (2) Band Theory of Metals; (3) Ferroelectricity and Luminescence.

Papers by the following will be delivered: A. F. Devonshire (Bristol University); E. W. Elcock, J. Ewles, F. E. Hoare, K. Hunt, P. Rhodes, E. C. Stoner, and R. S. Tebble (all of Leeds University); H. Jones and E. P. Wohlfarth (both from Imperial College, London University); L. F. Bates (Nottingham University); E. E. Schneider (King's College, Newcastle-upon-Tyne); W. Sucksmith (Sheffield University).

If sufficient applications are received, a coach tour to Bolton Abbey and Kirkstall Abbey will be arranged on Wednesday, 1 April.

Visitors wishing to attend this meeting should apply to the offices of the Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7, for further particulars. Closing date for applications is Monday, 9 March 1953. Non-members are welcomed.

DIARY

The Institute

- 23 March. Forty-third Annual May Lecture: "The Present and Future Requirements of the Chemical Engineer", by Sir Christopher Hinton. Non-members will be welcome; tickets of admission are not required. (Royal Institution, Albermarle Street, London, W.1, at 6.0 p.m.)
- 24-26 March. Spring Meeting. For full details, see January issue of the *Bulletin*, pp. 133-135.

Local Sections and Associated Societies

- 9 March. Scottish Local Section. Details to be announced later. (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, at 6.30 p.m.)
- 12 March. Liverpool Metallurgical Society. "Use of Aluminium in Shipbuilding and Structural Engineering", by Dr. E. G. West. (Liverpool Engineering Society, The Temple, Dale Street, Liverpool, at 7.0 p.m.)
- 17 March. South Wales Local Section. Annual General Meeting, followed by films of metallurgical interest. (University College, Metallurgy Department, Singleton Park, Swansea, at 6.30 p.m.)
- 18 March. Manchester Metallurgical Society. Visit to Thomas Bolton and Sons, Ltd., Froghall.
- 20 March. North-East Metallurgical Society. "The Role of Metallurgy in Atomic Energy", by Dr. H. M. Finnieston. (William Newton School, Norton, Co. Durham, at 7.15 p.m.)
- 31 March. Oxford Local Section. Annual General Meeting, followed by discussion of Papers to be discussed at the Institute's Annual General Meeting. (Black Hall, St. Giles, Oxford, at 7.0 p.m.)
- 2 April. Birmingham Local Section. Annual General Meeting and Chairman's Address. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 6.30 p.m.)
- 2 April. Leeds Metallurgical Society. "Recent Advances in Electrodeposition of Metals and Alloys", by Dr. J. W. Cuthbertson. (Chemistry Department, The University, Leeds 2, at 7.15 p.m.)
- 2 April. London Local Section. Annual General Meeting, followed by an Open Discussion. (4 Grosvenor Gardens, London, S.W.1, at 6.30 p.m.)
- 9 April. Liverpool Metallurgical Society. Annual General Meeting, followed by "The Basic Processes Involved in the Tempering of Plain Carbon and Low-Alloy Steels", by Dr. W. S. Owen. (Liverpool Engineering Society, The Temple, Dale Street, Liverpool, at 7.0 p.m.)

Other Societies

- 12 March. Institute of Metal Finishing, North-West Branch. "The Plating of Aluminium", by R. Ore. (Engineers' Club, Albert Square, Manchester, at 7.30 p.m.)
- 16 March. Institute of Metal Finishing, London Branch. "Detergents, with Special Reference to Metal Finishing", by F. H. Bell. (Northampton Polytechnic, St. John Street, London, E.C.1, at 6.0 p.m.)

- 18 March. Institute of Welding, North London Branch. "Hard Facing and Reclamation of Worn Parts", by M. Riddihough. (South-West Essex Technical College, Walthamstow, at 7.30 p.m.)
- 19 March. Institution of Mining and Metallurgy. General Meeting. (Rooms of the Geological Society, Burlington House, Piccadilly, London, W.1, at 5.0 p.m.)
- 20 March. Institute of Physics, Industrial Radiology Group. "Impressions of Non-Destructive Testing in North America", by R. Bentley. (The Institute of Physics, 47 Belgrave Square, London, S.W.1, at 6.30 p.m.)
- 27 March. Institute of Metal Finishing, Sheffield and N.E. Branch. "Preparation and Deposition of Silver upon Ferrous and Non-Ferrous Metals", by A. R. Knowlson. (Grand Hotel (Fitzwilliam Room), Sheffield, at 7.30 p.m.)
- 27 March. Manchester Association of Engineers. "Friction between Solid Bodies", by Dr. R. Schnurmann. (Engineers' Club, Albert Square, Manchester 2, at 6.45 p.m.)
- 27 March. Royal Aeronautical Society. Full-Day Discussion on Fatigue. (Chemistry Lecture Theatre, University College, Gower Street, London, W.C.1.)
- 27 March. Society of Chemical Industry, Corrosion Group. All-Day Symposium on "Corrosion Inhibitors". Joint Meeting with the Society of Chemical Industry, Manchester Section, the Royal Institute of Chemistry, the Chemical Society, and the Institute of Petroleum. (Chemistry Lecture Theatre, Manchester University.)
- 30 and 31 March. Physical Society. "Aspects of Solid-State Physics". (Department of Physics, The University, Leeds 2.) For details see p. 179.

APPOINTMENTS VACANT

MAGNESIUM ELEKTRON, LTD., have a vacancy for an experienced metallurgist for Research Department. Must have personality and ability to control Inspection Section, as well as technical qualifications of normal average calibre. Written applications should be addressed to Secretary, Magnesium Elektron, Ltd., Clifton Junction, Nr. Manchester.

METALLURGIST required for experimental heat-treatment laboratory and control of heat-treatment in Aircraft Works. Degree or equivalent required, preferably with experience of practical heat-treatment. Age 25-30. The position is a progressive one, and is superannuated. Please apply, giving details of qualifications and previous experience, to the Personnel Manager, Joseph Lucas (Gas Turbine Equipment), Ltd., Shaftmoor Lane, Hall Green, Birmingham.

MULLARD BLACKBURN WORKS, LTD., require a metallurgist for work on the development and technical control of high-quality tungsten and molybdenum wire production. The position offers considerable scope for someone with initiative and persistence, and will carry a salary commensurate with qualifications and previous experience. Apply, giving full particulars, to the Works Personnel Officer, Mullard Blackburn Works, Ltd., Philips Road, Blackburn, Lancs.

THE PRINCIPLES OF TECHNICAL CONTROL IN METALLURGICAL MANUFACTURE *

1448

By A. R. E. SINGER,† B.Sc., Ph.D., MEMBER

SYNOPSIS

The effects of economic and technical factors on the quality of manufactured products are examined, and the characteristics of controlled processes analysed in terms of basic principles. Some aspects of statistical control of plant are considered in relation to present practice and probable future developments.

I.—INTRODUCTION

THE science of technical control of quality in manufacture has an underlying unity that is revealed only by careful analysis. Its applications are widespread, for it embraces the control of raw materials, processes, and manufactured products in the factory, as well as the methods whereby control is effected. Despite this wide coverage, there is a coherent body of knowledge dealing with the subject, and a number of important principles can be seen to run throughout. Whenever the subject of technical control of quality is mentioned, the techniques of control used in the factory immediately spring to mind. Inevitably, a greater attention is paid to them than to the fundamental principles, which are often assumed to be self-evident and scarcely worth enunciating. It is appropriate, therefore, at the beginning of this series of papers on technical control of quality, to examine on a broad basis the main factors affecting control. This is particularly desirable because the subject is one on which a great deal of research and development work is being done. Much of the work is concerned with only a small part of the total field, yet the same basic factors are operating throughout, and the accumulated experience from one part may be of great help in another. It is necessary in these circumstances to take an overall view of the situation, put the various pieces of research and development work into a correct perspective, and to formulate a plan of action in conformity with the whole rather than with the individual parts.

The science of control of quality is developing rapidly, and at no time is the situation static. The pattern will not repeat itself exactly in the future, yet it is with the near future that a progressive scientist or industrialist is primarily concerned. A mere

accumulation of experiences from the past is of little use for planning action in a changed future, and the only way to resolve the difficulty is to extract principles from present and past experience and use them as a guide for the further development of processes and techniques. Experience has shown that principles are more persistent in time than practice, and a good deal more reliable. The purpose of this paper, therefore, is to outline some of the underlying factors operative in the technical control of quality and where possible to deduce from them promising lines for future research and development.

The technical control of processes is not an end in itself. It should always be carried out for a specific purpose in order to achieve certain desired results, and it is very revealing to examine more closely what these results are. It would be generally accepted that high quality in a product is desirable and the higher the better. Unfortunately, the attainment of quality is directly related to cost, either because of higher cost of the materials, machines, and labour, or because of additional charges required for accumulating knowledge and carrying out research and development necessary for the manufacture of the product. In addition, the mere setting up of a system of control inevitably causes additional expenditure of money, and this again must be put on the debit side of the account. Under the heading "The Economic Aspect" (Section III), the problem will be examined in greater detail, but it soon becomes apparent that at any one time within a concern there is an optimum standard of quality for a product, and control of quality in the region of this standard is economically desirable.

The economic aspect cannot be left out of any comprehensive picture of control. In fact, it becomes an essential function of management to measure the success or failure of a system of control by relating the

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and Casting", to be held in London on 25 March 1953.

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results achieved to the new total cost of the product. Whilst this view would generally be conceded when the point is emphasized, it is not always kept clearly in mind. Frequently it happens in industry that schemes of instrumentation or recording are embarked upon, apparently for their own sake, with only a vague and rather hopeful picture of how the quality of the product or the economy of production will be affected. Such a state of affairs cannot be described as control, and any steps taken to define accurately the purpose of control in relation to quality and the reasons for its installation would be invaluable.

II.—QUALITY AND ITS MEASUREMENT

The word quality is a simple one describing a complex state that is difficult to interpret. There are two concepts of quality, not incompatible, but often leading to a confusion of thought. In the first place quality may be thought of as being measured on a scale leading to an objective perfection without relation to uses or applications. Secondly, the quality of a product may be linked with its ultimate use, in which case the criterion is fitness for purpose. If either of these definitions is adhered to rigidly, then difficulties of interpretation may occur. But the two concepts are not contradictory, and when it is realized that in the case of metallurgical manufacture an ideal standard is set by the purpose for which the product is intended, then the difficulty is resolved. Thus the standard might be complete freedom from porosity, which in the case of a casting would be unattainable. Alternatively, the standard might be a particular thickness for strip material, which in practice would never be attained exactly.

This leads directly to the question of how quality can be measured. In a great many cases no simple method of physical measurement is available, and in its absence the best that can be done is to set up certain standard examples and use them for making comparisons, classifying the products on the basis of the unaided judgment of the inspector. Such methods are unsatisfactory from a scientific point of view, but have to be applied at least in part with such features as surface finish, defects and blemishes of all kinds, porosity, segregation, and internal cleanliness of castings. Gradually more and more of these features are becoming amenable to physical measurement, and part of the answer to the problem may be a closer analysis of the situation, so that, for example, in the case of porosity and segregation, its location and dispersion are taken into account as well as effects of density or chemical composition.

Where it is possible to make physical measurements relating to quality, much more can be done by way of interpretation, and it is on this basis that it is now proposed to deal with the concept of quality. Suppose we take a simple example of strip metal being produced for subsequent deep drawing. The quality of the strip will then be a function of its chemical composition, metallurgical structure and properties, its

surface condition, and its dimensions, especially its thickness. All these quantities, except surface quality, can be measured with precision, but for the present purpose only the thickness need be considered, as a similar state of affairs pertains with the others. This aspect of quality is important because of the clearances between the tool and die. It will be a maximum at one particular thickness or ideal dimension, X_i , and in the ideal case strip would be produced at this size. However, this is a counsel of perfection not attainable in practice, and this is recognized by manufacturing to certain tolerances, say, $X_i \pm 0.003$ in. This means that quality falls as the thickness departs from X_i , and at any point beyond $X_i + 0.003$ or $X_i - 0.003$ in. is no longer acceptable. The best index of quality for an individual article is then the nearness of the strip to the standard expressed as a number. Similar criteria can, of course, be used for all the other quantities involved, except surface finish. In the case of a group of such strips the best measure of this aspect of quality would be the arithmetic mean \bar{X} of the dimensions or quality characteristics of the individuals taken in conjunction with their standard deviation σ . Such objective standards of quality are an immense aid to everyone in the factory, as they enable operators and inspectors to detect any deterioration with the maximum speed and certainty, and permit corrective action to be taken at the earliest moment. This is the essence of control of quality, and it greatly simplifies the work of the technical officer in charge if numerical values and limits can be provided to which he can work.

III.—THE ECONOMIC ASPECT

It has already been shown that for any given process, quality of product and cost of production tend to be mutually opposed, so that in practice some compromise solution must be sought. The question immediately arising is that of choosing how much of each to aim for. The situation is necessarily tied to the overall economy of the process and may be clarified by considering in diagrammatic form the cost of manufacture of a product as compared with its value to the consumer in terms of its usefulness. Here we are not concerned with the other aspects of value related to cost, esteem, or exchange.

If it is assumed that quality can be measured on a physical scale—in this example as an approach to an ideal dimension—then a value/quality diagram might take on a form such as that shown in Fig. 1. The curve V will usually flatten out as the ideal dimension is reached at X_i , and will be zero at some point B , where the maximum acceptance tolerance for the article is reached. Such a value curve would refer to individual items of product at the exact dimensions indicated in the diagram. When applied to a productive process, the situation becomes more complex because it is not possible to manufacture at specific dimensions, and tolerances must be allowed. If the manufacturing process is considered alone and there is

no subsequent inspection of the product, then the frequency with which each quality of product occurs will in the general case follow a binomial distribution. In any process some defective items of product will

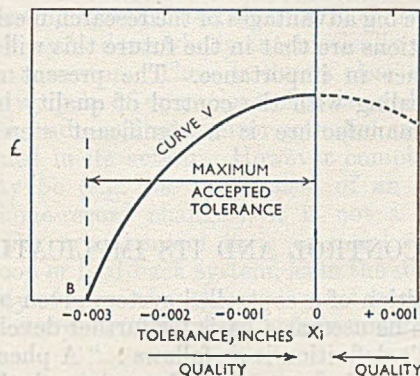


FIG. 1.—Value/Quality Relationship for Individual Items Produced.

always be made, and the manufacturing limits that can be held will depend on the proportion of defective items that can be tolerated in the output. With a normal frequency distribution, as shown in Fig. 2, and a proportion of defectives of, say, 1%, the tolerances will be $\pm 2.6\sigma$, where σ is the standard deviation for the process. On this assumption it is possible to draw both value and cost-of-production curves for manufacturing processes of varying degrees of precision, i.e. of varying σ . The curves may now take on the form shown in Fig. 3, where curve *V* is the value in pounds sterling of an individual item of those exact dimensions, as in Fig. 1. Curve *A* will then give the value of a product in which 1% of the output is defective or outside the manufacturing tolerances $\pm 2.6\sigma$. The curve will again flatten out at the ideal dimension and will be steep where it cuts the axis at *D*. At this point the value will be zero because of the large proportion of unacceptable material it contains—in this case about 2.3σ or 3%.

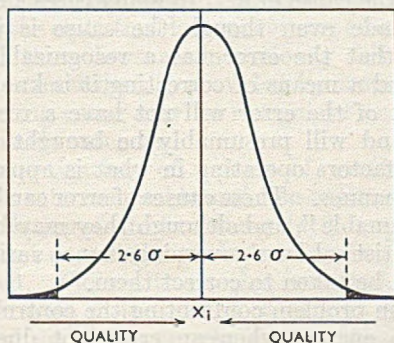


FIG. 2.—Frequency Distribution Curve for Varying Tolerances.

A further curve *C*, showing the cost of production by the process such that only 1% of defectives are produced at any particular tolerance, can now be inserted. Such a cost-of-production curve will always rise steeply as the ideal dimension is approached and

tolerances are narrowed, and will tend to a definite value in pounds sterling as tolerances are widened. It should be noted that curves *V* and *A* are hypothetical, in the sense that in practice it is possible to make only rough estimates of value at various qualities, but curve *C* can sometimes be drawn with fair accuracy. Furthermore, all the curves are drawn for one given state of technical knowledge and skill. As this improves with time, so curve *C* moves downwards and closer to the vertical axis at X_i , but at the same time, owing to competition in the industrial field, curves *V* and *A* tend to move in the same direction, so that the general pattern remains similar.

On the basis of the curves in Fig. 3, the point at which it is most profitable to manufacture is at X_p , where the value/cost-of-production loop is deepest. In other words, there is an optimum quality having tolerances of $\pm X_p$ where production should be held, and any departure from these tolerances with a rejection rate of 1% would lead to a decrease in profitability. If the two curves *A* and *C* did not intersect, then of course all production would be made at a loss.

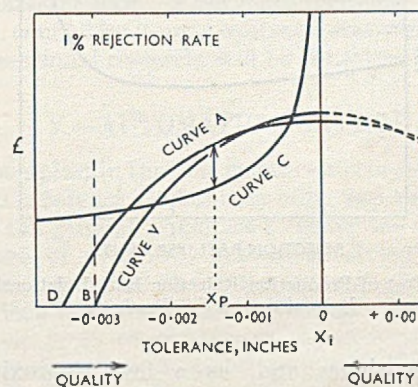


FIG. 3.—Value/Quality Relationship for Products Containing 1% of Defective Items.

Thus the curves, even though hypothetical in character, do succeed in illustrating the important point that ultimate economy dictates that at any one time in a manufacturing process the quality of the product should be controlled at one particular value, and that any divergence from this value will carry with it economic penalties. Here is a basic reason for the control of manufacturing processes.

It can be shown in a similar manner that for any process that is operating to fixed tolerances there is an optimum rate of rejection at which the cost of production per unit of acceptable product is a minimum. Such a curve might take the form shown in Fig. 4. The curves in Figs. 2 and 3 were, of course, drawn for a fixed rejection rate of 1%, but similar curves would have been obtained at any other rate. In any instance in practice there is a best rejection rate, or range of rates for a process, and efforts should be made to reach this rate rather than merely to reduce rejections to a minimum.

Mention has already been made of the fact that

improvement in quality of a product can be made in two principal ways. In the first place it can be achieved by raising the quality of raw materials, reducing tolerances by employing more skilled labour and supervision or machines of higher accuracy, and by more rigorous inspection methods. The other way of achieving higher quality in a product is to utilize scientific investigation with the object of finding better methods of manufacture. Both methods carry with them financial penalties, but there are important distinctions to be made between them.

The first method has as its principal advantage that of simplicity and the small time-factor involved. In response to an alteration in demand, it is usually possible to raise quality by this means within a short period, and the increase in cost of manufacture is then given by curve *C* in Fig. 3. The situation, however, is a static one, and the increase in cost is payable on every item of product made, however long pro-

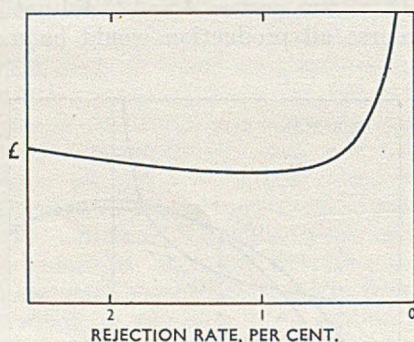


FIG. 4.—Cost of Production/Rejection Rate Relationship per Item of Acceptable Product.

duction continues and, as a first approximation, however many are made. In contrast, the method of scientific investigation achieves more lasting benefits. It is true that again a price has to be paid for quality in terms of costly research, development, and design, but once the work is done it is applicable to all the items of product manufactured, and the cost of investigation can be borne by indefinitely large numbers of the product. In addition, such work is cumulative, and one research worker starts building at the point at which another has left off. The situation is thus essentially a dynamic one, and a continual advancement in quality is the result.

The immediate disadvantages attached to such a method of improving quality are twofold. There is the time element to be considered, for research and development work is necessarily a lengthy process, and there is the need for the cost of the work to be spread over a large output. An additional point, of local significance only, is that the results of research are rapidly disseminated, and competitors soon use them to their own advantage. However, there is a constant interchange of such knowledge and, taking the broad view, the process is undoubtedly of benefit to the world at large.

The two ways of improving quality always proceed simultaneously, and it is virtually impossible to operate one without some intrusion by the other. The important thing is the emphasis given to each. The experience of the last two decades has brought out clearly the big advantages of the research method, and all indications are that in the future this will increase still further in importance. The present series of papers dealing with the control of quality in metallurgical manufacture is a significant step in this direction.

IV.—CONTROL AND ITS IMPLICATIONS

A definition of a controlled system given by Shewhart¹ can be used as a basis for further development. Shewhart's definition is as follows: "A phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future. Here it is understood that prediction within limits means that we can state, at least approximately, the probability that the observed phenomenon will fall within the given limits."

It is characteristic of machines and processes not subject to control, either automatically or by a human operator, that they will not continue of themselves to give a product of constant quality. After a time a discrepancy between the required and the actual quality value makes an appearance and can be called the "error". In any manufacturing process many variables will be operating at any one time, but to simplify the analysis we can suppose that each variable, with the error derived from it, is being considered by itself. The reason for the appearance of an error will then be twofold. One part of the error will have a recognizable pattern and will be attributable to a maladjustment of a known factor in the process. This cause of error can be termed an "assignable" cause, and action can be taken to correct the error by adjusting the cause of it. In many cases a correction can be made even though the cause is unknown, provided that the error has a recognizable orderly pattern and a means of correcting it is known. The other part of the error will not have a recognizable pattern, and will presumably be brought about by unknown factors operating in what is apparently an irregular manner. These causes of error can be termed "non-assignable", and although they may be treated by the statistical laws governing chance variations, no action can be taken to correct them.

The main problem confronting the control engineer is how to ensure, when an error not due to non-assignable causes is detected, that action is taken to reduce it. The recognition of errors having a regular pattern due to assignable causes, as opposed to those due to chance fluctuations (non-assignable causes) is not easy. In the first instance, therefore, it is best to consider the simple case where a succession of articles is being produced and the error indicated is an

integrated effect such that chance fluctuations do not make a significant contribution.

The way in which control is effected is by arranging for the error to set in action a mechanism that will lead to a reduction of the error. In other words, a compensating system is set up that is error-actuated, and this may be done wholly automatically or through a human operator. There is thus a clear distinction between a cycle of operations that is predetermined and rigid, and one that is error-actuated and not predetermined in its action. However complicated the first may be (e.g. the mechanism of an automatic gramophone-record changer), it is not a controlled cycle. For true control it is essential to have a closed-loop or feed-back system, as in the second case, and a way of correcting the error must be known and the necessary action taken before control can be effective.

Turning to the practical aspect of process control, it is convenient to take as an example the case of a product already in manufacture, on which technical control of quality has hitherto been a haphazard and arbitrary affair. The various steps to be taken to ensure adequate control can then be clearly brought out. The first step is to find out the major factors affecting the quality of the product in order to determine how, and to what extent, they affect it. This investigational stage is one of the biggest jobs in technical control, and may consume a large proportion of the time of trained scientific staff. The work, although lengthy and expensive, would employ normal scientific procedure for investigation, and should reveal assignable causes of variation in the quality of the product. But in every instance there are bound to be variations in manufacture that at any given state of knowledge cannot be tied to a particular cause. Some of these may show a regular and persistent pattern of behaviour, and can usually be related to some aspect of the process, in which case they can be placed in the category of assignable causes. The remainder can be termed non-assignable causes of variation. These variations are then best treated as random events following the statistical laws governing chance fluctuations. If these laws are not closely followed, then evidence is immediately provided by means of which the operating cause may be recognized and placed in the assignable category.

The investigation of causes of variation, their separation into assignable and non-assignable classes, and the relating of effect to cause is absolutely essential, and must be carried out before process control is established. Failure to do this is bound to lead to disappointment in the results of process control, and if the analysis of the process is unsatisfactory in this respect it is best to recognize immediately the grave limitations it will place on the effectiveness of control. In the metallurgical field this is generally realized, and a large proportion of the applied research effort is expended on obtaining a fuller understanding of manufacturing processes, and in particular the effect of manufacturing variables on the properties of the

product. Such effort is well directed, but it should be recalled that the research is not an end in itself and is only of value and can be justified only when it is used for effectively controlling the manufacturing processes.

The next stage in controlling the quality of a product during manufacture is to set up standards by defining the tolerances or limits within which the product may vary and yet remain acceptable. At the same time it is advisable to assign the corresponding limits to the factors causing or correcting the variations in quality. Whenever possible, such limits should be subject to physical measurement and expressed numerically. This stage is an important one for management because, as stated earlier, it involves a critical analysis of data on costs, yield, &c. The standards may be arrived at on a statistical basis or, more frequently, by a common-sense assessment of the position. The essential part of the process, however, is the setting up of standards and the defining of tolerances; once this is done control can be established. At this stage the method of control to be used has to be considered, and a number of different ones are available, each with its own characteristics. Four main methods, automatic control, control by human operator, statistical control, and operational research, will be considered here.

V.—AUTOMATIC CONTROL

It is simplest in the first instance to consider control systems involving mechanisms only, and then later to extend the general principles to cover the more complex case of a control system involving a human operator. A definition of control was given earlier, from which it appeared that an essential part was the indication of an error between the expected and the actual performance, followed by action to reduce the error. In the case of automatic control this is performed by a mechanism, and it is necessarily implied that some physical indication or measurement of the controlled variable is available. The field of application of automatic control is therefore limited at the moment to systems in which physical measurement of the variables can be made. However, within this field automatic mechanisms have revolutionized the outlook for process control, and complex problems involving the analysis of data relating to several variables can be solved quickly and reliably.

It might at first be thought that if the measurement of error was sufficiently sensitive, the construction of a system giving control within the required limits would be a simple affair. Yet when considered in detail it becomes clear that a stable and accurate system of control is dependent on a number of factors such as time, capacity, and transfer lags. It is not appropriate here to enter into the technicalities of automatic control, and indeed the published literature on the subject is immense,²⁻⁴ but a brief note of some of the problems associated with automatic mechanisms is useful, especially as many of them apply equally to human operators.

1. AUTOMATIC CONTROL OF PLANT AND PROCESSES

In all automatic control mechanisms a measuring or indicating unit is required for each variable being controlled. If we limit consideration to the control

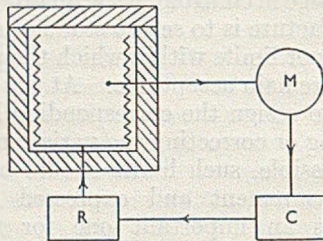


FIG. 5.—Annealing Furnace with Closed-Loop Automatic Control.

of a single variable, then we shall require in addition a regulating unit capable of effecting a change in the controlled variable and, connecting the two, a controlling unit that operates the regulating unit in response to the signal given by the measuring unit. The system is thus a closed loop of the type shown in Fig. 5. It is interesting to note that, although this type of control is accepted nowadays with scarcely a thought, it is of fairly recent origin, and until a short while ago metering of plant was used solely for performance and accounting purposes.

The signal from the meter (*M*), and therefore the input to the controller (*C*), is usually a weak one, and will need amplification and modification before it can be used satisfactorily for operating the regulating unit (*R*). The way in which this is done determines the performance of the controlled system, and is the chief problem in the design of automatic control

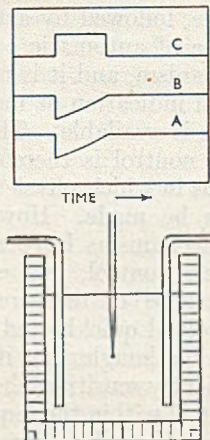


FIG. 6.—Temperature-Controlled Salt Bath, Showing Capacity Lag.

A = Temperature of bath.
B = Input to controller.
C = Output of regulator.

mechanisms. The application of automatic control to production processes in metallurgical industry differs from the more usual engineering applications in that the time element is much more extended. For

instance, an automatic pilot of an aeroplane is designed to correct errors of flight in short periods of time, whereas in many process-control applications the correction of an error may occupy many minutes or even many hours. The chief reasons for this difference lie in the magnitude and importance of transfer lags and capacity lags associated with production processes. The time lags occurring between the metering of the controlled variable and the operation of the regulator are relatively small and unimportant, as this connection is usually made electrically.

The effect of a capacity lag on a control system is clearly brought out in diagrammatic form in Fig. 6, where a step change in the controlled variable is caused by the addition of a metal charge to a temperature-controlled salt bath. It is assumed that the system is provided with an "ideal" two-position

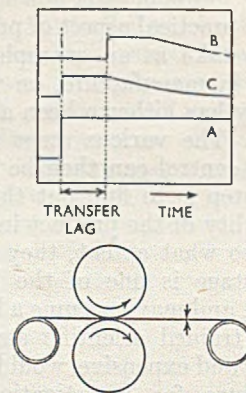


FIG. 7.—Rolling Mill Fitted with Gauge Control, Showing Transfer Lag.

A = Ingoing thickness.
B = Meter reading.
C = Outgoing thickness.

controller and that the heating elements immersed in the salt have a small thermal capacity. Because of the thermal capacity of the salt, a fall in temperature, although followed immediately by heat input from the immersed heaters, will not be corrected for an appreciable period of time, and control will be deficient to this extent.

A transfer lag is illustrated in Fig. 7 by a rolling mill whose screw-down gear is automatically operated through a proportional controller by a gauge measuring the thickness of the rolled strip. In this case the gauge is separated from the rolls by a short distance, so that there is a time interval between the rolling and the measuring of any particular part of the strip. A step change in the thickness of the ingoing strip will cause an increase in the outgoing thickness because of the elasticity of the rolls and housings, but the change will not register on the meter, and corrective action will not begin for a finite period of time because of the transfer lag. Then, provided that the lag is not too great compared with the rate of operation of the screw-down motor, the thickness of the strip will gradually be rectified. The transfer lag, together with its deleterious effects on quality, may

of course be reduced by decreasing the distance between the rolls and the thickness gauge, or it may be eliminated altogether by the method of Hessenberg

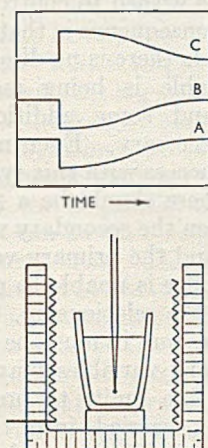


Fig. 8.—Controlled System with Capacity Lag and Thermal Resistance.

A = Temperature of metal.
B = Input to controller.
C = Output of regulator.

and Sims,⁵ using the rolling load at a constant roll setting as a measure of outgoing thickness.

The third example (Fig. 8) shows the effect of a step change in the temperature of a crucible of molten

motor. Similarly, cumulative oscillations, as in Fig. 9 (e), would occur in the system shown in Fig. 8, if the heat input to the elements were too high and the heat capacity of the furnace appreciable. At all cost, oscillations of this type must be eliminated from a system of control.

The type of controlling and regulating unit has to be chosen carefully so as to give the most effective control of the system. If the output from the regulating unit could be made instantaneously equal and opposite to the error, then the error would vanish and control would be ideal. As we have seen, various lags make this impossible, and the best that can be done is to correct the error as quickly and effectively as possible. By further amplification of the signal received from the meter, the output of the regulator, and therefore the rate of correction of the error, can be increased. But for a given set of lags the amplification that can be used is limited, because beyond a certain point over-correction exceeds the original error and an unstable condition is set up in which cumulative oscillations occur. The system is then wholly out of control and the amplitude of the oscillations will increase until limited by some other factor in the process.

The types and characteristics of automatic control units used for ensuring the best result in any given situation are not pertinent to this paper, although they form the hard core of control engineering. Suffice

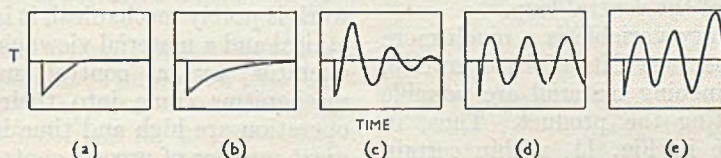


Fig. 9.—Responses of Controlled Systems to a Step Change in the Controlled Variable.

metal on a system having a single capacity lag and a thermal resistance. Here it is assumed that the furnace has a negligible heat capacity and that the system is fitted with a proportional controller. The step change in temperature causes an immediate input of current into the heating elements, but because of the thermal resistance of the crucible and the thermal capacity of the metal, there is a perceptible lag in the rise in temperature of the thermocouple. After a time, provided that the heat input is not too great, the temperature will once more attain the original level.

Fig. 9 illustrates some characteristic responses of controlled systems to a step change in the controlled variable. The fully damped response in (a) approaches the ideal and bears some similarity to that of Fig. 6, but the same system fitted with a proportional controller would give the characteristics of (b). The damped oscillations of (c) are a common effect, and are permissible for many industrial purposes. The hunting response of (d) would be given by the system shown in Fig. 7, if the transfer lag was too large in relation to the rate of operation of the screw-down

it to say that nowadays types of control unit are available to serve most of the needs of metallurgical processes. The limiting factor is usually in some other part of the control system. The conclusion is, therefore, that the characteristics of a process and of a control unit have to be considered together and must be carefully matched to give a product of good and consistent quality. Neither, considered separately, is likely to yield good results and, as we have seen, it frequently happens that the characteristics of a piece of plant are such that no control unit can give it a satisfactory performance.

2. CONTROL OF PRIMARY AND SECONDARY VARIABLES

One important factor applying forcibly to metallurgical process control is rarely given sufficient attention in the technical literature. It concerns what may be called the primary and secondary variables in a control system. Suppose we take the case of a continuous annealing furnace used for the annealing of metal strip, the temperature of the furnace being controlled automatically by an efficient controller. We can then

assume that the temperature of the strip is raised to a prearranged value and is allowed to remain there for a known period of time. It follows that if the original strip was of the correct composition, structure, and condition before annealing, it will possess the expected properties afterwards. The important point here is that the ultimate requirement is annealed strip with a certain structure and properties, whereas the variable being controlled is temperature. Putting the situation in diagrammatic form, as in Fig. 10, it is apparent

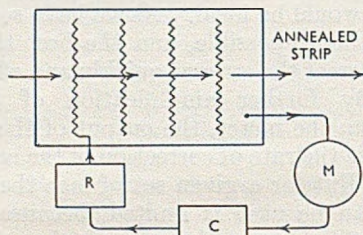


FIG. 10.—Control of Secondary Variable During Continuous Annealing of Strip.

that the primary variable—the structure and properties of the strip—does not form part of the closed loop and is not controlled directly. This state of affairs can clearly be distinguished from the true control of a primary variable, as in the control of thickness of metal strip during rolling by altering the front tension applied.⁵ Here the strip thickness is measured directly and forms part of the control loop.

The control of a primary variable is a much more satisfactory procedure, because if it is fully operative, then variations in the ingoing material are possible without seriously affecting the product. Thus, in the rolling-mill example in Fig. 11, within certain

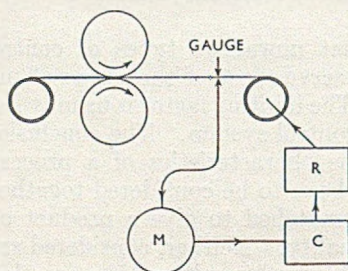


FIG. 11.—Control of Primary Variable During Continuous Rolling of Strip.

limits the gauge of the product is controlled irrespective of the variations of the ingoing strip, provided these are not too great. In the case of the annealing treatment under consideration we have an entirely different picture, for here it is essential to the formation of a uniform product that the ingoing strip be standardized. In other words, the structure and properties of the ingoing strip itself must be maintained within fine limits. This process may have to be pushed back still further in the sequence of processes, and eventually we may have to manufacture to fine limits throughout—a very costly and

time-consuming business. The control of a secondary variable does tend to have this effect in manufacture, so that whenever possible it is best to introduce the variable which it is wished to control into the control loop. A further consequence is that when controlling a secondary variable there is no direct indication that the primary variable is being maintained at the required value, and some additional independent measurement is necessary. Even more important is the fact that for success with this type of control it is imperative that there should be a fixed and definite relationship between the secondary variable, temperature in this case, and the primary variable, structure, because the controller is unable to make a correction for any change in the relationship. The relationship need not be linear, but it must be known with certainty, and auxiliary variables may also have to be controlled within fine limits to prevent undesirable disturbances being carried into the main control system. Later it will be shown that in spite of the obvious advantages of controlling primary variables, little progress in this direction has been made in metallurgical industry. This is both a challenge to and an opportunity for metallurgists.

VI.—CONTROL INVOLVING A HUMAN OPERATOR

Many of the principles of automatic control apply equally to control by a human operator. Where the work is purely mechanical, it is desirable from both an ethical and a material viewpoint to replace the human operator by a control mechanism. Automatic mechanisms come into their own when speeds of operation are high and time intervals short, but in a great number of process-control applications the time intervals involved are long and the situations complex. In many of these instances, ranging from the technical control of a small manufacturing variable to the managerial control of a works, it becomes advisable to employ a human operator. This is always true when the quantities are not measurable by physical means, or when the number of variables concerned is too great and their inter-relation too complex for automatic control, as in the last case. It is in connection with the simultaneous operation of a number of variables that the frailty of human judgement is brought out most clearly, and later we shall see that statistical methods of analysis and operational research methods may help us to make wiser decisions.

A good deal of light is thrown on the behaviour of a human operator when the characteristics of automatic control systems are extrapolated and applied to a closed-loop system of which he forms part. We can illustrate such a system by the independent process inspection of the quality of sheets produced by a simple two-high non-reversing rolling mill, as shown in Fig. 12. Several equivalences immediately appear. The transfer and metering lags correspond to the delay between the rolling of the sheets and their

inspection, and to the time taken by the inspector to arrive at a decision, respectively. Any persistent errors occurring during this period will lead to a quantity of bad product proportional to the lag, which must therefore be kept to a minimum, as with automatic systems. Where inspection is carried out in a haphazard manner, the lag is likely to be extended and may involve a prolonged post-mortem of many subsequent manufacturing processes before the trouble can be diagnosed and corrected.

Very frequently the inspection or measurement of an item of product can be used only for the correction of error on subsequent ones. This follows either from the time lags mentioned above or from the destruction of the article during inspection. During batch production the facts have to be faced that the maximum amount of information for control purposes is not being obtained and that the results of poor control are more serious numerically than with continuous production. For these reasons alone continuous production is more amenable to control and will generally give a higher yield of uniformly good product. Any delay between the discovery of a persistent error by the inspector and action being taken by the mill operator to reduce the error, will correspond to a time lag in the control and regulating part of an automatic system. Unless the organization is such that the transmission of information to the foreman and of an order to the mill operator can be effected quickly, then an appreciable output of bad work will occur.

If we now consider the overall characteristics of controlled systems we again find a number of parallels. It is essential for the process operator to know exactly how, and how much, to correct for a given error detected by the inspector. Such a correction will generally be of a step type, and two difficulties are

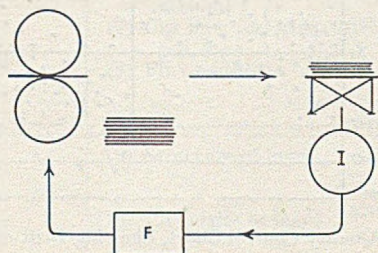


FIG. 12.—Control of Quality of Rolled Sheet by Human Operator.

I = Inspector. *F* = Foreman.

likely to arise, the first due to a faulty correction and the second due to chance fluctuations. Under-correction may continue to yield a poor product, but over-correction may be worse, for the initial cycles of the unstable system illustrated in Fig. 9 (e) (p. 335) may appear. Chance fluctuations always play some part in industrial processes, and due allowance must be made for them if control is to be effective. A situation where the normal run of product varies in a random manner is illustrated in Fig. 13. If the tolerances are set at the low value of $\pm 2\sigma$, then we

must expect approximately 1 in 20 of the products to be outside the tolerances. No special significance is to be attached to *A*, and no control action should be taken on such an isolated example. If a correction were made on the evidence of *A*, then point *B* would be out of tolerance, together with many subsequent ones. There are two ways of treating the problem. The more usual one is the common-sense way of waiting for an arbitrary number of readings to confirm a change in the process, but the problem may be

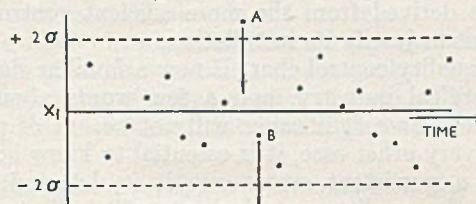


FIG. 13.—Random Distribution of Quality Values.

tackled on a statistical basis with considerably more confidence and accuracy.

The example first given related to a simple manufacturing process, but the principle is equally applicable to the control of a department or works. Lack of knowledge of how to correct errors, or delay in detecting and correcting them because of poor supervision or procrastination, allows a situation to get out of control. When action is taken, it is often a desperate measure leading to heavy over-correction as shown in Fig. 9 (d) and (e). Unfortunately, examples of this are familiar to everyone in industry, when affairs proceed from one crisis to another with monotonous regularity and lead to a general deterioration of morale and lowering of output. Such a situation is essentially related to that described above, and the cure for it is similar.

VII.—STATISTICAL CONTROL OF QUALITY

The particular feature of statistical control of quality is the recognition of the part played by chance fluctuations in manufacturing operations. It contains a procedure for dealing with them and reaching definite conclusions on action despite their occurrence. The fact that the statistical method makes allowance for chance happenings enables it to extract the maximum amount of legitimate information from data supplied by the meter in a control system. Consequently, it leads to the most efficient form of control, provided that the time interval allowable between metering and the necessary action is sufficiently long for the data to be studied. The admission of chance has another effect, namely that of eliminating the illusion of certainty and making it possible to predict only the best probable course of action. This apparent loss of certainty is unimportant, as uncertainty is inherent in the nature of the data supplied. It merely shows up clearly in a statistical analysis and is not derived from it. Moreover, the degree of uncertainty can be reduced at will by taking a greater number of observations, and in

each case the probability of error can be estimated. From a technical point of view statistical control of quality is evidently desirable wherever it can be operated. There is, however, the total economy of the process to be considered, for the installation of a system of statistical quality control means an initial increase in overheads, at least during the change-over period. This aspect cannot appropriately be dealt with here, except to note that it is an important managerial responsibility to decide whether or not the benefits derived from the more efficient control are sufficient to justify its installation.

The quality-control chart is now a familiar sight in metallurgical industry, and a few words about its limitations and significance will not be out of place. As in every other case, it is essential to know how to reduce a persistent error once it is detected in a system, for quality-control charts will indicate only when to take action and not what action to take. Similarly, it is necessary to distinguish the assignable causes of variation in quality so that they may be used for control purposes. The non-assignable causes of random variation are then treated in a statistical manner, and action is predicted on this basis.

Suppose we take a simple case where one variable is being controlled by individual meter readings and chance fluctuations are occurring. Then, for a given state of control at a value X_i , assuming a normal distribution, we can draw a diagram of the type shown in Fig. 2 (p. 331), giving the frequency with which each value of X occurs owing to chance causes. The diagram immediately shows the proportion of product falling within any given tolerances, as in Table I,

TABLE I.—*Rejection Rates at Given Values in Terms of Standard Deviation σ .*

Values	Rejections, %
σ	32
2σ	4.6
2.5σ	1.0
3σ	0.27
4σ	0.006

so that the value of A in Fig. 13 is not surprising even though the system is under full control. The effectiveness of control is shown by a value of \bar{X} as near as possible to X_i and a constant value of σ . This criterion holds for the great majority of practical cases, even though the distribution is appreciably skew or irregular.

The usual quality-control chart consists of quality data plotted chronologically in graphical form, and it is best to insert both action and warning lines, as in Fig. 14, so as to help in securing good control. If the two pairs of lines are calculated in terms of σ , then the probability of an individual exceeding these values is given by Table I, and too high a frequency of points outside the 2σ -band would serve as a warning that the process may be moving out of control. A close watch can then be kept on the process to see

whether the departure is a significant one. If it is, action to correct a persistent error can be taken with confidence when the action line is reached, and the amount of rejected product so kept to a minimum. Quality-control charts also show any evidence of drift in a process. This will be evident from a gradual widening of the difference between the \bar{X} and X_i values, and in magnified form gives the pattern shown in Fig. 15. The re-setting of the process at D is the

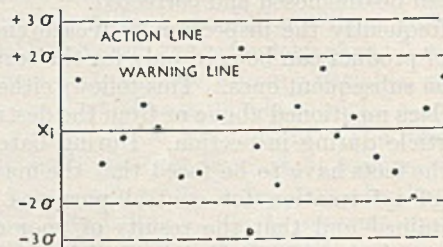


FIG. 14.—Quality Control Chart, Showing Good Control.

obvious action to take and, if drift is inherent in the process, appropriate new action and warning lines can be drawn.

Some instances occur in industry where the only satisfactory measure of the quality of a product is its performance in service. Little difficulty is caused by this when the number of items concerned is large, but when the number is small, and when some guidance is urgently needed for control purposes because the consequences of any decision are far-reaching, then operational research methods may be used. The object of operational research is to collect and analyse

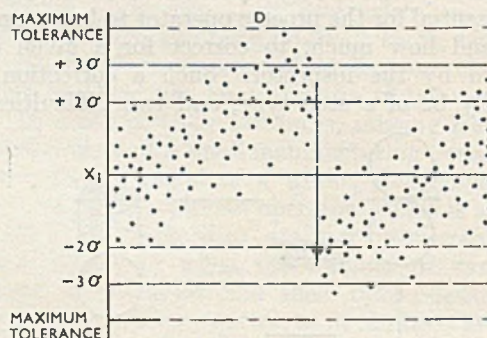


FIG. 15.—Quality Control Chart, Showing Drift of Process.

data obtained during normal manufacturing operations or usage, and to present the results as a basis for executive action. It is best separated from normal research activities, and is usually conducted by a group reporting directly to an executive, who, in this instance, would be responsible for controlling some essential technical factors in production. Statistical methods of analysis are invariably selected for dealing with the collected data, and a few results can be treated as effectively as large numbers. The only consideration when dealing with a few individuals is that the decisions to be made should be of sufficient importance to justify the higher cost of analysis of the data. These were, of course, precisely the reasons

prompting the widespread use of operational research during the latter stages of the Second World War. The method has great flexibility and uses all the available data for deciding the action to take at any given time and the standard at which to operate a control. It seeks to obtain the best answer from data that are necessarily limited and inadequate, and as such it should not be ignored.

VIII.—THE TECHNICAL CONTROL OF PROCESS VARIABLES IN INDUSTRIAL PRACTICE

After surveying the principles of control of quality it is instructive to see to what extent they have been

applied in practice. A review of all the metallurgical manufacturing processes would be far too lengthy, and it is intended to give here as an example only the melting and casting operations for producing non-ferrous ingots. Table II summarizes the situation, but is intended to be typical rather than comprehensive, although it represents the present state of technical advancement in the foundry. The principal purpose of the table is not so much to show present practice as to bring out ways in which technical advances may be made in the future.

We have already seen that in any manufacturing process there are variables whose control is essential for the output of a high-quality product. When such a variable was fundamental in relation to the process,

TABLE II.—*The Measurement and Control of Process Variables During the Melting and Casting of Non-Ferrous Metals.*

Operation	Variable	Type	Method of Measurement or Inspection	Type of Adjustment or Control
Melting	(1) Temperature of melt	Primary	Pyrometer or visual estimation	Manually controlled to required temperature by adjustment of fuel or power
	(2) Chemical composition of melt	„	Analysis of samples	Usually fixed by heat weighing. Occasionally controlled in accordance with rapid spectrographic analysis. With copper the oxygen content is controlled in accordance with the "set" of cast samples
	(3) Heat input to furnace	Secondary	Metering of fuel or power	Manually adjusted for the control of (1)
	(4) Composition of furnace atmosphere	„	Not generally measured	Rough adjustment made by means of air and fuel supplies, see (5)
Degassing and fluxing of melt	(5) Gas content of melt	Primary	Pfeiffer method, or visual observation of cast samples; density measurements	Sometimes controlled manually by adjustment of degassing agent or furnace atmosphere
	(6) Structural potentialities of melt (aluminium-silicon alloys and magnesium)	„	Examination of fracture of cast sample	Sometimes controlled manually by adjustment of sodium, flux, or other additions
	(7) Gas flow (chlorine, nitrogen, &c.)	Secondary	Metering of flow and quantity	Gas flow either fixed or manually adjusted for the control of (5)
	(8) Flux additions	„	Weighing	Flux additions either fixed or adjusted for the control of (5) or (6)
Casting	(9) Structure of ingot	Primary	Visual examination or measurement of grain-size, segregation, structure, and inclusions	No short-term control. Structure determined by (12), (13), (14), and (15)
	(10) Properties of ingot	„	Measurement of mechanical properties, density, porosity, hot and cold deformation; examination for internal defects by X-ray or ultrasonic methods	No short-term control. Properties determined by (9), (12), (13), (14), and (15)
	(11) External characteristics of ingot	„	Examination for surface defects, pipping, and cracks	Partially controlled by adjustment of temperature and rate of pouring
	(12) Rate of pouring	Secondary	Visual estimation or fixed by tundish	Adjusted for control of (11) within certain limits fixed by (9) and (10)
	(13) Temperature of pouring	„	Pyrometer or visual estimation	Usually fixed; occasionally adjusted for control of (11) within certain limits fixed by (9) and (10)
	(14) Mould temperature (15) Rate of withdrawal of ingot and flow of water in continuous-casting process	„ „	Pyrometer or unaided judgment Metering of withdrawal rate and flow of water	Fixed Adjusted for control of (11)

we termed it primary, and when a variable was introduced only because it affected a primary variable, we termed it secondary. To take an example from Table II, in the melting operation the desired end-product is a bath of metal of a particular composition and temperature. The two latter quantities are then the primary variables. The heat input to the furnace is a variable not of value in itself and is used only for controlling the bath temperature. It is therefore a secondary variable. On the other hand, the temperature of the metal is a secondary variable during the casting operation, because it is useful only in that it helps to determine the structure and properties of the ingot. In Table II the words "controlled", "adjusted", and "fixed" are used frequently. In every case control is given the precise and restricted meaning of error-actuated control, as defined in Section IV (p. 332). Control is thus dynamic, and can be clearly distinguished from adjusting or fixing, which are essentially static.

An examination of Table II reveals that the only primary variable always controlled is the temperature of the metal in the melting operation. In view of the remarks made earlier as to the advantages arising from the control of a primary variable, this is a depressing state of affairs. It is true that in some instances other primary variables numbered (2), (5), (6), and (11) are controlled, but this is by no means universal. The reasons for the relative absence of control are, of course, the associated practical problems, which are undoubtedly of considerable magnitude. It is significant that the variables numbered (2) and (5) are quite recent additions, and in particular the rapid analysis of the metal bath is becoming more and more attractive to manufacturers. The practical problems

of controlling other primary variables will gradually be solved and bring a corresponding increase in the quality of the product. The control of secondary variables is less necessary when primary variables are controlled, and in any case they present an easier problem. Similar situations occur in other sections of non-ferrous metal manufacture, such as rolling, forging, drawing, annealing, heat-treatment, and welding. The general picture is, in fact, that big opportunities are offered for improving quality by the extension of control to other primary variables in manufacture.

IX.—CONCLUSIONS

(1) Physical measurements of quality characteristics should be made wherever possible in order to control production with certainty at economic tolerances and rejection rates.

(2) It is expected that an extension of automatic control to many metallurgical operations will occur in the near future. A better understanding of all industrial processes involving a human operator will result from applying the principles derived from the study of automatic control mechanisms.

(3) The use of continuous manufacturing processes will increase, together with the application of statistical quality control for achieving high and consistent quality at low cost. A greater use of statistical methods in industrial problems involving small numbers of products may be forecast.

(4) From a sample survey it is concluded that advances in the control of quality will be made by extending technical control to cover more of the primary variables in manufacture.

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THE CONTROL OF QUALITY IN THE PRODUCTION OF BRASS INGOTS AND BILLETS*

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SYNOPSIS

After reference to relevant general considerations important in the formulation of quality-control procedures, the paper is mainly concerned with the application of basic principles and practical knowledge to eliminate or minimize the incidence of defects and so ensure the regular production of high-quality brass castings for the manufacture of alloys of this type in wrought forms.

The control of raw materials used in their production is dealt with, and the various factors involved in melting processes are considered with particular reference to low-frequency electric-furnace practice. Following some general observations on casting which include data concerning casting temperatures for different alloys and comments on cast structures, the significant factors relating to moulds and mould materials are reviewed. Pouring and the subsequent operation of feeding, which together constitute the process of casting, are in turn considered, and finally brief reference is made to inspection of cast products.

I.—INTRODUCTION

ALTHOUGH this paper is primarily concerned with the technological factors involved in controlling the quality of brass castings for the production of wrought products, there are other associated elements and functions of no less significance, since they feature importantly in the formulation of quality-control procedures and their successful application. A detailed consideration of these is, however, outside the scope of the paper, and therefore it is not possible to make more than brief mention of them.

Little more than a generation ago brass casting was carried out with practically none of the technical control which is so extensively exercised today. During the last three or four decades a wealth of knowledge has been accumulated regarding the effects which various factors have on the quality of castings, and it is now possible to specify with a high degree of precision the procedures that should be followed. It is indeed the effective implementation of this knowledge regularly in manufacturing processes which is the essence of control of quality.

The acquisition and application of information of this kind is continually increasing, and involves several important functions of an organization, such as production, research, laboratory control, inspection, engineering, work study, &c. The responsibility for maintenance of quality would seem fairly and logically to reside with production management, but the closest co-operation at all levels between production and the functions named is essential, if the maximum benefit is to be realized. From this

effective co-operation sound manufacturing procedures are born and established.

It does not suffice for details of techniques to be known to those immediately concerned and passed on by word of mouth, for therein lies the danger of inaccuracies arising and unauthorized changes being introduced which so often are the cause of quality falling below the standard that can otherwise be attained. They should take the form of written records in which the procedures to be followed and conditions to be observed are set out with clarity and precision. Such records or process manuals, which should be accessible to all connected with the supervision of the operations, provide the basis not only for control, but also for training and other schemes. While strict adherence to laid-down procedures is essential, it is also clearly important that these should be kept under constant and responsible review, in order that they may be immediately and appropriately modified in the light of new knowledge or as a consequence of plant or process alterations.

Successful control of quality depends vitally on the adequacy of supervision, the task of which is essentially to ensure that agreed and defined procedures are, in fact, meticulously carried out. Whilst, to this end, use is made of analytical and other technical services, instrumentation, and other aids, these are not to be regarded in any way as substitutes for the vigilance and skilled observation in the shops, which are so necessary to prevent deviations in detail from approved techniques.

As quality is affected by the way, and extent to which, the practised skill of operatives is utilized,

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it is essential for them to be fully instructed in the processes on which they are employed. Explanations of the why and wherefore of processes and of the cause and nature of defects of different types, as well as of their consequences at later stages of production or in the finished product, promotes an appreciation of the importance of quality and stimulates interest in working to techniques which have been devised to yield the best results.

Although melting and casting, by their very nature, are dirtier than many other metallurgical operations, the importance of effort directed to improving the standard of cleanliness cannot be gainsaid, not only with the object of minimizing contamination but for many other reasons also, including such obvious ones as increased efficiency, safety, and the like. That much can be achieved in this direction is abundantly demonstrated by the transformations brought about in some casting shops in recent years.

The whole subject of brass casting has been admirably surveyed by Hull.¹ The basic principles governing the production of good-quality non-ferrous metal ingots and billets for working have been dealt with by Bailey and Baker,² and the most important features of brass-melting practice, especially those of metallurgical interest, have been reviewed by Cook and Fletcher.³ The latter pointed out that many thousands of tons of chill-cast brass shapes are produced every week, and a high standard of quality is reached and maintained as a normal, everyday matter. Where defects do occur it is not because of serious technical difficulties in processes, or unsolved major metallurgical problems, but owing to ignorance, or lack of application, of the knowledge derived from long practical experience and specific investigations.

The purpose of the present paper is to indicate the manner in which basic principles and practical knowledge are applied and controlled to ensure the regular production of brass castings of high quality for the manufacture of substantial tonnages of these products for subsequent fabrication into sheet, strip, tube, rod, section, and wire. The alloys dealt with are the straight copper-zinc alloys containing 3-43% zinc, the more important of the copper-zinc alloys having relatively small additions of lead, tin, aluminium, &c., and the nickel silvers.

The quality of a metal casting for processing into wrought products such as sheet, strip, section, rod, tube, and wire, is determined by its composition, surface condition, internal soundness, and structure. The casting should be of uniform composition and alloying elements and impurities within specified limits. The surface must be substantially free from defects, such as cold shuts, pits, folds, porosity, entrapped oxides, or foreign matter, and even when such operations as scalping or milling are used to remove the cast surface either before or during fabrication, cast surface quality is still of importance in order to keep the scrap resulting from this operation at a minimum. A high degree of internal soundness

is required, and castings should be as free as possible from shrinkage cavities, blow-holes, gas pores, and other discontinuities. Finally, the structure of the cast product should be that most suitable for the particular method of working, or operation, to be used in processing the casting.

The maintenance of a high standard of quality in brass castings is essential, not only in order that the end product may have certain required properties and characteristics and be free from defects originating in the melting and casting operations, but also so that fabrication can be carried out in the most economic manner on the plant available. The total cost of fabrication is closely related to the amount of good saleable material that can be obtained from the cast product, and, in an endeavour to keep this cost as low as possible, scrap must at all stages be reduced to a minimum. Most avoidable scrap during fabrication can arise from faulty melting and casting techniques, and defects due to this cause may not become apparent until a late stage in fabrication has been reached and substantial expenditure incurred.

II.—RAW MATERIALS

The main raw materials used for the production of brass castings are virgin metals—copper, zinc, lead, tin, aluminium, nickel, &c.—temper alloys such as copper-iron, phosphor-copper, and cupro-manganese, and scrap brass. Rigid control over the quality of these raw materials and also over the relative proportions used for each particular alloy is necessary in order to ensure that the cast product is within the desired limits of composition. These limits may be those imposed by normal commercial specifications, by users' special requirements, or by the method of working to be employed. The importance of the latter consideration can be illustrated by the effect of small amounts of lead on the working properties of α -brasses. Whereas these alloys can be successfully cold rolled from the cast condition when containing lead up to the maximum of approximately 0.07% permitted in normal commercial specifications, for satisfactory hot rolling the lead content must not exceed 0.02%. Control over the quality of raw materials is effected by inspection, sampling, and analysis, supplemented by hand-sorting, magnetting, &c., where such treatments are required. The particular form and extent of control applied to the various raw materials depends on their origin and on knowledge and experience of their quality and reliability.

Virgin metals are today of such uniform quality and purity that it suffices to take representative samples from each delivery for the determination of impurities by suitable analytical methods. Temper alloys, although used in relatively small proportions, can be the cause of variable composition and a source of excessive impurities in the cast product, and they are, therefore, carefully sampled and analysed both for their main alloying elements and for impurities.

The raw material most likely to give rise to compositional variation and excessive impurities in the cast product is scrap brass, which is extensively used. The types of scrap commonly available can be classified into three broad groups:

- (i) Scrap arising during the normal course of fabrication of the casting into the finished or semi-finished product.
- (ii) Webbing scrap, trimmings, &c., returned from users.
- (iii) Miscellaneous scrap.

Process scrap arising during the normal course of fabrication is unlikely adversely to affect the quality of castings if due regard is paid to the proper segregation of alloys during manufacture. It is relevant in this connection to note that one of the commonest causes of mixing of scrap is an inadequate supply of suitable transportable containers in the processing plants and inadequate heat-room facilities. Sorting of mixed scrap not only throws increased responsibility on the casting-shop supervision, but involves substantial expenditure, despite which metal may have to be disposed of for low-grade usage.

Purchased scrap is the least reliable of all raw materials, and consequently requires the closest measure of control. Alloys may be mixed, there may be contamination by other metals such as iron, solder, metals used in plating, &c., and considerable amounts of non-metallic materials such as dirt and oil may be present. It is necessary, therefore, for all incoming scrap to be inspected, sorted where necessary, sampled, and analysed for major alloying elements and impurities.

The removal of particles of iron from brass swarf, turnings, and small scrap can readily be effected by use of the conventional belt-type magnetting machine. Baled scrap, however, because of its tightly packed form, cannot be dealt with in this manner, but may be checked for iron inclusions by passing the bales through a coil carrying a D.C. current. An indication of the amount of iron present in the bale can be obtained by measurement of the induced e.m.f. set up in a second coil wound concentric with the first. Bales found by this method to be contaminated may need to be broken down for further treatment on the magnetting machine. When the composition of scrap or swarf is unacceptably variable for use directly in making-up heats, it is separately melted—and so homogenized—and cast into the form of remelting ingots or pigs, the composition of which is then checked before the material is passed out for use.

The proportions in which virgin metals, scrap, and temper alloys are used in making up any particular alloy are determined to some extent by the nature of the alloy itself and also by the availability and purity of these alloying ingredients. It is clearly one of those matters which does not admit of generalizations. The make-up of each heat or furnace charge should be the responsibility of a qualified member of the supervisory staff, and written instruc-

tions should be given to those responsible for carrying out the actual heat preparation. Of the weighing operations themselves, it is necessary only to point out the obvious but sometimes overlooked importance of accurate weighing equipment. Because of the heavy duty to which this is subjected, checking must be frequent and, where it can be arranged, check weighing of charges on duplicate scales is a worthwhile additional control. Containers must be kept clean and tare weights frequently checked. Where charges contain alloying additions in such small quantity that they are liable to be overlooked if added to the main charge, and possibly introduced into the furnace at the wrong time, it is usually more satisfactory to make a separate issue of these materials in packets direct to the melting furnace.

III.—MELTING

The important defects in brass castings which can have their origin wholly or partly in the melting operations are incorrect or variable composition, the presence of undesirable metallic and non-metallic impurities, and, in the case of certain alloys, unsoundness due to gas absorption. Control over the melting operation should be such as to avoid, as far as possible, the incidence of these and also to ensure that the metal is raised to the requisite pouring temperature in the minimum time.

Today most of the brass produced for manufacture into wrought forms is melted in low-frequency furnaces. Units with melting capacities of 600–2400 lb./hr. are in common use, and recently furnaces of 10,000 lb./hr. capacity have been built.⁴ Crucible furnaces, both pit-fired up to approximately 200 lb. capacity and larger tilting units of up to approximately 1000 lb. capacity, are also extensively used, but more particularly in the melting of special alloys or relatively small tonnages, where the low-frequency furnace is unsuitable or uneconomic. Limited use is made of the arc furnace for certain alloys, particularly where a non-oxidizing atmosphere is advantageous. When considerable quantities of molten metal are required at a given time, as in the production of large plates, reverberatory furnaces are still employed to some extent.

While the economic advantages which the low-frequency furnace possesses over other methods of melting may have been the main reason for its introduction as a melting unit for brass, its adoption by the industry has itself been a major contribution to the maintaining of a high quality of casting. This is not to suggest that high-quality cast products cannot be obtained by the other methods of melting, for indeed everyday experience shows that they can, but it is to emphasize the comparative ease with which a high standard of quality can be achieved and maintained by low-frequency melting.

Compositional variations can arise in the melting operation from two causes: incomplete mixing of the constituents of the melt and excessive loss of one or more constituents by oxidation or volatilization

due to incorrect order of charging, overheating, or prolonged heating. In low-frequency melting the "motor" effect results in a very thorough mixing of the melt, even when elements of widely differing density are present, as in leady brass, but even so it is advisable to stir well immediately before skimming to ensure that any alloying additions that may have become entrapped in the oxide dross are completely dissolved in the melt. With other methods of melting, where the bath of metal is relatively quiescent, great care is necessary to ensure thorough mixing of the melt. In pit-fired crucibles a double stirring is advisable, one immediately before removing the crucible from the pit and the other immediately before pouring. With larger crucibles the stirring operation becomes more difficult owing to the buoyancy effect exerted on the stirrer, and particular attention to this operation is therefore required when furnaces of this type are used, if compositional variations are to be avoided.

Some loss of metal due to oxidation and volatilization is unavoidable during the melting of brass on a commercial scale, and it is customary to make allowance for this when weighing the furnace charge. Control of this loss is not only of considerable economic concern, but is of importance in maintaining a correct composition, since excessive loss of one or more elements from a melt will result in the cast product failing to meet specification requirements. Excessive loss is indicative of faulty melting technique, and loss figures provide an overall reflection of the standard to which the melting operation is being conducted.

The order and manner in which a furnace is charged have an important bearing on the amount of metal loss that occurs during melting. It is usual when melting in low-frequency furnaces to make an initial charge of medium scrap, followed by copper and light scrap and later by heavier scrap. Zinc, because of its high rate of loss at the temperature of molten brass, is added towards the end of the melting cycle. It is important that each addition should be completely immersed as quickly as possible, the effective introduction of light scrap and swarf being facilitated if it is in the form of bales or briquettes.

The form in which minor alloying elements are added, and the stage of the melting cycle at which they are introduced, depends on the amount of these additions and on such factors as their rate of solution, susceptibility to oxidation, volatilization, &c. Nickel, tin, and aluminium can conveniently be added as virgin metals, and it is usual to add these elements about three-quarters of the way through the melting cycle to allow time for complete solution and mixing. Lead is added as virgin metal or as a 50 : 50 copper-lead alloy, and it has been shown that in low-frequency furnaces the addition of this element can be made at any stage of the melting cycle without its distribution in the solidified ingot or billet being adversely affected.⁵ Although iron can be added in the form of thin sheet, this, because of its relatively slow rate

of solution, involves the risk of segregates of iron-rich constituents in the cast product, and, therefore, the addition of this element as a copper-iron or zinc-iron alloy containing 5-10% iron is the procedure normally followed. Manganese, phosphorus, and silicon, usually in the form of alloys with copper containing, respectively, 30% manganese, 5-15% phosphorus, and 10% silicon, are added at the end of the melting cycle. Additions of arsenic and antimony can conveniently be made as virgin metals in the finely divided form immediately before pouring.

It has been shown by one of the present authors⁶ that a substantial reduction in metal losses during the melting of brasses in low-frequency furnaces can be obtained by maintaining a protective cover over the melt and by adding a suitable flux before pouring. Although various carbonaceous materials such as coal, anthracite, and charcoal are effective as covers, charcoal in stick form is the most convenient to use. Sufficient should be added to the residual metal in the furnace before beginning the charging to provide a layer approximately 2 in. thick, and this should be maintained by further additions, if necessary, during the melting cycle. During melting, a dross cover consisting of a mixture of unburnt charcoal, metallic oxides (mainly that of zinc), together with particles of untrapped metal, builds up on the surface of the melt. By fluxing it is possible to lower considerably the metallic content of this dross, and although several materials such as salt, borax, ground glass, &c., are effective, it is usual to employ only salt because of its relative inertness to furnace linings. The quantity of salt used depends on the amount of dross formation. Where this is small, as in alloys of relatively low zinc content, approximately 1 lb. of salt/1000 lb. of melt suffices, but for alloys of high zinc content, or where a substantial proportion of swarf or light scrap has been melted, it may be necessary to increase the amount of salt to approximately 4 lb./1000 lb. of melt.

The heavy dross build-up which occurs during the melting of most of the brasses must be removed by skimming before pouring, to prevent its being carried into the tundish and possibly into the mould, where it might become entrapped in the casting. An exception to this procedure is common in the case of gilding metals, where the rate of build-up is much less and the dross layer can therefore be allowed to remain for a number of melts before removal. The insertion of a small piece of wood or plumbago in the furnace or crucible spout during pouring assists in preventing carry-over of residual dross into the tundish or mould.

In the majority of brass alloys of the type under consideration defects arising from the inclusion of oxides in the molten metal are not of common occurrence. Alloys containing additions of elements such as aluminium and silicon are, however, exceptions, and care is necessary at all stages to avoid turbulence or other conditions liable to result in the formation of the oxides of these metals and their inclusion in the molten bath.

Since metal loss is related to the time of melting, as well as to the temperature attained by the molten metal, it is desirable to standardize the melting cycle as closely as possible. This can more readily be effected in low-frequency furnaces, where heat input can be easily regulated, than in crucible furnaces, where the heat input is dependent on factors such as method of firing, quality of fuel, condition of crucible, &c. With the object of enabling a closer control over the melting cycle to be exercised, an instrument has been designed for use in conjunction with low-frequency furnaces which provides a record, shown diagrammatically in Fig. 1, of the time that a furnace is on full input, on standby input, and the time during which it is tilted for pouring. Such information provides those responsible for supervision with a means of detecting faulty melting technique and an opportunity for taking the necessary remedial action at the earliest moment.

Contamination of the melt can arise either from iron and other associated metals dissolved from the

if necessary. The walls and channels of the furnace must be thoroughly scraped, and it is advisable, too, for the volume of the wash charges to be larger than usual in order to cleanse as thoroughly as possible the area of furnace brickwork just above the normal metal level. Additionally, all tools used on the furnace should be thoroughly cleaned to remove any adherent metal.

Because of the high vapour pressure of zinc at the temperature of molten brass, gas absorption by these alloys is so small under normal conditions as to have no significant effect on the soundness of the casting and consequently no degassing treatment is called for. Nickel silver alloys, however, are liable to this type of defect, thus necessitating a modification to the general melting procedure to allow for the well-known oxidation-reduction treatment for the removal of dissolved gases to be carried out. Approximately 15 min. before pouring the charcoal cover is completely removed and the melt allowed to oxidize for about 10 min., after which a fresh charcoal cover

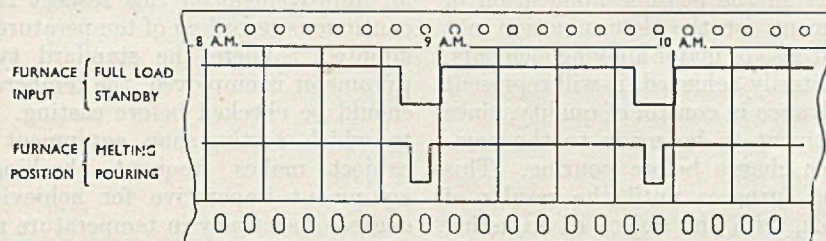


FIG. 1.—Record Chart Showing Electrical Input to Melting Furnace and Time Occupied on Melting and Casting.

tools used for stirring, or from the alloy previously melted, where a furnace has been changed from melting one alloy to another. To guard against contamination from stirrers, &c., it is usual for these to be fitted with plumbago or similar refractory sheaths of adequate length to ensure that the steel does not come in contact with the molten metal. The provision of suitable racks adjacent to furnaces to hold tools used in melting reduces the risk of impurities being introduced by pick-up from the floor of the shop. Contamination due to changing from one type of alloy to another is less likely to occur when small crucibles are used for melting, since it is generally convenient to use one crucible for one type of alloy. As far as possible the same procedure is adopted when low-frequency furnaces are used, or an endeavour is made so to arrange the sequence of alloys melted during the life of a furnace that the composition of each is not likely to be adversely affected by that preceding it. Frequently, however, changes of alloy have to be made which do not fall into this convenient sequence, and these can satisfactorily be carried out either by completely emptying the furnace or by reducing the molten heel in the furnace to a very low level, and in both cases melting two "wash-out" charges which are cast, analysed, and cut up for scrap

is added to the furnace. Immediately before pouring, a deoxidant in the form of cupro-manganese is added and stirred in. The charcoal cover is left in position during pouring, to avoid re-oxidation.

The analysis of a sample taken at the time of casting provides the final control of composition. When casting large rolling slabs and extrusion billets, a sample approximately $3 \times 1 \times \frac{3}{4}$ in. is taken from the pouring stream during the actual pouring operation; rolling slabs up to approximately 2 in. in thickness, such as are commonly used for cold rolling, can conveniently be sampled at the gating operation. Correlation between sample and casting is effected by a system of numbering or lettering, and castings are segregated until the results of analysis are available.

Although discussion of the analytical methods employed is outside the scope of this paper, it is necessary to refer to the frequency and type of analyses required for the proper control of composition. Frequency is determined by consideration of such factors as the specified limits of composition, the quantity and reliability of the various raw materials, particularly scrap, used in the preparation of the charge, and the significance of small amounts of impurities in relation to the working properties of the alloy.

Statistical analysis has shown that it is advisable, for the large majority of alloys, to determine copper on each cast. Alloying additions such as aluminium, nickel, tin, and lead, can, for most purposes, be appropriately determined on alternate casts, and intermediate casts submitted for analysis in the event of material falling outside specification limits. Impurities are determined, usually spectrographically, on every cast of alloys such as α -brasses and nickel silvers when these are to be fabricated by hot rolling, and on all alloys, whatever the method of fabrication, where close limits of impurity are specified. For fabrication by extrusion, cold rolling, &c., the impurity content is generally not so critical, and it suffices that impurities are determined on every third or fourth cast.

Speed of analysis is an important factor in effective control of composition, and aluminium and steel production is being aided in this respect by the use of the direct-reading spectrometer, which enables eleven or more elements to be determined in a matter of a few minutes. Considerable interest is being shown by the brass industry in the possible application of this type of instrument for the determination not only of impurities but also of major alloying elements. If this can be satisfactorily achieved, it will represent a most important advance in control of quality, since it will enable adjustment to be made to the composition of a furnace charge before pouring. This technique of holding furnaces until the results of analyses are available, with the object of adjusting the composition when necessary, is used to a limited extent and is a valuable form of control when furnace charges contain large percentages of scrap of uncertain composition. In order to avoid excessive delay, the analysis is usually confined to the determination of copper, which can be effected within approximately 10–15 min.

IV.—CASTING

Surface quality, structure, and, to a large extent, internal soundness of a casting are determined by the conditions which exist before, during, and immediately after the casting operation. These conditions, such as pouring temperature, type and condition of moulds, mould dressing, rate of pouring, and method of feeding, are determined for each alloy by metallurgical considerations and by the form and size of the castings.

1. TEMPERATURE

Control of temperature throughout the melting cycle is essential to the production of castings of high quality, and the regular measurement of temperature is even today not practised as completely as it should be. Too often it is left to the caster, by observation of various physical phenomena such as zinc burning, oxide-film formation, &c., to judge the pouring temperature. Whilst it may be that experience does allow some degree of skill to be attained in assessing the temperature of molten alloys, visual

judgment is, nevertheless, an undesirable practice, for it is neither sufficiently accurate nor reliable because it cannot adequately assess the influence which various factors, such as lighting conditions, emissivity, &c., can have on the appearance of the melt.

The various types of temperature-measuring equipment suitable for use in brass-melting shops are well known, and it suffices to say that the most desirable from the control aspect is one that gives a continuous record of temperature. As mentioned earlier, such a record is of value in controlling other features of the melting cycle. A record of this type (see Fig. 2, Plate XLVI) requires the use of a continuously immersed couple, and the problem arises of finding a sheath of adequate mechanical properties and ability to withstand, without rapid deterioration, continuous immersion in molten brass. Up to the present time the most satisfactory material for this purpose has been an iron-chromium alloy containing approximately 28% chromium. Even when using this alloy, lives of couple sheaths are relatively short and variable, and an improvement in this respect is necessary before continuous recording of temperatures can be generally adopted. Where the standard type of immersion pyrometer is employed, the temperature of each melt should be checked before casting. The rough usage to which casting-shop equipment is so commonly subject makes frequent checking of pyrometric equipment imperative for achieving a satisfactory degree of accuracy in temperature measurement.

The pouring temperature for a given alloy and type of mould is usually a compromise between that which will result in the greatest internal soundness and that which will produce the best surface condition and cast structure. A temperature below the optimum is liable to give rise to cold shuts, entrapped splittings, and oxides on the surface, although the casting will be of finer crystal structure and less prone to central unsoundness. A temperature above the optimum, while enabling an improved surface to be obtained, is likely to cause central unsoundness due to shrinkage, and a coarser structure. The optimum temperature for each alloy varies with the size and form of casting and the type of mould employed. In Table I are listed suitable casting temperatures for a number of brasses for casting into the form of rolling slabs and extrusion billets in cast-iron and water-cooled moulds. It will be seen that temperatures are specified to limits of $\pm 10^\circ\text{C}$., although it is not suggested that such close limits are necessary in many cases. For some alloys, however, control of temperature to within $\pm 10^\circ\text{C}$. is essential to obtain the necessary structural condition in the casting. This applies especially to the 66–67% copper alloy of the copper-zinc series, which falls within a critical range of composition inasmuch as at optimum hot-rolling temperatures a small proportion of the β phase is present. If the ingot is cast under conditions which cause it to have a coarse and mainly columnar type of structure, the β phase tends to segregate at

the boundaries of these large crystals, and severe cracking occurs in hot rolling. On the other hand, if the casting conditions are controlled so as to yield ingots composed mostly of small equiaxed crystals, the β phase is not segregated but distributed in the form of much smaller particles, a dispersal essential

Cast-iron moulds were introduced for brass casting during the last century, and it was usual until about 25 years ago for ingot moulds to be inclined at an angle of about 30° to the vertical; as a result metal as it entered the mould impinged on the lower face, causing severe local attack and overheating of the mould and consequent defects in the casting. With moulds so positioned there was additionally a tendency for oxide and other impurities to become entrapped on the upper face of the casting during solidification. These difficulties were overcome by the introduction of vertical moulds and pouring tundishes such as are now commonly used in brass casting.

TABLE I.—*Casting Temperatures for Brasses.*

Alloy Composition, %			Pouring Temperature, $\pm 10^\circ$ C.		
			Rolling Slabs		Billets
Cu	Zn		Water-Cooled Moulds	Cast-Iron Moulds	Cast-Iron Moulds
			Size of Casting $24\frac{1}{2} \times 3\frac{1}{2} \times 40$ in.	Size of Casting 4 to $16 \times 1\frac{1}{2} \times 39$ to 24 in.	Size of Casting 5 to 7 in. dia. $\times 60$ to 70 in.
97	3		1180	1210	...
95	5		1170	1200	...
90	10		1150	1180	...
85	15		1130	1160	...
80	20		1110	1140	...
70	30		1070	1100	1080
67	33		1000	1050	...
65	35		1030	1060	...
64	36		1020	1050	...
63	37		1030	1060	...
76	22	Al 2	1110	...	1190 *
70	29	Sn 1	...	...	1080
62	36	Pb 2	...	...	1060
58	39	3	...	...	1010
58	40	2	1000	...	1010
		Ni		Size of Casting 8 to $12 \times 1\frac{1}{2} \times 34$ in.	
60	32	8	...	1170	...
60	30	10	...	1180	...
60	28	12	...	1190	...
60	25	15	...	1200	...
60	22	18	...	1220	...
54	28	18	...	1220	...

* Durville casting. Billet size 4 to 7 in. dia. $\times 42$ to 24 in.

to the successful hot rolling of this alloy. Fig. 3 (a), (b), and (c) (Plate XLVII) show the structures obtained when this alloy is cast in a water-cooled mould at temperatures of 980° , 1000° , and 1020° C., respectively. As cast at 980° C., the ingots possess a fine equiaxed structure, whereas at 1020° C. the structure is mainly columnar, but the former is too low a temperature in respect of other considerations such as surface condition, and the optimum is 990° – 1010° C.

2. MOULDS

Both cast-iron and water-cooled moulds are extensively used for the production of brass castings, cast iron mainly for rolling slabs of relatively small section such as are required for cold rolling and for extrusion billets, while water-cooled copper-faced moulds are utilized mainly for slabs of relatively large section for hot rolling, although increasing interest is being shown in their use for billet casting.

Because of the severe thermal variations to which cast-iron moulds are subjected during a full casting cycle, they develop surface cracks which become progressively worse, and frequent and regular routine inspection of all moulds is necessary to ensure that they are withdrawn from service as soon as they have deteriorated to an extent that affects the quality of the casting. If allowed to remain too long in service severely cracked moulds give rise to blow-holes or internal porosity in castings through mould dressing or cooling water being entrapped in the cracks and vaporizing during the solidification of the metal. In extreme cases, this mould condition can interfere with contraction of the casting during solidification to such an extent that hot tears are caused on the ingot surface. The incidence of cracking is more acute when using this type of mould for alloys such as cupro-nickels and nickel silvers, where the pouring temperature is relatively high. To use two sets of moulds per furnace and to allow them to cool in air instead of cooling by water results in a significant improvement in mould life.

A substantial tonnage of brass rolling slabs and extrusion billets is today cast in copper-faced water-cooled moulds, which, in addition to providing more uniform mould conditions and greater chilling effect than are obtainable with the cast-iron mould, have the important advantage of not developing surface cracks during use. The successful operation of moulds of this type, however, requires careful attention to the quantity of water circulated through the mould during casting, the temperature at which the cooling water is delivered to the mould, and the manner in which it is distributed over the mould surfaces.

It has been found that cooling conditions suitable for the casting of brass rolling slabs weighing 1000 lb. in Junker-type moulds can be obtained by circulating water through the mould at the rate of approximately 100 gal./min. The temperature of the water delivered to the mould is maintained at approximately 70° F. (21° C.), which, under normal atmospheric conditions, is sufficiently high to prevent condensation occurring on the mould surfaces. Unless the cooling water is evenly distributed over the mould plates, castings having asymmetric structures may be produced, and the mould plates may become severely distorted. Uneven distribution of the cooling water may be due to faults in mould design or construction,

or to local blockages caused by waste products carried into the mould by the circulating water. Faults in mould design can be traced by a survey of the water temperatures in various parts of the mould, while blockage due to waste products is best prevented by providing adequate screens in the cooling system and by routine inspection of moulds after removal of face plates.

Owing to the expansion and contraction of the copper plates which occur during the casting cycle, moulds of the Junker type are prone to develop water leaks, particularly round the bolts holding the plates to the mould body, and routine maintenance is necessary if defective castings due to the presence of water in the moulds are to be avoided. Water leakage can be minimized by the choice of a suitable jointing material between the copper plate and water-jacket. Of the various materials used, such as lead wire, lead sheet, composite asbestos/lead packings, &c., the most satisfactory results have been obtained with a thin woven asbestos strip coated with white lead. The stresses set up in the mould during casting also result in progressive distortion of the mould plates, and a check on the extent to which this has developed should be carried out so that plates may be removed for reflattening or replacement when the distortion exceeds approximately $\frac{1}{16}$ in. These stresses are also liable to cause cracks to develop from the bolt holes, and it has been found that plates made from non-arsenical deoxidized copper are less liable to develop this type of defect than plates made from other varieties of copper.

3. MOULD DRESSINGS

Care in the selection of suitable mould dressings for different alloys and different casting conditions is essential to the production of satisfactory castings. The functions of a mould dressing have been summarized by Bailey and Baker² as:

- (i) To reduce the initial surface chill on the molten metal.
- (ii) To protect the mould face and prevent adherence of the molten metal to the mould.
- (iii) To provide, when desirable, an atmosphere of reducing gas within the mould and around the stream of metal.

These functions can be satisfied for the majority of brasses by the use of a mixture of mineral oil and powdered charcoal, with the addition of small amounts of tallow for alloys such as gilding metals which are poured at higher temperatures. Exceptions to this general practice are adopted for the casting of brass and gilding-metal rolling slabs in cast-iron moulds, when dressings of resin for brass and a mixture of tallow and charcoal for gilding metals are preferred. Nickel silvers, which are liable to absorb gas from normal oily dressings, are cast with mould coatings of lard oil and black lead thinly applied and thoroughly rubbed into the surface. When aluminium brasses

are cast by the Durville process, it is unnecessary to use a mould dressing of any type. In Table II are itemized the dressings used on water-cooled and cast-iron moulds for the more important commercial brasses.

To ensure consistency in quality and make-up, the preparation of mould dressings should be carried out in bulk under controlled conditions. Charcoal powder with a degree of fineness such that 95% will pass a 200-mesh sieve and a mineral oil having a Redwood No. 1 viscosity of 100 sec. at 200° F. (93° C.) and a flash point of 420° F. (215° C.) yield, when mixed in the proportions of 7 lb. charcoal to 1½ gal. oil, a mixture of suitable working consistency. The dressing must be well boiled before use to remove traces of moisture which, if allowed to remain, would impair the quality of the casting.

TABLE II.—*Mould Dressings for Commercial Brasses.*

Alloy Composition	Form of Casting	Type of Mould	Composition of Dressing
Cu 58-75%, balance Zn	Rolling slab	Water-cooled	Mineral oil and charcoal
" "		Cast-iron	Resin
Cu 76-97%, balance Zn		Water-cooled	Mineral oil, tallow, and charcoal
" "		Cast-iron	Tallow and charcoal
Nickel Silvers		"	Lard oil and black lead
Cu 76, Zn 22, Al 2%		Water-cooled	Mineral oil and charcoal
Cu 70%, balance Zn	Billets	Cast-iron	Mineral oil and charcoal
Cu 70, Zn 29, Sn 1%		"	" "
Cu 58, Zn 39, Pb 3%		"	" "
Cu 76, Zn 22, Al 2%		Cast-iron (Durville)	No dressing

The correct quantity of dressing to be applied to a mould is largely a matter of experience and does not lend itself to precise definition. Even distribution is essential and is facilitated by applying the dressing while hot to slab moulds by brush and to billet moulds by mop. The latter must fit closely in the mould and frequent replacement of mop coverings is necessary. The thickness of coating applied is varied for different alloys. Brasses containing 58-63% copper, for example, require, when cast in a water-cooled mould, a lighter application of dressing than alloys containing 64-75% copper, whereas for gilding metals a thicker coating is needed and is obtained by the addition of tallow to the oil-charcoal mixture. The rough areas liable to occur at the bottom corners of slabs and over the lower few inches of billet surfaces can be reduced or eliminated by dusting a little charcoal powder into the corners of slab moulds and by pouring a small quantity of liquid dressing into the bottom of billet moulds after the surface-dressing operation has been completed. The effects of faulty technique in the choice and application of mould dressings readily reveal themselves on the cast product. Too little dressing results in the casting sticking to the mould, while an excess gives rise to dirty

castings, sub-surface porosity, or, in extreme cases, blow-holes and gas inclusions.

Burnt mould dressing must be completely removed by scraping and brushing after each cast and, in addition, it is necessary to eliminate at frequent intervals the hard encrustation, consisting mainly of a mixture of zinc and zinc oxide, which builds up locally on the walls of cast-iron moulds. Unless removed, these encrustations tend to hold excessive quantities of mould dressing and thus give rise to surface imperfections.

4. POURING

The transfer of metal from crucible to mould at a rate and in a manner which would produce a sound casting was at one time a most important part of the art of casting. Distribution of the metal stream and the rate at which the mould was filled were dependent entirely on the caster's judgment. Today these are matters of accurate control, the introduction of the tundish for brass casting having provided a method both for ensuring constant rate of pouring and an even entry and distribution of the liquid in the mould.

Tundishes, usually of cast iron, are provided with a number of holes of a size to permit a rate of rise of metal in the mould of approximately 1-1½ in./sec. For slab casting, the holes, approximately ⅜ in. in dia., are evenly spaced along the centre line of the tundish. For billets, a single central hole of ¾-1 in. dia., depending on the size of billet, is used. The depth and positioning of the holes must be such as to ensure that the stream of metal falls cleanly down the centre of the mould and does not at any point impinge on the mould walls. In order to avoid progressive diminution in the rate of pouring or uneven distribution of metal in the mould, these holes must be carefully cleaned out by reamer after each cast to free them from the deposit of oxides and other matter with which they become coated.

Tundishes should be kept full during the whole of the pouring operation to ensure a steady supply of metal to the mould and also to reduce the risk of dross entering the mould with the metal stream. The initial filling of the tundish is important, and a sufficient volume of metal must be poured into it to cause a steady flow to begin almost immediately from each of the holes. This is achieved by inserting a plug in the spout of the furnace or crucible to hold back the metal until a sufficient degree of tilt has been attained. The steady flow of metal from furnace or crucible to tundish is also dependent on the spout being kept clear of dross and other material and on the correct shape being maintained by careful re-shaping to repair wear or damage.

Because of the impingement of molten metal, often on a constant and restricted area, tundishes are liable to severe erosion which, in addition to shortening their useful life, may lead also to iron contamination of castings. A dressing with tar provides a sufficient protective treatment for most purposes, although

when high-temperature alloys are being cast the additional provision of a small patch of refractory on the impingement area is a further safeguard.

Although brasses containing up to 2% aluminium can, under carefully controlled conditions, be successfully cast in vertical moulds with flaming dressings, the less convenient and more expensive Durville process is still employed for alloys of this type. The Durville machine, if it is in good mechanical condition and carefully operated, is capable of producing castings of exceptionally high quality, both as regards surface condition and internal soundness, although the rather coarse structure of brass ingots cast by this method may not be acceptable in all circumstances. Because of difficulties associated with adequate feeding, it is usual to confine the use of the process to the production of relatively short castings. As with all casting equipment, a high standard of cleanliness must be maintained, and the Durville machine, being somewhat less accessible than the normal mould and being fitted with a refractory-lined container from which particles of refractory readily become detached, requires particular attention in this respect. As stated earlier, mould dressings are not necessary when using this equipment for casting aluminium brasses, but the mould should be preheated to a temperature of approximately 100° C. before use to prevent the formation of cold shuts on the surface of the ingot or billet. Metal is usually transferred by ladle from the melting furnace to the container, and dross and oxide carefully removed by skimming before tilting. The tilting operation, which may be performed mechanically or manually, must proceed slowly, steadily, and smoothly, and this requires machines to be maintained in good mechanical order, for any jerkiness in movement as the assembly is turned about its point of balance gives rise to serious folds on the surface of the casting.

5. FEEDING

The purpose of feeding, which is a continuation of the pouring process, is to prevent unsoundness from two volume changes which occur during solidification, the initial contraction of the liquid as it cools to the point of solidification, and the further contraction during the actual solidification process. Good feeding practice demands an ample and as far as possible uninterrupted supply of metal at a suitable temperature to the top of the casting during the whole of the solidification process. The supply may be either direct from the furnace or crucible or via a hand ladle, depending on the operating conditions. Where a number of small castings or one large casting is being produced, direct feeding from the furnace is practised, but where a number of relatively large castings is being produced from one furnace it may be more convenient to feed one casting by hand ladle while the next is being poured. Even distribution of feed metal is facilitated by allowing it to pass through the runner box or tundish.

The temperature of the feed metal should approximate to that at which the casting was initially poured. In practice some drop in temperature does occur, but this is usually so slight as not to interfere with satisfactory feeding of castings of most brasses. For such alloys as gilding metals and nickel silvers, which solidify at relatively high temperatures, some provision for reducing heat losses of the feed metal and preventing premature solidification of the casting is to be recommended, and this can best be effected by the addition of a small quantity of charcoal to both the tundish and the top of the casting.

"Self" feeding by the use of "hot tops" is not normally practised for the production of brass castings for further fabrication, except indirectly in the continuous-casting processes where feeding proceeds continuously from the liquid metal lying above the solidified casting. A reduced rate of heat extraction in the upper part of the mould may, however, in some instances, provide a means of improved feeding. The reduction in wall thickness of billet moulds for the top few inches, and the provision in this area of an insulating material such as sand, have been found to improve the efficiency of the feeding operation; while for the casting of nickel silver in cast-iron moulds it is advantageous to apply an insulating coating of bone ash over the upper part of the mould before adding the normal mould dressing.

V.—INSPECTION

A routine system of inspection of all castings is essential for the proper control of quality, and, by enabling withdrawal of defective material at the first stage of processing, ensures that wasteful expenditure is kept to a minimum. The type of sampling and analysis necessary for checking composition has already been dealt with, and reference has been made to the main types of surface defects that may occur in brass castings. Trained personnel are required for the visual examination of cast products, and it is important that the inspection is carried out as soon after the casting operation as possible in order that the earliest opportunity can be taken of correcting any operational faults.

By experienced visual inspection the presence can be detected of certain impurities which impart a

distinctive colour to the casting, even in small quantities. Aluminium, for example, when present in amounts as low as 0.05% causes castings to have a golden colour, while small amounts of manganese and iron give rise to a reddish tinge and silicon to a silvery appearance.

Information regarding internal soundness is provided by examination of the sawn or sheared face after removal of the gate or top end, and before being passed out for processing castings are cut back until there is no evidence of unsoundness on the cut or sheared surface. To the practised and discerning eye other features, as well as unsoundness, which have a bearing on quality are revealed. The critical examination of cropped billets or ingots is not only an important but an essential part of the process of quality assessment, and calls for experience, knowledge, and meticulous care. Provided the melting and casting processes have been carried through all stages in accordance with well-established practice based on the results of experience and careful experiment, and all the necessary precautions observed, the amount which it is necessary to cut from an ingot to remove top-end unsoundness is but a small fraction of the length of the casting. The actual extent of the discard varies with the size and shape of the ingot, but if this is not only small, but consistently small, and the appearance of the sheared surface satisfactory in other respects, it provides adequate testimony of the success and effectiveness of quality control of many of the operations involved in the production of castings.

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THE CONTROL OF QUALITY IN MELTING AND CASTING COPPER AND HIGH-CONDUCTIVITY COPPER-BASE ALLOYS *

1450

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SYNOPSIS

Control is necessary at all stages during the production of high-conductivity copper shapes for subsequent working. The selection of raw materials and their blending into suitable furnace charges are discussed in relation to the type of furnace to be used. The fire-refining process for the production of high-conductivity copper wire-bars is outlined, and control methods are described in detail. Photographs show the changes occurring in the structure of button and tube samples during the course of oxidation and the later stages of the reduction process. The removal of arsenic by soda ash-lime fluxing is described, and a method is given for its control by conductivity testing.

Desirable qualities required for mould dressings are indicated, and reference is made to the influence of pouring speed and the oxygen content of the copper on the set of the final casting. Typical pouring temperatures and speeds are given.

Methods used in the production of phosphorus-deoxidized copper, tellurium copper, cadmium copper, and silver copper are outlined, with reference to the time of alloy addition and the control of oxygen content in the bath.

Typical casting defects and their causes are listed, and inspection and analytical methods outlined.

I.—INTRODUCTION

IN dealing with the control of quality in the melting and casting of copper and its alloys, it is inevitable that some reference be made to well-known processes and practices, since technique varies with the type of equipment and its function. The method of control will depend on the technique, and therefore it is impossible to avoid a certain amount of repetition of common knowledge.

The scope of the paper is confined to methods of control employed in melting and casting fire-refined copper, electrolytic copper, phosphorus-deoxidized copper, cadmium copper, tellurium copper, and silver-bearing copper. Some of the methods used to produce a sound casting are fairly general and applicable to other copper alloys not specifically mentioned. The selection of raw materials and charge make-up are considered in relation to the type of furnace and the metal or alloy to be produced. The control of contamination from fuels, furnace launders, ladle linings, and from charge materials is considered.

This is followed by a more detailed description of control methods employed during the fire-refining of copper in a large oil-fired reverberatory furnace, and its subsequent casting into horizontal wire-bars.

The production of vertically cast billets and rolling slabs is described, and mention is made of the effects of pouring speed, funnel shape and size, oxygen con-

tent of the metal, mould temperature and size, on the quality of the final casting.

The final section covers the testing and inspection of the cast shapes.

II.—RAW MATERIALS FOR MELTING AND REFINING

The materials available to fire-refiners and melters of copper include blister copper, process scrap, virgin electrolytic copper, and secondary electrolytic copper. The character and chemical composition of such metal varies very considerably, as can be judged from typical analyses given below, and careful attention must be paid to the make-up of individual charges. It will be appreciated later that there are limitations to the normal fire-refining process, and individual impurities in the charge must be kept below certain limits if economical furnace operation is to be ensured. In particular, bismuth, nickel, selenium, tellurium, cobalt, silver, and gold are not normally removed. Antimony and arsenic can be more or less entirely eliminated by special fluxing techniques. Tin and lead can be reduced to reasonable limits by excessive slagging, with a consequent increase in copper losses and reduction in refractory life. Iron, sulphur, zinc, cadmium, and aluminium are fairly readily removed.

Blister copper supplies to the United Kingdom come almost entirely from the copper belt of Northern

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Rhodesia. They arrive in the form of 350-lb., horizontally cast cakes, and the following analysis is typical of blister obtained from the Mufulira mines¹:

	Per Cent.		Per Cent.
Cu	99.5	Sb	0.0003
Pb	0.0012	Ni	0.0062
Fe	0.011	Co	Trace
S	0.066	Se	0.0017
Bi	0.0018	Te	0.0001
As	0.0012		

Each consignment of blister is stock-piled separately. Cakes are taken for drilling and the drillings mixed, quartered, and sent to the chemical laboratory for complete analysis.

With large consignments of scrap wire, sufficient samples are taken to make up a 3000-lb. melt. This melt is cast into ingots which are drilled and a truly representative analysis of the parcel obtained. The analyses obtained from various batches are used for blending satisfactory furnace charges.

Domestic scrap arisings, having already been refined, present no difficulties in usage, provided that efficient segregation is maintained in the mills. Too great an emphasis cannot be placed on the necessity for efficient scrap segregation. All scrap should be clearly identified and baled without delay. The advantages of baling are not confined to facilitating storage, as time is saved in furnace charging and oxidation losses are kept to a minimum.

Merchant scrap is normally the worst type of material to be handled, calling for rigorous inspection by trained scrap sorters and rapid analytical checks, normally by spectrographic means. Clean bright copper and clean burnt paper-covered wire present no great difficulties from the point of view of contamination. Heavy copper, burnt tinned wire, lead-splashed wire, and brazier copper present greater difficulties, as they contain higher amounts of tin, lead, or arsenic. They are not used in the production of high-conductivity copper, and are generally disposed of in special low-grade charges or as anodes for electrolytic refining. Alloys such as chromium copper and cadmium copper are undesirable, and use should be made of magnets to remove tramp iron and copper-clad steel.

Electrolytic copper cathodes are normally run down separately in special small oil-fired tilting furnaces, or in electric furnaces of the direct-arc type with atmosphere control. A typical analysis of primary electrolytic copper is: Cu 99.98, S 0.0003, Fe 0.0009, Bi 0.0001, Ni 0.0005, Se 0.0006, Te 0.0001, Sb 0.0001%. Secondary electrolytic copper usually conforms to British Standard No. 1035, but when it originates from pickling-acid regeneration plants it is often undesirably high in lead and occluded sulphate. However, compared with other materials available, the output of cathodes from acid-regeneration plants is almost negligible.

Small quantities of mill scale may also be added to a refining charge, but only if it is of very high grade. Scale with a high iron content is added to

anode casting furnaces for ultimate electrolytic refining.

Control in the selection of raw material is dependent on the accurate analysis of representative samples. Such analysis may be made chemically or spectrographically. With the exception of selenium and sulphur, for which the quartz spectrograph is unsuitable, all other elements of interest can be determined more rapidly by spectrographic analysis. The introduction of the direct-reading spectrograph for the analysis of non-ferrous metals has increased the speed at which results can be obtained. One of the minor disadvantages of this instrument, however, is its dependence on a minimum sample mass for accurate quantitative estimations. This means that the casting of standard-size test-pieces is desirable.

Inspection and segregation of alloy scrap follows similar lines, though this is even more important in that no refining occurs during remelting. Any undesirable elements present in the scrap will inevitably be reflected in the analysis of the final cast billet.

III.—CHARGE MAKE-UP AND BLENDING

In making up furnace charges consideration must be given to the method of melting to be employed, and to the extent to which the material can be refined. Where no refining is possible, charges must be blended so that a satisfactory analysis is achieved in the final casting.

Light scrap is usually charged in the larger refining furnaces to form a cushion on to which the heavier scrap and blister can be loaded. Small scrap should be baled tightly, and the charge arranged carefully in the furnace so that high melting rates are obtained. It must not be stacked in such a way that the flame is deflected on to the furnace roof or side walls, as incomplete combustion of the fuel may result. In the case of crucible furnaces, a dense charge in good contact with the crucible will result in maximum melting rates and minimum losses by oxidation.

IV.—TYPES OF FURNACE USED IN GREAT BRITAIN

1. OIL- OR FUEL-FIRED FURNACES

Within a particular metallurgical industry a considerable diversity of furnace construction and operation will usually be found. Some of these differences are due to local conditions, others to differences of opinion. Every good furnace operator or designer is continually testing his views by making minor changes in furnace operation or construction. Thereby progress is achieved.

The bulk of the high-conductivity shapes cast in the United Kingdom is produced from blister copper and high-grade copper scrap. Melting, followed by fire-refining, is carried out in reverberatory furnaces fired either by pulverized fuel or by fuel oil. Furnace capacities may vary from 50 to 180 tons, but the

charging, melting, refining, and casting sequence almost always covers a 24-hr. cycle.

The time during which tough-pitch copper can be maintained at pitch is limited, and casting must be arranged so that the furnace is emptied as rapidly as possible. When the charge is cast into horizontal wire-bars, or vertical-cast cakes on the casting wheel, little difficulty should be experienced in holding the metal at the correct pitch. However, in a plant which has to cast mixed shapes daily, e.g. vertically cast cakes, billets, and horizontal wire-bars, it is the practice to make use of 5-ton portable holding furnaces.

Metal is run down side launders to 5-ton portable furnaces before casting on the wheel is begun, and also at intervals while casting is proceeding. These furnaces are provided with oil burners so that the metal can be kept hot for long periods, thus making operations more flexible. If the copper has to be held for prolonged periods, the oxygen content of the metal is maintained at slightly less than 0.07% in order to get a minimum sulphur pick-up from the furnace gases. The bath is finally poled to the correct

of the reverberatory tilting type has been installed in the works of the Enfield Copper Refining Co. Melting in this furnace is rapid, and by careful control of combustion conditions the copper is nearly blown at the end of this operation; 45-50 tons/day are being cast from this furnace into 1000-lb. vertically cast cakes. Fuel consumption is very good. Charging times are eliminated in the normal sense, as the furnaces melt at the same time as they are being charged.

Special charges of electrolytic copper cathodes are melted in reverberatory furnaces, and in some cases only a limited refining process need be employed. Depending on the degree of purity and physical character of the cathodes, the oxidation period may be stopped when the bath contains 0.6% oxygen. At this stage sulphur, which is usually the principal impurity, will have been removed and poling operations can be begun.

2. FURNACES FOR DIRECT MELTING

Furnaces in which high-conductivity copper can be melted without the need of the oxidation-reduction cycle are of the electric type utilizing a form of atmosphere control.² The material making up the charge is invariably electrolytically refined copper in the form of cathodes.

Copper alloys containing the more refractory metals, such as chromium, are generally produced in rocking-arc furnaces of up to $\frac{1}{2}$ -ton capacity. The Durville method of casting is preferable for this type of alloy. Adequate chilling of the mould is necessary to reduce the possibility of segregation within the final casting. Chromium coppers can be produced in crucible furnaces provided that sufficient superheat is obtained in the copper before the chromium additions are made. Temperatures of the order of 2750° F. (1510° C.) are required, and thus the arc furnace is often considered more suitable.

Crucible furnaces of the oil- or gas-fired type are used for the production of alloys such as tellurium copper. Phosphorus-deoxidized copper cakes may also be produced from crucible furnaces, though more generally they are cast from the 5-ton portable furnaces mentioned above.

V.—THE INFLUENCE OF FUELS AND FURNACE ATMOSPHERE

In electric-arc furnace melting the risk of serious contamination of the charge is slight. The ash content of graphite or amorphous carbon electrodes is normally 0.5%, and the iron content of electrodes should be less than 0.1%.

Solid-fuel-fired furnaces of the grate type may be quickly dismissed, as they have been almost wholly superseded by furnaces fired with pulverized fuel or oil. Solid fuels should have a very low ash content and a high volatile content, particularly in the case of pulverized fuel where the whole of it is introduced into the furnace chamber. The sulphur content should be

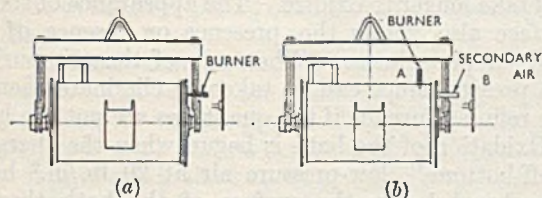


FIG. 1.—Sketch of 5-Ton Portable Furnace, Showing Burner Positions for (a) Horizontal and (b) Vertical Firing.

pitch when required for producing side-cast shapes on a wheel or in racks. Sulphur pick-up is also minimized if vertical firing is used on the portable furnaces when they are being brought up to temperature to receive molten copper, and also for the period during which the metal is being held. Horizontal firing is reverted to when the copper is being brought to pitch and during casting operations.

Fig. 1 shows a 5-ton portable furnace with the two burner positions indicated. When fired vertically the oil is atomized by high-pressure primary air, and enters the furnace as shown by the arrow (A). Secondary air enters the furnace through a second port in the end of the furnace (see arrow B). When horizontal firing is used, the oil- and primary-air burner is moved from position (A) to position (B). In this case the burner becomes more conventional in design, in that the oil, the primary air for atomization, and the secondary air, all enter the combustion zone in approximately the same direction.

Control of the operations in oil-fired or pulverized-fuel-fired rotary furnaces and tilting furnaces of up to 20 tons is similar to that practised on the larger reverberatory furnaces, though the whole refining cycle may be completed in as little as 6-8 hr. Rotary furnaces of the Thomas or Gottschalk type have been in use in Europe for copper refining for the past 15 years or so. Recently a 6-ton oil-fired furnace

as low as possible, and the degree of combustion as high as is practicable, to prevent its absorption into the bath.

In the case of oil-fired reverberatory furnaces two types of oil are often employed. During melting down, when a high heat input is required, and during part of the oxidation period in the refining process, heavy fuel oil is used. This may contain as much as 2.75% sulphur, but provided that oxidizing conditions and efficient combustion are maintained, no serious sulphur pick-up occurs. When the oxidation process has reached the stage where about 0.6% oxygen is present in the molten copper, the heavy oil burners are replaced by burners using a light gas oil. This oil is employed during the rest of the refining cycle, and it is desirable that it should have a sulphur content of less than 0.2%. In actual practice oils with sulphur contents up to 0.5% have been used successfully.

Satisfactory combustion is essential for economic furnace operation, and control of the fuel burners must

TABLE I.—*Flue-Gas Figures During a Complete Refining Cycle of a 175-Ton-Capacity Oil-Fired Furnace.*

Process	Time, hr.	Mean Flue-Gas Temperature		Oil Consumption, gal./hr.	Mean CO ₂ Content, %
		°F.	°C.		
Charging	6	1770	966	Rises from 50 to 300 in 1st hour, then constant.	15
Melting	6	1900	1038	300	15
Oxidizing	4	1850	1010	180	10
Poling	3	1850-1900	1010-1038	50	8
Casting	5	1090	588	30-40	5

be very flexible. Oil burners capable of efficient combustion over a range of fuel flow from 15 to 170 gal./hr. are not uncommon.

To assist in obtaining the desired atmosphere during the refining process, draught gauges and carbon-dioxide recorders are installed in the furnace stack and uptake. Maximum fuel efficiencies are generally obtained when the flue gases contain 10-14% carbon dioxide, and during melting a maximum content is required, indicating complete combustion. Flame intensity and furnace temperature are increased with the aid of secondary air during melting. An oxidizing flame is necessary when blowing, and the excess air introduced to the furnace causes a reduction in the carbon dioxide content of the flue gases. During poling operations a neutral or slightly reducing flame is maintained, and the furnace is put under slight pressure with the object of drawing in as little oxygen as possible. Table I shows the mean carbon dioxide content of the flue gases from a 175-ton oil-fired refining furnace, during a complete refining cycle. Mean flue-gas temperatures and oil consumption are included for the sake of completeness. The charging time is longer than usual, as the charge in question had a rather high scrap content.

VI.—CONTROL OF THE FIRE-REFINING PROCESS

1. GENERAL PRACTICE

The process of fire-refining is well established in principle and has been described in considerable detail recently by Miller.³ In a straightforward charge in which no specialized processes are necessary for the removal of arsenic or antimony, four skimmings are usually made. The first skim is made when the bath is flat, and this is followed by taking the first button sample with a bone-ash-dressed "say-ladle". The first few buttons from a new ladle are usually unsatisfactory, and the ladle is burnt by dipping in the molten copper five or six times.

The appearance of the sample during and after solidification gives an indication of the length of time which the oxidation period is likely to take. Some brands of blister copper are highly oxidized and usually show a flat or sunken set in the button; others, low in oxygen, may contain from 0.05 to 0.10% sulphur, and buttons from these coppers will show a spew and will take longer to oxidize. The appearance of the set surface also shows the presence or absence of tin, lead, or phosphorus. When any of these impurities are present, steps can be taken to eliminate them in the refining furnace if the quantities are not too high.

Oxidation of the bath is begun when the charge is "off-bottom", low-pressure air at 20 lb./in.² being introduced below the surface of the bath through $\frac{3}{8}$ -in.-dia. steel pipes. Subsequent button samples change in appearance from a dirty brick red to a coarse-grain fracture. As the blow progresses, types of structure are obtained which are known as fine-grain, small-block, and big-block. The fine stringy grain structure contains 0.4% oxygen, corresponding to the eutectic point, and the big-block structure contains 0.9% oxygen. The oxygen content of "low-set" buttons (rising to 0.9%) may be estimated microscopically. The button is sectioned, polished, etched with nitric acid, and finally polished on dry Selvyt cloth before examination (see Fig. 4, Plate XLVIII, for photomicrographs of typical sections, and Appendix I, p. 362, for details of the etching reagents employed).

The second and third skims are usually taken at the fine-grain and small-block stages, respectively. When the big-block structure has been obtained, the furnace is skimmed perfectly clean for the last time, using silica sand and charcoal to thicken up the slag. The furnace is then covered with approximately 1 ton of low-sulphur coke, the dampers on the furnace are set, the flame adjusted to a neutral or slightly reducing condition, and poling begun.

After poling has been in progress for some time the taking of samples in the say-ladle is resumed. The ladle is coated with charcoal by rubbing it on a burnt poling tree, and the set obtained corresponds to a slightly lower oxygen content than that existing in the bath. The furnace operator is thus provided

with a small safety factor when estimating the condition of his melt.

In the early stages, immediately before the final solidification of the button sample, the "nigger" appears. This is actually a shrinkage cavity, and its presence is due to the low solubility of gases (hydrogen and carbon monoxide) in copper of high oxygen content⁴; the solubility is very low at about 0.07% oxygen, from which point it increases as the oxygen content decreases. The presence of gases in the copper diminishes the shrinkage of the metal on solidification. Thus, as poling continues, the shrinkage cavity decreases in size until it disappears entirely.⁵ When the copper is almost at pitch, as judged from the button samples, 9 × 4 × 4 in. block castings are taken.

Once the oxygen content of the bath is judged to be down to 0.07%, no further additions of coke are made. Charcoal, being sulphur-free, is used from this stage of poling until casting is completed. If sulphur has been picked up during the later stages of poling, button samples tend to spew, giving a similar effect to that obtained from an over-poled bath. The relation of sulphur to the over-poling of copper has been discussed by Skowronski.⁶

When block samples show a "crown" set, casting is begun. The set of the wire-bars will be slightly lower, owing to oxygen picked up during pouring. A slightly low pitch can be detected by the appearance of groups of small black spots at either end of the bar almost as soon as the copper begins to solidify.

Just before, and during casting, $\frac{3}{4}$ -in.-dia. tube samples are taken from the stream of metal tapped from the furnace and checked for oxygen optically, being compared against standard photomicrographs of known oxygen content (see Fig. 5, Plate XLIX, for photomicrographs of typical tube-sample structures, and Appendix I, p. 362, for details of the etching reagents employed).

2. PROCESSES TO REDUCE IMPURITIES

After a charge is flat, the first button sample sometimes shows a dirty area just under the set on fracturing. This usually denotes the presence of arsenic or antimony. These elements can be almost completely eliminated by the use of soda ash and lime slagging.⁷ A method for arsenic removal and its control is described below.

Once the charge is off-bottom blowing begins. When the melt contains about 0.75% oxygen and has attained a temperature of about 2200° F. (1200° C.), the bath is skimmed clean. Soda ash and lime are blown under the surface of the bath from a special tank, using a 1-in.-bore steel pipe, which is passed through a port in one of the side doors near the uptake end of the furnace. Sometimes a pole is put in at the same time to keep the bath stirred. Details of the construction of the blow tank are shown in Fig. 2.

The arsenic slag is quite thick and floats on the surface of the bath, from which it can easily be skimmed as it accumulates.

A sample is taken from the furnace after each tank has been blown, transferred to a graphite pot in a preheated coke-fired furnace, poled up to pitch, and cast into a $\frac{1}{2}$ -in. square slug about 9 in. long. This slug is then rolled to $\frac{1}{4}$ -in.-dia. rod on a small sample mill, annealed, pickled, and drawn down to 0.0808-in.-dia. wire, annealed, cleaned, cut to length, and tested for conductivity. Details of the method of testing, using

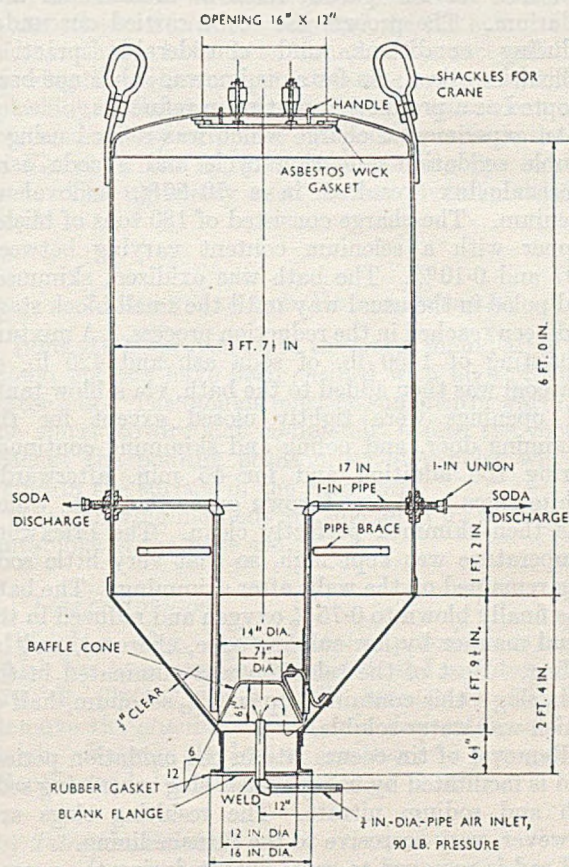


FIG. 2—Details of Construction of Blow Tank.

a Leeds and Northrup instrument, are given in Section XI (p. 361). If the result is less than 100% I.A.C.S.,* more soda ash and lime are blown into the furnace until a test gives the correct conductivity. The bath is kept skimmed clean until the result is available, and a pole is put into the metal between blows. When 100+ % conductivity has been obtained, the furnace is covered with coke and poled up to pitch.

It is possible to eliminate nearly all the arsenic, but generally it is reduced only to less than 0.0015%. Spectrographic tests can also be carried out for arsenic determination, and to some extent these remove the need for running conductivity tests during the blow.

* International Annealed Copper Standard.

Only the final one is necessary, once the spectrograph result has shown the arsenic content to be less than 0.002%. The quantities of soda ash and lime used depend upon the amount of arsenic present in the melt, but generally they approximate to 10–15 lb./ton of metal in the furnace. Soda slags are deleterious to the refractories, and a basic brick lining is desirable when this treatment has to be carried out. Rapid skimming of the furnace helps to minimize the destructive effect of the slag on the refractories.

Nielsen⁸ has suggested the use of a soda ash–lime–coal flux for the partial removal of selenium and tellurium. The process has to be carried out under reducing conditions, and considerable practical difficulties arise. As far as is known, it has not been adopted as a production routine in refineries.

An experimental charge which was refined using a double oxidation–reduction cycle and a soda ash–charcoal flux, resulted in a 70–80% removal of selenium. The charge consisted of 180 tons of blister copper with a selenium content varying between 0.07 and 0.10%. The bath was oxidized, skimmed, and poled in the usual way until the small-block stage had been reached in the reduction process. A mixture consisting of 1450 lb. of soda ash and 425 lb. of charcoal was then added to the bath, via a blow tank. All openings were tightly closed except for the skimming door, and poling and skimming continued during the addition and for 45 min. afterwards. White silica sand was thrown on to the bath, which was then skimmed perfectly clean. The brickwork temperature was kept high, so that very little soda slag remained on the walls after skimming. The bath was finally blown to 0.75% oxygen and reduced in the usual manner by low-sulphur coke, charcoal, and by poling. Most of the selenium was eliminated in the soda slag; this contained up to 5% selenium, half of which was water-soluble.

Removal of tin occurs late in the oxidation period, and is facilitated by using a basic slag containing soda ash and sodium nitrate. The resulting slags are, however, very corrosive to the furnace lining.

Lead is removed to some extent during the normal refining operations, though prolonged slagging with silica sand is necessary if a very low lead content is to be obtained from a charge high in lead. The slags removed may run as high as 30% copper, and it is obviously desirable to keep the volume of slag produced to a minimum.

3. CONTROL OF TEMPERATURE DURING REFINING AND CASTING

During melting, the maximum heat input to the furnace is maintained, consistent with the high-temperature properties of the furnace refractories. As the oxidation stage proceeds, heat is generated as a result of the exothermic reactions occurring in the bath, and this more than offsets the cooling effect of the air being blown in to achieve oxidation. The oil flow to the burners has therefore to be cut back

progressively, so that a fairly constant, high bath temperature is maintained.

High temperatures favour the absorption of oxygen, thus assisting the blowing operation. Experienced furnace operators can judge the metal temperature quite accurately from the solidification of the normal ladle button samples, but the use of pyrometers is more satisfactory. A Leeds and Northrup potentiometric optical pyrometer of the disappearing-filament type is often used for measuring molten metal temperatures. It is calibrated directly in degrees Fahrenheit, and measures temperatures with a high accuracy. It is light in weight, rugged in construction, and easily and rapidly operated.

Temperatures can be taken in crucibles and in induction and arc furnaces by sighting down a closed-end tube to give black-body conditions. If the temperature is to be taken just before pouring, a silica tube may conveniently be used, as the time lag for such a measurement is only about 45 sec.

Sighting the pyrometer on to the surface of the bath is not to be recommended, owing to the differences in thickness and composition of the oxide cover on the metal. Dip-type thermocouples are also used, with the platinum/platinum–rhodium couple protected by a primary silica sheath and a graphite secondary sheath.⁹ Continuous bath-temperature readings are not taken owing to the danger of mechanical damage to the protective sheath during furnace operations.

It is important during poling that the temperature be maintained as uniform as possible, and not allowed to fall or rise suddenly. If the metal temperature falls near the end of poling, and is then suddenly raised again, over-poled metal or a coarse-set bar will result, owing to absorption of sulphur from the fuel. Careful control of temperature as well as of the atmosphere in the furnace is, therefore, necessary to ensure the production of good-quality metal.

Typical temperatures taken at intervals during the refining process¹⁰ are given in Table II.

TABLE II.—*Typical Temperatures Taken During a Refining Cycle.*¹⁰

Stage During Process	Temperature	
	°F.	°C.
Off bottom or "afloat"	2150	1176
Coking	2175–2200	1191–1204
Poling: 1 hr. after coking	2125	1163
2 hr. " "	2100	1149
Ready to cast	2070	1132
Casting	2060	1126

Before casting on the wheel begins, a 5-ton portable furnace is filled and the temperature finally checked by sighting an optical pyrometer on to the molten stream.

The usual pouring temperatures for horizontally cast wire-bars are:

135-lb. Bar	2050°–2060° F. (1121°–1126° C.)	Ladle to mould.
250-lb. Bar	2030°–2050° F. (1110°–1121° C.)	" "

4. CONTAMINATION FROM REFRACTORIES

Contamination of the metal from the magnesite-brick lining of the furnace hearth is negligible, as the impurity content of the refractories is very low. Some trouble is experienced with sulphur pick-up during the first few charges after the walls and roof have been rebricked with chemically bonded chrome magnesite, as the binders employed contain certain quantities of barium and sodium sulphate which are decomposed progressively.

The launder and ladle refractory must resist erosion by the hot metal, for otherwise non-metallic inclusions will be found in the final castings. The linings must also have a low heat capacity and a low thermal conductivity, so that no severe chilling of the metal occurs. A mixture found suitable consists of 49% washed sand, 49% Portland cement, and 2% fireclay (37% alumina). The ladle pouring lip is washed with a highly refractory cement (high alumina content), which sets extremely hard and withstands the chipping carried out to keep the lips free from skull.

5. CONTROL OF PITCH IN THE POURING LADLE

The use of charcoal in the ladle should be kept to a minimum, as its effect is not lasting and control to the desired pitch is made difficult. Whenever possible, the pitch should be regulated by poling and only sufficient charcoal briquettes or wood charcoal kept on the surface of the metal in the ladle to prevent atmospheric oxidation. When various sizes of castings are being produced, particularly if they vary in width, charcoal has to be used, as it offers the only method of rapidly changing the pitch to the desired level. Wider castings in general require less poling or charcoal to obtain a flat set, though pouring speed also has an influence, a fast pour tending to give a lower set, and vice versa.

Charcoal briquettes are normally preferred for ladle work, as wood charcoal tends to be small and dirty and dust blows into the moulds, affecting the quality of the castings. Wood charcoal is not so satisfactory for regulating the pitch of the metal in the ladle, but if the metal temperature tends to be low, less heat will be removed than if briquettes are used.

A wooden rabbie is used to skim and stir the charcoal cover, thus eliminating iron contamination in the copper.

VII.—CONTROL IN THE CASTING OF HORIZONTAL WIRE-BARS

1. POURING

The tilting of the ladle and the speed of rotation of the wheel are controlled by the operator seated in the control box at the centre of the wheel. Pouring is a highly skilled job, but can be made easier by the use of a Vickers V.S.G. drive to the wheel. This makes possible a very fine and steady control over the acceleration and speed of rotation, necessary to pre-

vent movement of the copper in the mould, so forming rolled edges as the mould moves away from the pouring position. The temperature of the moulds at the time of casting has also to be controlled, and is usually held at about 160° F. (71° C.). A small pocket, 2 in. deep, is cast into the mould block so that a thermometer can be inserted as required.

The shape of the pouring lips of the ladle plays an important part in the production of sound castings free from splash marks. The channel is 2 in. square, and the lower corners are cut back and rounded with a $\frac{1}{4}$ -in.-dia. rat-tail file. The bottom surface of the lip is smoothed off into the edges of the file cuts. Lips of this shape have been found very successful in drawing the molten copper into a single stream without splashing. The channel must be kept quite clean and free of skulls by chipping. A pouring ladle is shown in Fig. 6 (Plate L), and three pouring lips can be seen. The refractory used is that given in Section VI, 4.

2. BONE ASH FOR MOULD DRESSING

Bone ash is sprayed on to the warm mould after the mould pockets have been cleaned with high-pressure water jets. The moulds must be sufficiently warm for the slurry to dry out completely before the mould reaches the pouring position, or blow-holes will be found in the surface of the wire-bars.

The following methods are suggested for testing the suitability of the bone ash :

(a) Loss on Ignition

Weigh a 10-g. sample into a porcelain crucible which has been previously ignited, and maintain it at 1700° F. (926° C.) in a muffle furnace for 30 min. Remove the crucible, cool it in a desiccator, and reweigh. Express the loss on ignition as a percentage. (Recommended limits 0.32–0.84%.)

(b) Titration Value

Transfer a 5-g. sample to a 250-c.c. beaker, add 200 c.c. distilled water, heat to boiling, and then cool. Add 10 drops phenolphthalein indicator and titrate with 0.5N-HCl, stirring rapidly until the pink colour disappears. The reappearance of colour is disregarded, as this will take place until the phosphate is all converted to the dibasic salt. The result is reported in c.c. of 0.5N-HCl used/5-g. sample. (Recommended limit \geq 1.2 c.c.)

(c) Screen Test

Transfer 100 g. of sample to a 300-mesh screen and apply water with a soft camel-hair brush until the water runs clear. Wash the remaining residue from the screen on to a filter-paper in a Buchner funnel and filter, dry, and weigh. Express the result as percentage passing through 300-mesh screen wet. (Recommended percentage 95%.)

(d) *Settling Test*

A glass measuring cylinder of 1½-in. inside dia., and 12 in. high between the 0 and 500 c.c. graduation is required. The temperature of the water should be 25° C. Measure 400 c.c. of water in the graduated cylinder and add 100 g. of bone ash. Shake until the bone ash is thoroughly wet, then invert five times and allow to settle. The time required for 1 in. of clear water to appear on top is recorded by a stop watch, and the average of several readings taken. If the bone ash has been packed very hard, it should be passed through a coarse screen before making the test, as it is then easier to get the sample thoroughly wetted. The result is expressed as the number of seconds required for 1 in. of clear liquor to appear at the top of the cylinder. (Recommended limits 200-550 sec.)

3. MOULD MANUFACTURE AND LIFE

A three-pocket wire-bar mould usually has a life of 50-60 tons of casting. Then fine cracks can be seen developing in the radii, and if left these would absorb moisture from the mould dressing and cause blow-holes in the wire-bars. In the case of a wheel carrying 14 mould blocks, one or two would normally be replaced each day, depending on their condition, and the old ones recharged to the furnace.

In the production of a new mould very great care must be exercised to obtain metal at the correct pitch and temperature. The copper is tapped from the furnace down a side launder into the mother mould. The surface of the molten metal in the latter is carefully skimmed, and then a warm core which has previously been sprayed with 28° Bé. bone ash, is lowered into the copper. The design of the cores and their water-cooling channels is of great importance. After manufacture the mould pockets are very carefully examined for surface defects before being put into service.

4. CASTING DEFECTS IN HORIZONTAL CASTINGS,
AND THEIR CAUSES(a) *Moisture Holes*

Moisture holes are caused by steam generation from damp moulds, and are generally found if old moulds are in use. Small cracks in the mould surface hold moisture from the dressing. The holes are irregular in shape, and may occur at any position on the bar; they are larger than, but not so deep as, heat holes.

(b) *Oil Holes*

These are caused by spots of oil on the mould, which may have originated from an overhead crane or from the compressed-air line of the bone-ash spray-gun. The area of the bar affected is usually small, but may be in any position. The reducing gases evolved penetrate the outer skin of the casting, and cause holes which are often too deep to remove by chipping.

(c) *Bone-Ash Inclusions*

Inclusions of this type are caused by the application of too heavy a coating of bone ash, and its consequent flaking away. Too high a mould temperature will give the same effect.

(d) *Cracks*

The cracks are usually transverse, and can be brought about by cracked or uneven mould surfaces which tend to grip the solidifying bar. They are also found if the temperature of the copper is too high or if the moulds have been badly dressed.

(e) *Sand Inclusions*

These originate from the casting ladle or pouring lips, and can be more or less completely eliminated by use of correct refractories.

(f) *High Set*

A high set is due to over-poling or too much residual sulphur in the bar.

(g) *Dimensional Defects*

The length and width of a cast bar are governed by the mould condition. The weight of the bar is controlled by the depth to which the wheel-man fills the mould pockets.

(h) *Laps*

These are caused by splashes or cold sets which have not been turned in by the fisher.

(i) *Heat Holes*

This type of defect is normally found when the metal temperature is too high. The holes are small, uniform in shape, and occur grouped together in comparatively small areas, generally in the area where the stream first strikes the bottom of the mould.

(j) *Rolled or Sloppy Edges*

These may be due to too rapid pouring, to vibration from the wheel, or to a bad finish up at the end of the pour.

VIII.—THE CASTING OF VERTICAL
SHAPES

1. THE USE OF PORTABLE FURNACES

Vertically cast shapes may be cast on the main wheel or side-cast on racks. When cast on the main wheel, copper is tapped from the furnace to either one or two pouring ladles. In rack-casting the metal is poured from 5-ton portable oil-fired holding furnaces.

The portable holding furnaces are filled with copper from the main furnace and placed in a convenient position near the pouring site. The metal is then skimmed and a sample block taken to ascertain the pitch and temperature. The experienced furnaceman can estimate temperature fairly accurately by watching the metal flow from the ladle, the formation of skulls in the ladle, and also the colour of the molten copper. Accurate temperature measurements are taken by pouring a small quantity of the metal from

the furnace and using a disappearing-filament pyrometer. If the copper is not up to pitch, poling is carried out in the holding furnace. Alloying with silver or tellurium is also done in the furnace just before casting. Neither charcoal nor coke is used on holding furnaces.

2. MOULDS FOR VERTICAL CASTING

The moulds used in the production of rolling slabs and extrusion billets in various alloys are made from solid tough-pitch copper castings. The castings are machined-out to form the desired shape, with a slight taper to allow easy dropping of the final shapes. Water-cooling channels are also drilled through the blocks to ensure satisfactory chilling of the casting. In the case of a 1000-lb. cake mould, the rate of water circulation is 150 gal./min. at 60 lb./in.² pressure. The water temperature is usually in the range 190°–205° F. (88°–96° C.).

After a time the tops of slab moulds tend to bow outwards and the lower sections to draw in, and in extreme cases this could result in the cake being jammed in the mould. Before serious jamming can occur, however, the mould pockets are re-machined.

3. MOULD FUNNELS AND PELICAN LADLES

When billets and vertically cast wire-bars are being cast, it is essential that the stream of metal does not splash against the side of the moulds. They are therefore poured through a refractory-lined funnel, the size of the orifice being determined by the size of casting being made. For a 4-in.-square vertically cast bar, $\frac{9}{16}$ in. dia. is normally used, and $\frac{5}{8}$ in. dia. for $4\frac{1}{2}$ -in.-dia. billets. A typical funnel is shown in Fig. 7 (Plate L). The shape of the refractory lining counteracts any tendency for a vortex to form, and an unbroken stream of metal flows into the mould. The funnel must be accurately positioned and aligned for satisfactory results.

Pelican ladles are used for "floating" vertically cast cakes over 3 in. in thickness, with the object of avoiding defects at the bottom of the casting such as cold shuts, oxide, and bone-ash inclusions. They serve an additional purpose in providing a more even distribution of heat, and tend to eliminate the hot zone in the middle of the bottom of the casting. Such a hot zone constitutes a weak area, incapable of withstanding the strains set up on cooling, and results in "shadow cracks".

Fig. 8 (Plate L) shows the simultaneous casting of two 1000-lb. rolling slabs from a 5-ton portable furnace, and Fig. 9 (Plate L) illustrates a pelican ladle. Fig. 10 (Plate LI) shows a 3000-lb. high conductivity copper cake being cast into a one-piece water-cooled copper mould.

4. MOULD DRESSING FOR VERTICAL SHAPES IN REFINED COPPER

For casting refined copper the bone ash used as a mould paint must possess certain properties. It

should adhere to the mould and form a smooth surface which will not react with molten copper. High magnesium content should be avoided, or adherence will be poor, and no volatile substances should be present.

When pouring vertically cast cakes into a freshly machined mould, the first few cakes have areas of "sweat" towards the top edge of the cake. If these areas are ground off, the sheets eventually produced will show corresponding discoloured areas due to the high copper oxide content of the metal. This defect is usually eliminated by spraying high-Bé. bone ash round the top inside surface of the mould cavity.

Bone ash contains 75% Ca₃PO₄, other constituents being sulphates, chlorides, carbonates, and oxides of calcium, magnesium, and potassium. Sodium and potassium hydroxides and some silica are also present. One per cent. of Na₂CO₃ and 1% NaOH cause pitting, but excess alkalinity can be reduced to 0.3% NaOH with sulphuric acid and pitting thus obviated. The presence of 3% silica will cause severe pitting. Up to 4% CaCO₃ in the bone ash does no harm, and little trouble is experienced in this respect, as bone ash usually contains only 2%. A fairly slow-settling bone ash is preferable.

5. POURING SPEED AND TEMPERATURE

Pouring speed is governed to some extent by the pitch of the metal being cast and the size and shape of the casting. As in the case of horizontal casting, a faster pour tends to give a lower set, and the speed at which a particular shape is cast is controlled in relation to the set obtained on the previous one. Approximate pouring speeds are as follows:

Cakes (1000-lb.)	. . . . .	400 lb./min.
Billets (4½-in.-dia.)	. . . . .	72–90 sec.

Pouring temperatures in general use are as given below:

Ingot	2080°–2095° F. (1138°–1146° C.)	Ladle to mould.
Billets	2085°–2090° F. (1140°–1143° C.)	Holding furnace to funnel.
V.C. Bars	2090°–2100° F. (1143°–1149° C.)	Holding furnace to funnel.
V.C. Cakes (wheel)	2010°–2030° F. (1099°–1110° C.)	Ladle to mould.
V.C. Cakes (rack)	2030°–2050° F. (1110°–1121° C.)	Holding furnace to mould.

6. DEFECTS IN VERTICAL CASTINGS

(a) Shadow Cracks

Shadow cracks always occur towards the centre and within 4 in. of the bottom. If this portion is free from cracks, it may be taken that the cake as a whole is free. Unless the cracking is severe, these fine hair cracks can be detected only by removing the surface with a pneumatic chisel. The more nearly the cross-section of the mould approaches a square, the less likely is the occurrence of shadow cracks.

(b) *Cold Sets*

Cold sets or splashes are generally due to off-centre pouring or too rapid pouring which has caused turbulence in the mould.

(c) *Pitting*

This is caused by off-centre pouring which has washed dressing from the side of the mould, or is due to bone ash or cement inclusions.

IX.—HIGH-CONDUCTIVITY COPPER ALLOYS

1. PHOSPHORUS-DEOXIDIZED COPPER

In the production of phosphorus-deoxidized non-arsenical copper, the metal in the holding furnace is superheated to 2200° F. (1204° C.), skimmed, and poled to 0.040–0.045% oxygen. Copper–15% phosphorus alloy is then added to the bath to the extent of 1.1 g./lb. of metal in the furnace. A small tree is used to mix the addition and to stir the bath. The metal is poured after standing for 5 min. The range of phosphorus content is 0.015–0.030%.

Phosphorus-deoxidized copper is also produced in low-frequency induction furnaces of the Ajax–Wyatt type. Alumino-silicate linings can be used if the charges contain at least 80% deoxidized copper scrap. Oxygen-bearing scrap gives trouble by excessive attack on the refractories.

Moulds for use with phosphorus-deoxidized copper are oil-dressed with a mixture of machine mineral oil and lamp black, applied with a lambskin mop. The moulds should be as cool as possible, the colder the better. The metal is poured through funnels in the case of billets and through multiple-hole tundishes for cakes. Water is run into the mould through two $\frac{1}{8}$ -in.-dia. pipes once the bottom is covered with molten metal. Sufficient water is added to stop the dressing from flaming, approximately 500 c.c. being necessary on a 600-lb. cake. This helps to reduce the amount of phosphide slag which may be trapped in the sides and edges of the cakes. However, the danger of using water in the mould if the phosphorus content is very low or absent cannot be stressed too strongly.

2. 0.05% SILVER-BEARING COPPER

This alloy is also produced in 5-ton holding furnaces. The copper is poled to 0.05% oxygen and the alloying addition made in the form of pure silver. The melt is then stirred with a pole and the oxygen brought down to 0.04%. Casting proceeds into water-cooled moulds, as with refined copper shapes, using a bone-ash mould dressing.

3. TELLURIUM COPPER

Alloying is carried out using metallic tellurium or a 50:50 master alloy of copper and tellurium. The master alloy is made by melting copper swarf and

tellurium metal powder in a small crucible furnace, and no great difficulties are involved.

In the manufacture of the 0.5% tellurium high-speed machining alloy in a crucible furnace, the master alloy is added at an early stage. Melting is carried out under charcoal, and the metal poled until button samples give a slightly crowned set. The metal is then cast into water-cooled copper moulds, dressed with bone ash.

When large quantities are required, the alloy may be prepared in portable furnaces, using a similar procedure to that employed for silver-bearing copper.

4. CADMIUM COPPER

Cadmium copper castings for fabrication into trolley wire, line wire, and resistance-welding electrodes, are cast from a variety of melting furnaces, oil-fired tilting crucible furnaces, low-frequency induction furnaces, rocking-arc furnaces, and rocking-resistor furnaces, all being used successfully. The large refineries, however, usually side-cast cadmium copper into water-cooled copper moulds from portable holding furnaces. It has been found necessary in the past few years to use such moulds, as inverse segregation and subcutaneous porosity are thus minimized or completely eliminated. Cracking of the alloys during hot rolling has been found to be associated with these two defects.

Good high-grade material, such as electrolytic cathodes or ingots, must be used and impurities kept to a minimum; in particular the bismuth content must be less than 0.001% or trouble will be experienced in the rolling operations.

The production of this alloy in a large refining plant is carried out by the following technique. Two 5-ton holding furnaces are employed, one of which is superheated for a few hours before use. The second furnace, also superheated, is filled with tough-pitch copper from the wire-bar furnace, and a weighed quantity poured into the superheated furnace. The metal is then skimmed clean, poled up to a high "crown set," and covered with clean stick charcoal. Such a quantity of 15% phosphor copper is then added as to leave a residual phosphorus content of 0.008–0.010% in the metal. Copper–cadmium master alloy wrapped in copper foil is added and stirred with a pole. Casting follows immediately through a pouring funnel into oil-dressed water-cooled copper moulds. (The same oil dressing is used as with phosphorus-deoxidized copper.) The moulds should be kept as cool as possible. An improvement in the surface of the billet can be brought about if, just before casting, the inside surface of the mould is sprayed with finely atomized water. Cadmium copper should be poured hot, and the master alloy is not added until the bath temperature is up to 2300° F. (1260° C.).

About 0.10% loss of cadmium is allowed for when making 0.80% cadmium copper. A 35 or 50% cadmium alloy is used, and this is made by melting copper shot and metallic cadmium in a graphite crucible at as low a temperature as possible.

X.—INSPECTION AND TESTING OF REFINED COPPER SHAPES

1. SPECIFICATION REQUIREMENTS

The wire-bars, billets, or slabs must be free from non-metallic inclusions, fissures, and blow-holes. The porosity present to give a level set must be extremely fine and confined to the region immediately below the set. All surfaces must be free of holes, laps, cold sets, and inclusions, and the set surface should be of minimum area. Variations in the size of castings should be small, so that subsequent working operations will be facilitated.

The analysis of the copper should be well within the limits of the appropriate specification, and the electrical conductivity of the final rolled or drawn product in the annealed condition must be greater than 100% I.A.C.S.

2. PHYSICAL INSPECTION

All surfaces of the casting are carefully examined for laps, cracks, blemishes, and non-metallic inclusions. If any cracking is found, the material is automatically rejected and sent for remelting. The mould used is examined to find whether there are any irregularities in the mould surfaces that are liable to cause the hot tearing or cracking. Superficial cold sets and defects are chipped out and the casting re-examined for subsurface defects in the locality which has been chipped clean. If further cracks or holes are revealed, the shape is rejected.

The cropping of cakes and billets is not begun until the results of the chemical and spectrographic analyses have proved satisfactory. The shapes are re-examined after sectioning to see whether any unsoundness has been revealed, and if any is discovered the material is remelted. Cast numbers are restamped on the sections cut from each billet, to allow of identification during subsequent working operations.

Density measurements are regularly carried out on the high-conductivity shapes by weighing them first in air and then in water, while they are suspended by a special stirrup attached to a steelyard-type weighing machine.

3. LABORATORY SERVICES

Samples are taken from furnace melts and from the cast shapes according to the requirements of the appropriate specifications. These samples may be drilled for chemical analysis or machined to a standard-size test-piece for spectrographic examination, depending on the elements to be determined.

The laboratory of the Enfield Copper Refining Co. is equipped with the conventional apparatus for volumetric and gravimetric estimations, and also with a Hilger medium quartz spectrograph, a polarograph, and Spekker photoelectric absorptiometers; a more recent addition is a direct-reading spectrograph.

Appendix II (p. 363) gives an outline of the methods of analysis employed for particular elements.

c c

XI.—CONDUCTIVITY TESTING IN CONTROL OF REFINING

Conductivity testing plays an important part in the production of refined copper. Wire samples are produced from slug samples cast from the furnace bath. The following stages are involved in the measurement of conductivity:

- (i) Drawing the sample to wire—preferably 12 gauge.
- (ii) Annealing the wire to bring the conductivity to a maximum.
- (iii) Cleaning the wire to remove oxide and superficial blemishes.
- (iv) Cutting the wire to exact length.
- (v) Weighing the wire to ascertain the correction factor required to compensate for any deviation in diameter from the standard.
- (vi) Measuring the conductivity in a bridge.

The wire, 0.0808 in. in dia., is submitted to the laboratory in the form of a coil about 20 in. in dia. with a tag giving its identification. Six ft. of wire are required for each test.

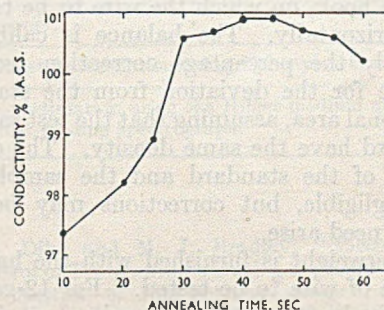


Fig. 3.—Effect of Annealing Time on the Conductivity of Copper.

The wire is annealed by passing a heavy current through it while it is suspended horizontally in the air between two brass clamps, supported on frames about 12 in. above the floor. These clamps are about 6 ft. apart, and form the terminals of a circuit from a special rotary converter producing a high amperage at low voltage. There are rheostats for adjusting the current flowing through the wire.

The wire to be tested is so fastened in the clamps as to be fairly taut. When the generator is up to speed, a switch is thrown and an initial current of about 155 amp. is passed through the wire. As the temperature of the wire increases, its resistance becomes greater and the current drops, so that in about 30 sec. it is down to 140 amp. The temperature of the wire increases during the first 50 sec., by which time it has levelled out at about 850°–900° C. The optimum duration of the annealing treatment for the particular kind of copper is established by tests, and each wire is subjected to the current for that time. Fig. 3 shows the effect of annealing time on the conductivity of the wire. At the end of the chosen time, the

current is interrupted, and the wire immediately cut about 4 in. from each clamp and allowed to fall into a V-shaped water trough extending from clamp to clamp.

During annealing the wire is superficially oxidized, and the oxide coating, and incidentally any small projecting imperfections, have to be removed. The wet wire is fastened at one end, wiped dry, scoured with fine emery cloth, and finally wiped clean. Care must be taken not to pull too hard on the wire and not to bend the wire with the fingers as the emery cloth passes along it, or re-hardening will occur. The wire is cut back 4 in. from the fastened end, and is then ready for cutting to length.

The special cutter employed consists essentially of a grooved bar with an adjustable plate on one end and a steel shearing knife on the other. The knife cuts the wire so that the end is flat and normal to the length. The wire is laid in the groove and about 4 in. cut from one end. The wire is then reversed in the groove with the square-cut end pushed against the back plate, and again cut, giving the 38-in. length required for weighing and testing.

A special balance is used for weighing, which has one stirrup extending below the balance and ending in a double hook, on which the wire to be tested can be laid horizontally. The balance is calibrated to give directly the percentage correction required to compensate for the deviation from the standard in cross-sectional area, assuming that the test sample and the standard have the same density. The difference in density of the standard and the sample wire is usually negligible, but corrections may be applied should the need arise.

A counterweight is furnished with the balance for each gauge of wire to be tested. For 12-gauge wire this is equivalent to 28.4 g. for wire 1 m. in length. The compensation for over- or under-weight is obtained by a rider sliding on a beam. The latter is so divided that when the counterpoise plus (or minus) the rider balances the wire, the reading equals the percentage correction to be applied by turning the compensator drum of the Hoopes bridge to the required number (with proper sign positive or negative); the bridge will then give the true reading directly.

The Hoopes conductivity bridge used was made by the Leeds and Northrup Co. The wire to be tested is clamped taut in the bridge, the sliding contact put in position on the wire, and the cover closed. As temperature affects the conductivity, it is necessary to have the wire tested at the same temperature as the standard. The wire is therefore left in the bridge until the temperature approximates that of the standard, as shown by the checking of two consecutive readings a minute apart. The sliding contact for balancing the bridge moves along a steel scale calibrated in conductivity per cent. Tenths are determined by a vernier scale attached to the contact. The bridge has an accuracy of 0.2%.

It is advisable to reverse the wire and repeat the test.

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APPENDIX I

Etching Solutions for Sample Buttons Taken During Refining

For "Low-Set" Buttons (O₂ up to 0.9%)

75 c.c. conc. nitric acid.
25 c.c. distilled water.
Polish on dry Selvyt cloth after etching.

For Tube or Bar Samples

70 c.c. 10-12% ammonium persulphate solution.
15 c.c. ammonia.
15 c.c. distilled water.

For Structure Samples

10 g. ferric chloride.
75 c.c. hydrochloric acid.
25 c.c. distilled water.

For Phosphorus-Deoxidized Copper

50 c.c. nitric acid.
50 c.c. distilled water.

APPENDIX II

Methods of Analysis for Specific Elements

Material	Shape	Elements Determined	Outline of Analytical Method Employed
H.C. Copper	Wire-bars and V.C. Cakes	Sulphur	Reduction in hydrogen stream at 900° C. Subsequent estimation of cadmium sulphide using iodine.
		Oxygen	Reduction in hydrogen at 900° C., and absorption of H ₂ O evolved in magnesium perchlorate anhydron.
		Iron	Visual colorimetric estimation using ferric thiocyanate.
		Bismuth	Visual colorimetric estimation using thiourea.
		Selenium	Distillation in hydrobromic acid, followed by sodium thiosulphate titration. ¹¹
Phosphorus-Deoxidized Copper	V.C. Cakes	Phosphorus	Spekker colorimetric estimation. Reduction of phosphomolybdate with stannous chloride. ¹²
Tellurium Copper	Billets	Tellurium	Spekker colorimetric estimation by reduction with stannous chloride, after addition of thiourea. ¹³
		Oxygen	As for H.C. copper.
		Iron	As for H.C. copper.
0.05% Silver-Bearing Copper	V.C. Cakes and Billets	Silver	Separation as silver chloride, and volumetric estimation using ammonium thiocyanate.
		Oxygen	As for H.C. copper.
Chromium Copper	Billets	Chromium	Spekker colorimetric estimation using diphenylcarbazide.
All Types of Copper-Base Alloys		General impurity content	Spectrographic estimation using the Hilger medium quartz instrument or direct-reading spectrograph.

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THE CONTROL OF QUALITY IN THE CASTING OF 1451 ZINC AND ZINC ALLOY ROLLING SLABS AND EXTRUSION BILLETS*

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SYNOPSIS

The various techniques and procedures adopted commercially for the production of rolling slabs and extrusion billets in zinc and zinc alloys are briefly described, and the metallurgical principles involved are examined. The origins of the defects normally encountered in the castings are indicated, and the means adopted to minimize the incidence of such defects are discussed. The importance of control of chemical composition both in raw materials and in the final products is emphasized, and it is concluded that, although certain defects can be associated with particular methods of casting, several methods are available whereby satisfactory slabs or billets can be produced provided that supervision of the operations is adequate.

I.—INTRODUCTION

THE control of quality in metallurgical manufacturing processes has become increasingly important in recent years and is likely to receive even greater attention in the future. The reasons for this modification of emphasis in the organization of production are many and various, but among the more important may be mentioned:

- (1) The increasing scarcity and cost of raw materials.
- (2) The increasing cost of labour.
- (3) The high cost and complexity of modern metallurgical plant.
- (4) The higher consistency in properties required in semi-finished products, particularly where finishing operations involve a high degree of mechanization.
- (5) The general higher standard of finish and performance required of metal articles and components.

In the production of zinc rolling slabs and extrusion billets, two separate aspects of quality are involved. Firstly, the quality of the castings must be sufficiently high to allow them to be rolled or extruded in the conventional machinery by normal methods. In other words, quality in a particular instance cannot be allowed to deteriorate to such an extent that special methods have to be adopted to work a particular casting or group of castings. Secondly, the castings must be of such quality that the sheet, strip, or extrusions produced from them by conventional

methods possess the required properties and are suitable for use in this state or are suitable to receive such further work or treatment as is desired. In certain cases the two points of view are complementary, but in others a certain degree of conflict occurs, and consequently the most suitable degree of compromise has to be adopted.

In the present paper the subject is treated on general lines. The various procedures adopted for melting and casting are briefly described, the metallurgical principles involved are examined, the origins of the various defects encountered in the castings are indicated, and the means whereby the incidence of the defects can be minimized are discussed. Rolling slabs and extrusion billets are treated separately, the latter in less detail, since the tonnage of zinc and zinc alloys extruded in this country (and indeed throughout the world) is small and the products are of less metallurgical interest.

II.—PRODUCTION OF ROLLING SLABS

1. RANGE AND REQUIREMENTS OF PRODUCTS

The applications of zinc and zinc alloy sheet and strip are, in normal circumstances, somewhat limited and specialized, a fact which is reflected, to some extent, in the comparatively small range of alloy compositions normally employed. Many of the alloys commonly used are, in fact, refined grades of zinc with the naturally occurring impurities, lead and cadmium, held within specified limits, though other elements are sometimes added in alloying proportions. They are usually referred to as rolling mixes. Some

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typical compositions in this category are shown in Table I.

True zinc alloys are used to a much lesser extent, those in general use in Great Britain being of the Kayem or Kirksite type, the compositions of which are also shown in Table I. A wide range of zinc alloys were developed in Germany during the war

Slabs of higher quality are required for strip rolling than for sheet production, the main reason for this being that in many cases the subsequent treatment of strip involves machinery working continuously and automatically. Certain defects in the strip may thus cause serious delays in the production lines and even extensive damage to costly machinery.

TABLE I.—*Compositions of Zinc Alloys for Sheet and Strip.*

Description of Alloy	Composition				
	Pb, %	Cd, %	Mg, %	Cu, %	Al, %
Ductile sheet	0.3–0.4	...	...	...	...
Engraving sheet *	0.3–0.4	0.15–0.25	0.006–0.010	...	...
Commercial sheet	0.8–1.3	...	...	...	...
Strip for Battery Cans {	1	0.8–1.0	0.04–0.07	...	...
	2	0.2–0.3	0.22–0.28	...	...
	3	0.15–0.25	0.06–0.10	...	...
Zilloy 40 (American)	0.10 max.	0.005 max.	...	0.85–1.25	...
Zilloy 15 (American)	0.15 max.	0.04 max.	0.006–0.016	0.85–1.25	...
Kayem	0.003 max.	0.003 max.	0.03–0.06	3.0	4.0
Kirksite		Similar in composition to Kayem			

* Nickel or iron, in amounts up to 0.01%, may also be present.

and were used in large quantities as substitutes for copper alloys. The main compositions are shown in Table II.¹

TABLE II.—*Compositions of Zinc Alloys for Sheet and Strip Developed in Germany.*¹

Description of Alloy	Composition					
	Al, %	Cu, %	Pb, %	Mg, %	Mn, %	Cd, %
Z410	4.0	1.0	...	0.04	...	...
Z010 . . . . .	...	1.2	...	...	0.2	...
Z020 {	(a)	0.6	2.0	...	0.03	...
	(b) . . . . .	...	2.0	...	0.03	0.6
Z100	1.0	0.4	...	...	...	...
Z1010	10.0	0.8	...	0.05	...	...
Z1000	10.0	0.3	...	...	...	...
Z040	0.2	4.0	...	...	...	...
Z001 Mn	0.2	0.3	1.0	...	0.5	0.1

The properties and general quality required in sheet and strip vary greatly and depend upon the type and degree of subsequent treatment necessary, and on the ultimate application. Roofing sheet, for example, must be free from those impurities that decrease resistance to corrosion and must be reasonably ductile, whereas strip for use in the production of battery cans by deep drawing or impact extrusion must possess a much higher degree of ductility and be of the chemical composition that will ensure maximum battery storage life. Surface quality is highly important in sheet for the production of engraving plates, and this sheet must also possess a considerable degree of rigidity.

Irrespective of the final use, however, rolling slabs should be free from all defects that are likely to cause trouble during rolling, e.g. the presence of surface cracks and impurities that promote hot shortness.

It is probably true to say that by no method of production can perfect slabs be made and that even to approach this standard would involve prohibitive cost. All the methods normally available have certain virtues and certain shortcomings, and the procedures adopted in industry are a compromise between what is desirable and what is practicable. The various points involved are discussed in later sections, but it is convenient to summarize here the ideal requirements of rolling slabs. They are:

(a) The composition of the slab must be uniform throughout.

(b) The composition must be such that the required properties can be obtained in the final products.

(c) Other considerations apart, the composition must be such that mechanical working can be carried out with maximum efficiency, i.e. at maximum speed with minimum energy absorption.

(d) Since efficient working is generally associated with a high working temperature, the slab must be free from those impurities that cause high-temperature embrittlement.

(e) The grain-size and degree of randomness in grain orientation must be such that an adequate number of slip planes are available to allow substantial deformation during the early stages of working.

(f) If a fine-grained structure cannot be secured in the casting and preferred orientation cannot be avoided, the grain orientation must be such that the planes of easy slip lie in the direction most favourable for deformation.

(g) The slabs must be free from dissolved gas

and internal defects such as gas cavities, shrinkage cavities, oxide inclusions, &c.

(h) The slab surfaces must be continuous and free from such defects as laps, cold shuts, sinks, &c.

It may be stated that, although difficulties occur from time to time in the casting of zinc and zinc alloy slabs, a number of methods of casting are available whereby satisfactory products are obtained at low cost and with low rejection figures.

The defects that normally occur in rolling slabs fall naturally into two categories: (i) those that originate in the raw materials and in melting, and (ii) those that are due to faults in casting. These are discussed separately in the following sections.

2. CHARGE MIXING AND MELTING

A substantial tonnage of the zinc rolled to sheet comprises metal in various degrees of commercial purity with total impurities ranging from 0.01 to 1.3%, the actual composition, apart from maxima for individual impurities, not being accurately defined. To obtain a reasonable degree of consistency in composition, it is normal practice to mix several grades or consignments of commercial metal when making up each charge. Apart from scrap derived from the manufacturers' own processes, little zinc scrap is available in a form suitable for remelting, and its inclusion is undesirable because of the danger of contamination of the melt with deleterious impurities.

For the large-scale production of commercial-quality sheet, the metal is normally melted in gas- or oil-fired reverberatory furnaces of up to 100 tons capacity. Melting on such a large scale helps to even out variations in composition throughout a consignment, since the analytical figures supplied by the smelters are average values and do not represent each ingot in a particular consignment. By maintaining the temperature of the bath as low as possible, a certain amount of refining is effected, since lead in excess of the solubility limit at such a temperature separates and settles at the bottom of the furnace and can be removed from time to time. The solubility of lead in zinc at 460° C., for example, is about 1.15%.² A certain amount of iron in the form of the compound FeZn₇ may also be removed in this manner. This method of open-hearth melting is perfectly satisfactory in the case of zinc, since the solubility of the common gases in the metal is very low, and consequently the problems associated with the liberation of dissolved gases during solidification do not occur to any appreciable extent. Precautions must, however, be taken to prevent excessive volatilization and oxidation of the metal by local overheating.

When producing slabs for the manufacture of high-quality sheet or strip, the metal is often melted in low-frequency furnaces of the Ajax-Wyatt type. By using furnaces of this type cleaner melting conditions can be maintained, alloying elements in the form of

hardener alloys or pure metals can be added directly to the bath, the constant stirring action in the melt ensures homogeneity of composition, and the metal can be cast directly from the furnace to the mould, since these furnaces are normally designed for tilting.

When manufacturing certain zinc alloy rolling slabs, particularly those with high aluminium and copper contents, gas- or oil-fired crucible furnaces are sometimes used. This method is very convenient where small tonnages are involved, particularly when the alloy composition and impurity limits are critical (as for zinc-aluminium alloys), since accurate control of melting conditions, bath temperature, and alloying additions can be maintained.

When slab casting is carried out at the works of the zinc refiners, remelting is often dispensed with altogether, the metal being taken directly from the holding furnace. This system can be recommended only when the refining process can be relied upon to produce metal of constant composition; otherwise the expense involved in remelting off-grade slabs would be excessive. Fortunately, modern methods of zinc refining, such as the refluxing system, produce high-purity metal of remarkably constant composition, but it is important, nevertheless, that the system of identification whereby slabs are correlated with sample analysis be unambiguous.

It is probably true that as far as control of mechanical and physical defects are concerned, melting conditions are less critical in the case of zinc and zinc alloys than with most of the other non-ferrous metals owing largely to the low solubility of the common gases in the metal. However, like some other non-ferrous metals and alloys, zinc is very adversely affected by the presence of certain impurities, and at this stage of production the main emphasis in the control of quality is on chemical composition.

3. CONTROL OF CHEMICAL COMPOSITION

(a) *Effect of Chemical Composition on Properties*

Broadly speaking, the chemical composition of zinc and zinc alloy rolling slabs is governed by the purity of the original metal, the accuracy with which alloying is carried out (where necessary), the extent of loss by volatilization or preferential oxidation, and by the degree of contamination that occurs during melting and casting. The purity of the grades of zinc normally available varies greatly and, depending on the concentrates used, the method of smelting, and the degree of refining, may contain up to 1.3% lead, 0.20% cadmium, and 0.08% iron, with much smaller quantities of copper, arsenic, and sometimes tin and bismuth. It may be added that several commercial grades of zinc are of a very high degree of purity, the metal produced by the electrolytic process reaching a purity of 99.9%+, while metal refined by the refluxing system is normally of a purity greater than 99.99%. The quality of metal selected for the production of rolling slabs is determined only partly by the properties required in the finished sheet, for the amount

of certain impurities that can be tolerated is limited largely by the effect such impurities have on the working properties of the metal, and this precludes the more impure grades from consideration.

Regarding the impurities normally present, lead has little effect on the rolling properties of zinc at normal hot-working temperatures, and up to 1.3% can be tolerated. In fact, up to 1% is sometimes added as an alloying element but, whether present by design or as an impurity, it is liable to segregate when the concentration is greater than 0.9%.

The solubility of lead in liquid zinc at temperatures near the freezing point is 0.9% and, consequently, when more than this amount is present in the melt, a second, lead-rich, liquid is formed which, being of greater density, segregates downwards. Obviously such alloys require adequate mixing and, in melting, considerable advantage is derived from the use of the low-frequency induction furnace.

Iron is considerably more objectionable as an impurity in zinc. The solid solubility of this element is about 0.002%,³ and quantities much in excess of this figure form an intermetallic compound, FeZn_7 , which, being finely dispersed, increases the hardness and reduces the ductility. This leads to excessive edge-cracking during hot rolling, and the concentration of this element is therefore kept as low as possible; 0.02% is the normal maximum for commercial-quality sheet, but, because of its effect on mechanical properties, it is limited to about 0.006% in sheet and strip for deep drawing, &c.

The presence of iron adds further complications in alloys of zinc and aluminium. In this alloy system equilibrium conditions in the melt are such that an intermetallic phase FeAl_3 or Fe_2Al_5 is precipitated at a very low concentration of iron. The density of this phase is about half that of the liquid alloy (with aluminium of the order of 3-5%) and, consequently, it separates rapidly at the surface of the melt. If the alloy is held quiescent in the pouring ladle for any length of time, the total iron content will be concentrated in the first few slabs poured (or in the last when a ladle with a bottom outlet is used) and the aluminium content of the slabs would also be increased somewhat. The trouble can be eliminated by using a grade of zinc with a negligible iron content when making such alloys, and by incorporating a mechanical stirrer in the pouring ladle.

The tin content of zinc and zinc alloy rolling slabs must be of a very low order; the element should preferably be absent altogether. The metal crumbles during hot working when 0.004% tin or more is present, and even 0.002% causes an undesirable amount of edge-cracking. The solubility of tin in zinc is very low, and it is probable that with certain other impurities present, it forms an intercrystalline envelope of a eutectic, the melting point of which is near the temperature of hot working. The effect of the presence of tin on the corrosion-resistance of certain zinc alloys is discussed below.

The effect of arsenic and bismuth on the rolling

properties of zinc is similar to that of iron, and consequently these elements should be excluded, as far as possible, from metal that is to be hot worked.

Cadmium has a considerable solubility in zinc, and is known to exert a pronounced influence on the work-hardening properties of the sheet. If a dead-soft material is required, the cadmium content is limited to about 0.020%. The influence of the metal as an impurity on the corrosion-resistance of zinc alloys is also discussed later below.

Because of its effect on the work-hardening properties of zinc, cadmium is sometimes added in alloying proportions, particularly where a stiff, resilient sheet is required. Sheet for the manufacture of engraving plates has already been quoted as an example, but material for the production of certain types of battery cans also contains this element; its presence in sheet for this application is reported to prolong the storage life of the battery. Cadmium may be added to the melt as pure metal or as a cadmium-zinc alloy. It promotes the formation of a tenacious oxide film on the surface of the melt, which may be carried into the casting under conditions of turbulent pouring. The point is referred to in Section 4 (b).

Magnesium is not a naturally occurring impurity in zinc, but small quantities may be introduced by contamination during melting, e.g. by the inclusion of zinc alloy scrap containing magnesium. The presence of this element in any grade of zinc other than the highest-purity metal is very objectionable, since, with the lead that is normally present as an impurity, it forms the intermetallic compound Mg_2Pb , which segregates at the grain boundaries. This compound is rapidly decomposed by moist air at room temperature, and consequently its presence might bring about embrittlement or disintegration of the sheet if stored or used in damp conditions. Practical experience indicates, however, that this trouble is unlikely to occur unless both lead and magnesium are present in amounts exceeding about 0.02%.

Apart from consideration of their effect on rolling properties, the percentages of lead, tin, cadmium, and bismuth must be of a very low order in alloys of zinc containing aluminium, since the presence of these impurities promotes intercrystalline corrosion, which takes the form of exfoliation of the surface of the sheet with general embrittlement. When preparing these alloys, therefore, only the highest-purity metal must be used, and the impurity elements must be limited to lead 0.005% max., cadmium 0.005% max., bismuth 0.005% max., and tin 0.002% max.

Although small amounts of copper are sometimes found in zinc as an impurity, its main importance to the present subject is as an alloying element. Certain binary zinc-copper alloys are of limited commercial importance, but copper is more commonly used as an alloying element in zinc-aluminium-copper alloys. These possess considerable strength and hardness, their main use, in the form of rolled plate, being for the manufacture of blanking dies and forming tools for sheet-metal work.

(b) Means of Control of Chemical Composition

Virgin zinc is normally obtained from established smelters in standard grades, the chemical compositions of which are reasonably constant. When several grades of metal are obtained for subsequent blending, storage should be systematic and particular consignments should not be issued for melting until the smelters' analytical figures are known. Samples from a percentage of consignments are normally sent for check analysis, the actual percentage varying with the consistency of the metal normally obtained. The system whereby rolling slabs of constant composition are obtained by blending several grades of zinc has already been mentioned.

The return of process scrap to the melting shop must be supervised with care, and every precaution must be taken to prevent contamination of the charges with other metals. Iron and steel can conveniently be separated by means of magnets, and copper-rich material is easily identified by the characteristic colour. No satisfactory means are available for the removal of such a material as solder, and consequently it is necessary to ensure that no possibility exists of the inclusion of solder-containing scrap. The point is of particular importance because of the sensitivity of zinc to a very small degree of contamination by tin and of the fact that large quantities of zinc sheet are used in the manufacture of battery cans, some of which are fabricated by soldering. Where this and other methods of fabrication are employed, it is usual to segregate the soldering activities as far away as possible from other operations and to use the scrap metal for the manufacture of such products as zinc chloride.

Sheet scrap is normally formed into bundles of convenient size by means of a power press. This makes handling and charging considerably easier, although, from the point of view of quality control, the main advantage is that oxidation during melting is greatly reduced.

Scrap from external sources is not often used for the production of rolling slabs, but when this is necessary the material should, after sorting, be melted, cast into ingots, and analysed. Metal slightly off-grade can be added to charges in very small quantities, provided that the dangers of such a procedure are realized.

Because of the trouble associated with the pick-up of impurities, it is desirable that zinc-sheet production, and certainly casting operations, be carried out in a separate section of the works. This is normal practice with the larger manufacturers, but is not always possible with firms engaged in the rolling of a number of non-ferrous metals or alloys, particularly where zinc rolling comprises a minor proportion of the total activities. Fortunately, the effects of contamination are widely known and often become apparent at an early stage.

In the melting stage it is important to keep the bath temperature as low as possible to reduce oxidation and volatilization. A flux cover is not normally used during melting, but a cleaning flux is sometimes

added to the ladle (or to the bath in the case of small furnaces casting directly into the moulds) and skimmed before pouring begins. Fluxes consisting mainly of ammonium chloride and zinc chloride are quite satisfactory; a number of proprietary fluxes are also available. The main purpose of the flux is to facilitate the separation of oxide and dross from the metal and to clean the surface generally.

The treatment of certain zinc alloys with chloride-containing fluxes is undesirable, since such materials tend to remove magnesium and aluminium.

The importance of adequate and continuous stirring, particularly of charges containing a high percentage of lead or aluminium and iron, has been discussed in the previous section (p. 368).

The procedure adopted for the sampling of melts varies considerably with local conditions. With large furnaces melting commercial-quality metal on a continuous system, a sample is taken to represent a weight of metal charged, and, since such a sample does not represent a specific mass of metal, the frequency with which such samples must be taken to ensure adequate control can be decided only by experience. Naturally, samples are taken at more frequent intervals when impurity contents approach limiting values. When small furnaces are used for the production of zinc alloys a sample is usually taken to represent one charge, but, when working with raw materials from reliable sources, a proportion only of the samples is actually analysed. All melts of zinc alloys containing aluminium are analysed because of the critical effect of impurities on the resistance of such alloys to intercrystalline corrosion. Apparatus capable of producing results rapidly, such as the spectrograph, is particularly useful for the control of composition in zinc melting, since, if necessary, the charge can be held while samples are analysed or, if casting proceeds, the results should certainly be available by the time the slabs are required for rolling.

4. CASTING

It appears that a greater variety of methods are used for the production of rolling slabs in zinc than in any other metal; no particular method can be used universally, however, and the actual procedure adopted is governed by the following considerations:

- (i) Standard of excellence required.
- (ii) Type of metal or alloy involved.
- (iii) Size of slab required.
- (iv) Whether the slab is for sheet or for strip production.
- (v) Output required.
- (vi) Cost of equipment.

The standard of excellence is, of course, always a factor of primary importance, but it does not follow that the methods of casting used commercially are those that will produce the most perfect slab. The choice finally rests with the method that will produce a slab of sufficiently high quality for a particular purpose

at the lowest cost, and since a considerable quantity of zinc sheet is used as "commercial ironmongery", an approach to perfection in such cases is not practicable.

In this section "control of quality" is treated by outlining the methods of casting used commercially, considering the principles involved, indicating the limitations and inherent deficiencies in the methods, and describing the means adopted to minimize the slab defects occasioned by these deficiencies.

(a) *Slab Casting in Horizontal Moulds*

The method of casting most commonly employed in the zinc-rolling industry is that involving the open-top horizontal mould. These moulds, which are normally constructed of cast iron, are mounted horizontally on a revolving table and filled by means of a hand ladle in the case of small slabs or from a pouring ladle slung from a gantry crane when larger slabs are required. The size of slab produced is governed by the dimensions required in the finished sheet and by the power of the mill; when necessary, variations in dimensions can be made by inserting liners to reduce the length and width of the standard mould or by varying the height of metal poured. Means of cooling the mould are normally provided; these take the form of water sprays directed upwards against the bottom or cooling fins extending downwards from the base into running water. By these means the mould temperature can be controlled fairly accurately, figures within the range 100°-160° C. normally giving satisfactory results.

Under these conditions of casting solidification takes place mainly from the bottom upwards, and to a lesser extent from the sides inwards, and, since the characteristic feature of the solidification of zinc is strong columnar crystal growth, the final structure of a slab cast in this way comprises large columnar crystals extending from the base almost to the free surface, with shorter crystals extending from the sides, parallel to the free surface. The effect of crystal structure on rolling properties is discussed in a later section.

In slabs cast by this method, the shrinkage that takes place on solidification causes the formation of a depression or sink in the upper surface of the slab or, if this surface solidifies before the interior, a shrinkage cavity is formed below the surface. These features become more marked with increasing slab thickness, and both are undesirable, particularly the latter. Owing to the fact that the upper surface is rarely continuous, the surfaces of the cavity become oxidized, and consequently will not weld together on rolling. This normally results in blistering of the sheet surface or the formation of a series of cracks below the surface. A certain degree of sinking can be tolerated, since it often becomes "ironed out" during the first few passes, but it sometimes happens that a considerable amount of "sponginess" occurs at the centre of the sink (caused by oxidation and shrinkage) which may persist as an area of poor surface in the finished sheet.

Sinking of the free surface can be minimized to some

extent by placing a sheet of asbestos on top of the mould immediately after casting (the oxide film having first been skimmed from the surface), but better results are obtained by using a hot top. This consists of a steel cover, lined with refractory material, dimensioned to fit over the top of the mould and furnished with electrically heated elements concentrated near the sides. The power is turned on some time before the metal is cast, and when pouring is complete the cover is placed in position. By keeping the surface liquid for a longer period, freezing is more likely to take place uniformly from the bottom upwards, and the possibility of a surface sink occurring is correspondingly minimized.

A second method of avoiding surface sinks is illustrated by the Erichsen mould. This, in its original form, comprises a water-cooled copper base and a rectangular detachable frame, fitted with heating elements, which forms the sides of the mould. The sides are brought to a suitable temperature before pouring, and it is not necessary to cover the top during solidification. The metal freezes progressively from the bottom upwards, the edge-chilling being negligible, and consequently there is little tendency for sinks to form in the top surface. Zinc-aluminium-copper alloys were cast in this way in Germany during the war, and the quality of the products was reported to be very good, the surface being absolutely smooth and free from shrinkage. There are, however, difficulties associated with the casting of unalloyed zinc slabs in the Erichsen mould. Because of the severe chilling action of the water-cooled copper base, the formation of cold shuts at this surface is difficult to avoid and, in addition, the steep temperature gradient within the solidifying slab promotes the formation of long columnar crystals. Increasing the metal pouring-temperature to minimize the occurrence of cold shuts (which can be done when casting zinc-aluminium-copper alloys) increases the size of the columnar crystals with attendant complications in the breaking-down stage of rolling, but the incidence of both defects can be reduced by substituting cast iron for copper in the base-plate.

This method of casting is not often used for the production of rolling slabs, but it would appear to offer some advantage when large slabs, substantially thicker than those normally cast in horizontal moulds, are required.

The formation of a surface sink is promoted by the existence of a steep temperature gradient within the solidifying slab, and consequently a pouring temperature as near as practicable to the freezing point of the metal or alloy and a mould temperature sufficiently high to prevent rapid edge-chilling are desirable. For fairly pure grades of zinc a metal temperature of about 460° C. and a mould temperature of 120°-140° C. would be satisfactory, provided that the rate of pouring is adequate. Pouring at too low a metal and/or mould temperature, particularly with slabs of large superficial area, frequently results in the formation of surface laps. This danger can be minimized

by-tilting the mould slightly at the beginning, so that the edge remote from the ladle is raised an inch or two. The mould is returned gradually to the horizontal position as pouring continues, and thus a metal front of some depth gradually moves across the mould bottom. Water cooling is delayed until pouring is complete. Unfortunately, this method of casting tends to favour the formation of edge laps at the two corners nearest the point of pouring.

The main advantages of the horizontal mould are the low cost, the simplicity of the design, the ease with which slabs can be ejected, and the small restraint to linear shrinkage that is imposed upon the cooling slab. Regarding the last point, the large columnar crystals that form in zinc on solidification are so oriented that the basal plane of the crystal is at right angles to the surface of the casting, and it is known that the tensile strength of zinc crystals is lowest in the direction normal to the basal plane. It is evident therefore that unless the slab is free to contract away from the mould surface and to shrink evenly in all directions, the formation of surface cracks is highly probable. Maximum facility for such movement is afforded in the open-top horizontal mould, provided that the mould surfaces are maintained in a smooth condition. The use of a mould coating also assists; graphite or a suspension of one of the refractory metal oxides is often used.

(b) Slab Casting in Vertical Moulds

Provided that supervision of the casting operation is adequate and that means of minimizing surface shrinkage are adopted, sound rolling slabs can be produced by the horizontal casting method, but rigorous inspection of slabs is nevertheless necessary, as high consistency in quality cannot be expected owing to the considerable human factor involved. Other methods of casting, such as those involving a vertical mould, allow of a higher degree of control in the casting operations, and consequently such methods are adopted when consistency in slab quality is of major importance; e.g. in strip rolling, where the mill is working to a strict production schedule. Serious loss of production would result if a large percentage of slabs were found to be defective in batches cast in quick succession, particularly when it is inconvenient to maintain a large stock of slabs. Further, in modern strip mills, 10-20 slabs are rough rolled simultaneously, and, if one or more slabs in a particular batch gives trouble during rolling, the time schedule may be seriously upset and the result may well be the scrapping of a complete batch of slabs in an intermediate stage of breaking down owing to loss of heat.

The principles underlying vertical casting are comparatively straightforward. A section through a typical mould is shown in Fig. 1, where the ideal state is that molten metal is introduced into the mould at such a speed and temperature, and heat is extracted from the metal at such a rate, that the solidification front is maintained just below the molten metal surface. Under these conditions the temperature

gradient within the system is low, the tendency to form large columnar crystals is at a minimum, segregation is unlikely to occur, and a supply of molten metal is readily available to fill the shrinkage voids formed on solidification. Unfortunately, such conditions are difficult to attain in practice, and methods of casting embodying various degrees of compromise are adopted.

The most direct arrangement is that in which the mould is held vertically and the metal poured through a tundish into the mould. A modification is sometimes introduced in the form of a distributing tundish which results in several streams of metal falling into the mould in place of one large stream. There are various objections to this method: (i) a considerable amount of splashing occurs, with the result that beads of metal solidify on the mould walls and may persist in the slab as shallow cold shuts; (ii) owing to turbulence, oxide films and air may be carried deep

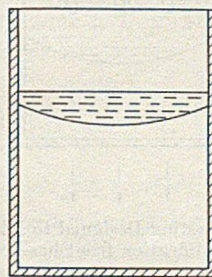


FIG. 1.—Ideal Conditions of Solidification in Vertical Moulds.

into the metal and may be entrapped between the growing dendrites; such inclusions would cause blisters or other defects in the finished sheet; and (iii) the weight of the stream carries hot metal well below the advancing liquid surface, and consequently freezing will proceed in a very irregular manner. The sides may freeze well ahead of the central portions, and bridging may occur across the upper area, while the lower centre is still molten. Feeding then becomes impossible, and shrinkage voids are formed within the slab or, if the shell is thin, the sides may collapse inwards, forming a surface sink. It may be added that, provided the walls of shrinkage cavities are clean and free from oxide or other films, they may weld up during rolling, but their presence is a considerable source of weakness, possibly causing trouble during the breaking-down stage, and is generally objectionable. Further, a central vertical column of molten metal is undesirable, since this allows segregation in a vertical direction to take place more easily. This is not very important, of course, when high-purity zinc is being cast. This method of casting is not often used for the production of zinc rolling slabs at the present time.

Some improvement is obtained when the mould is mounted on trunnions and tilted at the start of pouring so that the metal runs down the narrow side. Splash is negligible, the degree of turbulence is greatly decreased, and the influx of hot metal disturbs a smaller

volume of cooling metal. The contour of the solidifying front of metal synchronizes more closely with the rising liquid surface, and the tendency to bridging and the formation of central shrinkage cavities is hence less. Two additional complications are, however, introduced by this method of casting. First the mould is brought to the vertical position during pouring and, unless this is done continuously and smoothly,

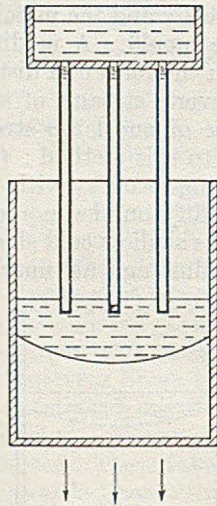


FIG. 2.—Method of Casting Designed to Minimize Turbulence. Contour of solidification front has been idealized.

surface laps may be formed at the short side remote from the metal stream or across the main surfaces of the slab. The rate of tilt should be so synchronized with the rate of pouring that a "tidemark" is not formed on the rising sides of the mould. Secondly, this system of pouring results in the side of the mould down which the metal is poured being considerably hotter than the corresponding opposite side, and consequently the metal solidifies preferentially on one side. This results in an unsymmetrical crystal structure and the concentration of the more fusible impurities near the hotter side, neither of which is particularly desirable. When pouring in this manner, metal may freeze in thin sheets on the mould surface adjacent to the stream, and these sheets may be washed into the mould later. Oxide films are thus introduced into the metal or, if the sheets are of considerable thickness and not remelted by contact with the molten metal, they form a defect akin to a cold shut.

A method used in Germany for the casting of zinc alloys and reported to produce good-quality rolling slabs appears to approach ideal casting conditions and will therefore be described briefly. The mould is of the conventional vertical type, either of "book" design or with a hinged bottom, and is mounted on a platform that can move in a vertical plane. The metal is poured through a tundish having three outlet tubes which extend almost to the bottom of the mould, the exit ports being at the lowest point of the tube wall, not at the bottom, and the mould is lowered con-

tinuously during the pour to maintain the port just below the liquid surface (Fig. 2). This method of casting appears to have several distinct advantages:

(i) The metal stream has minimum contact with the atmosphere, and consequently the possibility of oxide formation is reduced.

(ii) Provided that the tundish is kept full of metal, the possibility of introducing air or dross by turbulence is at a minimum.

(iii) Since the liquid metal enters the mould in a direction roughly parallel to the mould bottom, the solidifying areas below are disturbed to a lesser extent.

(iv) The rate of pouring can be accurately controlled by selecting stems of suitable diameter and, provided that the metal temperature and the rate of heat extraction from the mould are accurately adjusted, solidification should proceed along a front only slightly below the liquid surface.

Such conditions will minimize segregation and facilitate feeding and, since the possibility of introducing air and oxide is small, sound slabs should result. The main objection to this method of casting appears to be the provision of the moving platforms which, where large numbers of slabs are required, would add considerably to the capital outlay.

In this country, when slabs of the highest quality are required for the production of strip, Durville casting or a method akin to it is used. The Durville system of casting has been adequately described elsewhere, and when working with zinc of electrolytic purity, slabs of excellent quality of the approximate dimensions $30 \times 14 \times 2$ in. are produced with a very low rejection figure. The slab requires feeding from a hand ladle while solidification is in progress, and, if carried out effectively, only the top inch or two of the slab requires cropping.

The mould used in a method of casting that is somewhat similar to the Durville system is illustrated in Fig. 3. The mould is mounted on a horizontal axis,



FIG. 3.—Position of Mould During the Pouring Operation by the Method Similar to the Durville System.

and during the pouring operation it is inclined a few degrees from the horizontal, the open end being the higher. A few minutes after the end of pouring, the mould is brought to the vertical position and remains thus until solidification is complete. The top 25% or so of the slab is removed by cropping. The quality of slabs produced by this method is also extremely good.

In both these systems of casting the metal enters the mould in a comparatively tranquil state, and consequently the complications that result from turbulent pouring are virtually eliminated. However, even with the best combination of mould and metal temperature, a substantial volume of the metal is in the liquid state when the mould reaches the

vertical position, and there is, therefore, some risk of segregation occurring. This is not important when casting zinc of fairly high purity or the conventional rolling mixes, but it is doubtful whether either method would be particularly satisfactory for casting some of the zinc-aluminium-copper alloys, where one of the phases that may separate on solidification is of appreciably lower density than the liquid.

5. GENERAL REMARKS

(a) *Surface Cracks*

Contrary to the view sometimes expressed, it appears that surface cracks are comparatively uncommon in zinc slabs cast in vertical moulds. This may well be due to the care taken to ensure that the mould surfaces are maintained in a smooth state, as a roughened surface inhibits movement during cooling and thus promotes the formation of cracks. In addition, a shallow layer of equiaxial crystals, oriented somewhat favourably for slip to occur parallel to the mould walls, normally exists at the surface of the slabs and is, consequently, considerably more ductile than a structure comprising columnar crystals oriented with basal planes normal to the slab surface. This skin will deform when subjected to the stresses imposed by restraint to shrinkage, although cracks may occur in the underlying columnar crystals. Provided that this outer skin remains unbroken, thus preventing the entry of oxygen and other reactive gases, the fissures in the columnar crystals are comparatively innocuous, since they weld up during rolling.

(b) *Structure of Rolling Slabs*

Crystal structure is a point of primary importance in assessing the quality of rolling slabs, and considerable attention is normally directed to controlling grain-size, grain orientation, &c. The structure must be such that substantial deformation can be obtained at each pass in the breaking-down stage without the risk of excessive cracking, and this can normally best be accomplished when the structure consists of small equiaxial grains oriented at random, but under no conditions of casting that are commercially practicable can such a structure be obtained in zinc. Under normal conditions of casting the structure obtained comprises large columnar crystals, often extending from a plane near the surface to the centre of the slab, with a shallow layer of equiaxial crystals at the surface. The columnar crystals are so oriented that the basal plane is approximately normal to the surface,^{4,5} and it appears probable that, in the shallow outer layer, the orientation is such that the basal plane is parallel to the surface or within $\pm 15^\circ$ of this position.⁴ Much of the data necessary to analyse the mechanism of deformation in the hot rolling of zinc is lacking (such an analysis is in any case outside the scope of this paper), and consequently it is not possible to define with any degree of accuracy the most desirable structure in rolling slabs or to assess how far this

columnar structure is removed from the ideal. There is little doubt, however, that a coarse columnar structure in the slabs adds appreciably to the difficulties in the breaking-down stage of zinc rolling, and consequently attempts are made to decrease the size of the columnar crystals. Rapid chilling and inoculation with zinc dust⁶ bring about some improvement, and certain proprietary grain refiners are also used. The addition of small amounts of titanium brings about a considerable degree of grain refinement,⁷ but the presence of titanium has a marked effect on the mechanical properties of the finished sheet, and there is no evidence to indicate that this procedure has been adopted commercially.

(c) *Slab Surface Quality*

A higher quality of surface is required in zinc rolling slabs than in slabs of most other non-ferrous metals, since the former are not normally scalped. This operation is omitted partly to reduce cost, but mainly because the cutting action of the tool tends to tear the zinc crystals and thus form cracks. Alternatively, the removal of the outer surface of the slab by scalping may merely expose fissures that were already present in the underlying crystals.

(d) *Inspection of Rolling Slabs*

The most important point in the control of quality is to select methods of production that are fundamentally sound and capable of producing satisfactory slabs; the operations must be adequately supervised to ensure that the selected system is strictly followed. Inspection should include intelligent observation at the melting and casting stages, and any abnormalities such as excessive drossing, interrupted pouring, &c., noted; the castings involved should be treated as suspect.

The control of chemical composition has been discussed in an earlier section (p. 369). It is important that the system of identification whereby slabs are correlated with chemical composition be unambiguous, as otherwise the value of this aspect of control is lost.

Visual examination of slabs is invariably carried out, and products containing defects such as excessive sinks, surface cracks, laps, surface oxide inclusions, &c., can be segregated in this way. When cropping is carried out by sawing, examination of the exposed surface may be used to assess the probable degree of internal soundness. Radiographic examination of a proportion of slabs as a means of quality control is not common practice, but is to be recommended particularly where the castings are transported over a considerable distance between foundry and rolling mill.

Sectioning slabs to assess internal soundness is normal practice when the casting procedure is being developed or modified, and is frequently used for routine inspection when trouble from this source is encountered. Behaviour during rolling as a means of routine inspection can be very costly, since a "suspect" slab may damage equipment by its erratic

behaviour. However, the presence of a serious defect usually becomes evident during the first few passes, and the particular slab can be rejected before any serious trouble occurs.

Examples of internal defects in a vertically cast rolling slab of 2 in. thickness are shown in Figs. 4-8 (Plates LII and LIII). Fig. 4 is a reproduction of a radiograph taken through an area of the slab in which interdendritic shrinkage has occurred, and Fig. 5 is a photograph of a vertical section through this area. It will be observed that the interdendritic shrinkage has affected a considerable volume of metal.

A defect in a rolling slab caused by entrapped gas, secondary piping, or a combination of both is shown in Figs. 6 and 7, the former being a print from a radiograph and the latter a photograph of a horizontal section through the affected area.

The macrostructure of a vertically cast slab is shown in Fig. 8; the crystals are predominantly of the columnar type and the dendritic structure is very evident. Interdendritic shrinkage can be seen in the area at the left-hand end of the photograph which corresponds approximately to the centre of the rolling slab.

III.—EXTRUSION BILLETS

1. RANGE AND REQUIREMENTS OF PRODUCTS

Virtually all the extrusion billets cast in this country are used for the production of rod that is subsequently drawn to wire for use in the zinc-spraying process or, in finer gauges, for the production of woven brake linings. In the former application the main requirements are high resistance to corrosion, combined with sufficient strength and ductility to withstand the stresses encountered during the drawing operation. Wire produced from metal of purity greater than 99.99% (B.S. 1003) fulfils these requirements.

The finer wire, normally 32 S.W.G., for the production of woven brake linings, must also possess high resistance to corrosion and, apart from the additional stress encountered in drawing to this gauge, must be sufficiently strong to withstand the not inconsiderable shock loading that is imposed in the weaving process. The high-purity metal can be used for this application also, but because of the danger of grain growth after excessive cold work, small proportions of other metals are sometimes added as grain-growth inhibitors. The problem is similar to that encountered in the rolling of foil in high-purity zinc, where excessive grain growth may cause severe embrittlement. This is because the temperature of recrystallization in zinc is a little above room temperature and decreases with increasing degrees of cold work. As in the case of foil, the addition of small quantities of manganese inhibits crystal growth; the presence of other metals in small proportions has a similar effect, but complications may be introduced by the effect of such metals on hot-working properties and resistance to corrosion.

Apart from correct chemical composition, the main requirements of these extrusion billets are freedom from internal unsoundness, such as piping or shrinkage, and freedom from gross surface defects; shallow surface defects are not particularly important, since the outer shell of the billet is left in the extrusion press. The crystal structure, and hence the mechanical strength of the billet, is of less importance, since, unlike rolling slabs, the casting is supported on all sides during the hot-working process.

2. MELTING

At the authors' works, high-purity zinc extrusion billets are cast in metal taken from the holding bath of the "refluxer" (which produces high-purity zinc by fractional distillation). This method of refining produces metal to specification B.S. 1003 with remarkable consistency, and the routine system of sampling and analysis (spectrographic) is adequate to ensure that all billets conform to specification requirements, typical analytical figures for the metal being lead 0.002%, iron 0.002%, cadmium 0.001%, and other impurities present in traces only. All billets are stamped with a serial number so that they can be correlated with the relevant sample and are segregated until the results of analysis are known.

The metal for billets from which the fine wire is made is melted in crucible furnaces of approximately 1 ton capacity, and the required amount of manganese added as a zinc-5% manganese hardener. A sample from each melt is analysed, but this is not a particularly arduous system of control, since the alloying constituents and the impurities can be determined by means of the spectrograph.

3. CASTING

To a large extent the problems associated with the casting of extrusion billets are similar to those already discussed in connection with the casting of rolling slabs in vertical moulds, but three additional points must be taken into consideration: (i) The ratio of height to cross-sectional area is normally somewhat greater in the case of extrusion billets, and greater precautions must therefore be taken to prevent internal unsoundness, since the problem of ensuring adequate feeding is considerably more complex with castings of such shape. (ii) For reasons already stated, less importance attaches to surface quality provided that the defects present are comparatively shallow. Methods of casting can therefore be selected primarily to ensure internal soundness even when this involves some sacrifice of surface quality. (iii) The presence of large columnar crystals is less objectionable in billets than in rolling slabs, the reasons for this having already been indicated. Billets may therefore be allowed to cool more slowly and, if cooling is controlled so that the upper portion remains liquid while the bottom solidifies, feeding is facilitated.

It may be mentioned here that from the point of view of control of quality, the main problem in billet

casting is to prevent the occurrence of secondary piping, i.e. piping in the lower portions of the billet; primary piping can usually be prevented by feeding from a hand ladle, an operation that requires some degree of skill.

The mould used for casting extrusion billets consists of a cylinder of length 36 in. and internal dia. 5 in., the material of construction being good-quality grey cast iron; the bottom is detachable and the bore is tapered slightly to facilitate ejection of the billet. The upper half of the mould is lagged with asbestos sheet to ensure slower cooling of the metal in this area both by retaining heat in the mould walls between casts and by reducing the rate of heat loss when the mould is full and the metal solidifying. No dressing is used, but the mould walls are brushed between casts.

In the actual casting operation the mould is vertical and the metal poured through a tundish; pouring is completed in approximately 1 min., and feeding from a hand ladle is continued for approximately 10 min. Satisfactory results are obtained with a metal temperature of 450°–460° C. and an average mould temperature of 80°–100° C.

It is essential that the tundish be located accurately, since, if it is off-centre, the metal will impinge on the mould wall, causing a relatively deep defect in the billet surface. The tundishes inevitably receive rather rough treatment during service and, to ensure uniformity of casting conditions, they must be well maintained and replaced when necessary.

Although it departs from the theoretical ideal in several respects, this method of casting produces very satisfactory billets, and the percentage rejection is low. The large metal fall is undesirable in that it causes considerable splash, produces turbulence, and disturbs the progress of solidification at the lower areas. The surface defects that result from splashing are comparatively shallow, and are rarely sufficient to justify rejection of the billet. By keeping the tundish full, the entry of oxide and dross is largely prevented, but air is undoubtedly introduced by turbulence. However, it appears probable that pouring is complete before solidification has proceeded very far, and consequently the included air can coalesce and escape to the surface. Undoubtedly the lagging of the upper half of the mould reduces the rate of solidification in this area, and thus facilitates feeding of the lower centre. This method of casting is perfectly satisfactory for the production of billets in pure zinc or single-phase alloys, but an undesirable amount of segregation would probably occur if it were used with some of the more complex alloys.

The macrostructure of a billet of high-purity zinc cast in this manner is shown in Fig. 9 (Plate LIII). The working properties of such a billet are quite satisfactory, although the structure is obviously coarse and strongly columnar.

When casting billets in zinc alloys, a more satisfactory method is one similar to that described previously for the casting of slabs (Section II, 4 (b)), where the tundish has an extended stem and the mould is lowered continuously during pouring. This system was used in Germany during the war.

The system known as chill casting may also be used. The moulds are constructed of steel sheet of about 14 S.W.G. and are placed in tanks fitted with a water inlet at the bottom and an exit near the top. The moulds are filled and the water turned on so that the level rises slowly in the tank to a point about 6 in. below the top of the mould. Solidification takes place progressively and rapidly from the bottom, thus decreasing the possibility of segregation and facilitating feeding.

4. INSPECTION OF BILLETS

The high-purity zinc and zinc-manganese alloy billets are cropped to 30 in. before despatch, the cropped ends being remelted. Most of the billets are despatched without further treatment, but since they are cut into 15-in. lengths before extrusion, one in ten is cut in half before despatch and the exposed surfaces examined to assess internal soundness. Should a pipe be revealed on cropping or halving, the billet is rejected and a number on either side of it are rigorously examined for piping so that the extent of the trouble can be ascertained. The surface of the billets is also carefully inspected, and billets containing gross surface defects are rejected. The number of billets rejected owing to piping or surface defects is normally very low.

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THE CONTROL OF QUALITY IN THE MELTING AND CASTING OF ALUMINIUM ALLOYS FOR WORKING*

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SYNOPSIS

The special problems arising in the melting and casting of aluminium alloys and the best methods of quality control are considered in relation to nine standard groups of alloys intended for use in wrought forms.

The effects of the alloying additions and of impurities and incidental contaminants on foundry practice, on the setting up of standards of quality, and on the ultimate properties of the material, are treated under the specific alloy groups.

The limitations of the melting and casting processes available, and in particular of the direct-chill casting method, are outlined, and the degree of control which it is possible to exercise through routine physical and chemical inspection at the various stages is indicated.

I.—INTRODUCTION

THE preparation of cast blanks for extrusion, rolling, or forging entails problems which do not arise in the metallurgically simpler case of shaped castings, e.g. gravity die-castings, since the material must combine the requisites—seldom similar—for both casting and working. Foundries producing cast forms for working are called upon to supply these in alloys developed not primarily for their casting characteristics, but rather for their hot- and cold-working properties and for their good mechanical properties in the as-produced or heat-treated condition. Moreover, the requirement that the wrought material, both in the intermediate processes and in its final form, should approximate as closely as possible to the ideal elastic-plastic state imposes a restriction on the use of alloying additions which often detracts from the casting qualities. In the absence of an ideal casting process, standards of control must, therefore, be limited by the scope of the methods available, the use for which the material is intended, and economic considerations.

Since the war, a series of specifications has been drawn up by the British Standards Institution, in collaboration with the industry, to cover wrought aluminium alloy products for general engineering and Service requirements. Typical alloy compositions are set out in nine groups in Table I. Many of the variations in alloy content are very slight.

The problems of successful manufacture are increased by the fact that these nine alloy types are required in a wide diversity of cast forms, namely:

- (i) rolling slabs;
- (ii) extrusion billets;
- (iii) cast forging uses;

- (iv) wire-bars;
- (v) hollow billets for tube manufacture;
- (vi) slugs for impact extrusion;
- (vii) stock for rolled sections.

To meet specific demands it is usual to select a particular form and type of alloy, rather than to adopt the alternative of varying the quality of any one alloy or form at the casting stage. The aim of the foundry must be to produce consistently the best quality in every case, since the overriding requirement is that the material should meet the needs of the working process. Some scope as regards control of quality lies in the choice of melting and casting methods, and where more than one method will produce workable material, economic considerations will be decisive.

As the complexity of the alloy system increases, the limitations imposed by the fact that insufficient eutectic is available to ensure soundness tend to disappear,¹ but the higher alloying additions may be associated with segregation or gross intermetallic forms which give trouble in working. In some cases, owing to the solution-age-hardening effect typical of these alloys, hot or cold stress-cracking may result if the direct-chill-casting method is used. Of the wrought materials at present being produced, the aluminium-zinc-magnesium-copper group is the most prone to this type of failure.

The relation between the tendency to crack during freezing and alloy composition has been well demonstrated by the work of the Aluminium Development Association's Welding Research Team at Birmingham University.² The behaviour of the materials studied by these investigators under critical welding conditions has been found to be a reliable guide to the behaviour of similar material when cast in large sections under

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conditions of accelerated freezing. The employment of high freezing rates is peculiar to the casting of wrought alloys, being necessitated in part by the large products involved, up to 500 in.² cross-section, and in part by the need to minimize segregation and suppress the formation of large constituent particles.

The following examples illustrate these points: (a) The simple binary aluminium-magnesium alloy is of the solid-solution type, exhibiting nearly ideal properties in the wrought state in all forms, but as a casting alloy it has an insufficiently long freezing range to permit large-section castings to be made free from shrinkage. In the preparation of large

avoidance of oxide in any form. Oxide in the grosser state can lead to failure during working, in a finer state to rejection of the semi-finished product, and in the most highly dispersed forms may result in premature failure of the final product. There is some evidence³ to suggest that oxide films, even of molecular thickness, strongly influence recrystallization, and so play a vital part in determining metallurgical properties. Therefore, if high quality is to be ensured, oxide formation in melting and casting must be strictly controlled.

The charge may prove a major source of oxide. With reverberatory furnaces, the melting loss may be

TABLE I.—Typical Compositions of Main Groups of Wrought Aluminium Alloys.

Group No.	Alloy Type	Alloying Additions or Impurities °									British Standard Designation
		Mg, wt.-%	Cu, wt.-%	Zn, wt.-%	Si, wt.-%	Fe, wt.-%	Mn, wt.-%	Ni, wt.-%	Ti, wt.-%†	Cr, wt.-%	
1	Commercially pure Al	0.05	0.10	...	0.12	0.25	0.05	...	...	...	1
2	Al-Mn	0.05	0.10	0.10	0.25	0.60	1.0-1.3	...	...	...	N3
3	Al-Mg	1.8-2.3	0.10	0.10	0.20	0.40	0.15-0.35	...	...	...	N4
		3.0-3.5	0.07	0.10	0.20	0.40	0.35-0.55	...	...	...	N5
		4.0-4.5	0.05	0.10	0.20	0.30	0.35-0.55	...	...	...	...
		4.6-5.3	0.05	0.10	0.20	0.20	0.15-0.35	...	...	...	N6
		6.5-7.0	0.05	0.05	0.20	0.20	0.15-0.35	...	...	...	N7
4	Al-Mg-Si	0.50-0.70	0.10	0.10	0.4-0.7	0.50	...	...	...	...	H9
		0.80-1.0	0.10	0.10	0.7-0.95	0.40	0.15-0.25	...	...	...	H10
5	Al-Cu-Mg	0.7-1.0	4.0-4.8	0.10	0.4-0.7	0.4-0.7	0.5-0.9	0.10	...	...	H14
6	Al-Cu-Mg-Si	0.55-0.85	4.2-4.6	0.10	0.65-0.9	0.3-0.6	0.65-0.85	0.10	...	...	H15
7	Al-Zn-Mg-Cu	2.2-2.7	1.2-1.5	5.5-6.0	0.15	0.40	0.25-0.30	...	...	...	...
		1.8-2.2	1.5-2.0	6.6-7.4	0.25	0.40	0.1-0.30	0.10	...	0.05-0.15	...
8	Al-Cu-Ni-Fe-Si	0.7-1.1	1.9-2.2	...	0.9-1.1	0.9-1.1	0.10	0.9-1.3	0.15	...	H12
9	Al-Si-Cu-Ni-Fe	0.8-1.2	0.7-1.0	...	11.0-11.5	0.4	0.10	0.7-1.3	0.10	...	...

* Alloying additions are printed in heavy type; other figures represent maximum permissible contents of impurities.

† Grain-refining agent; may be present in 0.01% content range.

rolling slabs, shrinkage may occur either at the mid-section or at the surface, depending upon the precise freezing conditions. To avoid both these faults calls for closely controlled foundry techniques. (b) Similar difficulties are encountered in the ternary group based on aluminium-magnesium-silicon, which are particularly versatile in the wrought state. The disparity between the requirements for working and those for casting is shown by the fact that the wrought forms have compositions approximating to aluminium-1% magnesium-1% silicon, whereas the cast material contains 2½% silicon or more.

II.—MELTING

1. BASIC PRINCIPLES

(a) Inclusions

The mechanical and chemical cleanliness of the metal can be controlled only in the liquid state, and in this respect the outstanding requirement is the

as much as 10% when fines are charged, as against 2.5% when melting pig and heavy process scrap.⁴ Such losses may be affected by the surface condition of the stock. If corrosion products are present on the solid charge, then a significantly higher melting loss due to oxides will occur; moreover, owing to the particularly objectionable form the oxide films can take, more difficulty will be found in removing them from suspension in the melt.

Another main cause of oxide formation is the reaction of the products of combustion of reverberatory furnaces with the surface of the melt, though this may be minimized by maintaining, as far as practicable, a non-oxidizing atmosphere over the hearth. The present authors' experience with a wide range of furnaces, variously fired, suggests an overall loss of about 2.5%, as practical considerations limit the degree of control that can successfully be exercised. Covering fluxes, which are discussed in more detail in Section II, 3, may be used to protect the melt from oxidation.

If a serious attempt is to be made to suppress oxide formation during melting, induction-heating methods must be employed. Although considerably lower figures for metal loss can be obtained by this means, the expected improvement in quality does not necessarily result, as the marked degree of turbulence caused by convection currents tends to retain the oxide entrapped in the melt. A separate settling operation in a radiant-heated holding bath is therefore needed to produce metal of adequate cleanliness.

With reverberatory melters, either of the batch or continuous type, the same necessity for holding arises, but in general a holding time is inherent in the process. In the present authors' opinion the value of holding is unquestionable. This view, however, is not fully supported by other producers, owing no doubt to the subtle variations in the form of oxide inclusions that may occur with different techniques.

Common inclusions, other than simple oxide films, which may be present, are :

	Density, g./c.c.
Al ₂ O ₃ (corundum)	3.95-4.10
Al ₂ O ₃ .MgO (spinel)	3.50
SiO ₂ (quartz)	2.65

In reverberatory melting these conglomerates of compound oxides are formed on the surface of the melt by thermit reaction; hence the first operation in removing them is surface fluxing and skimming. The accumulation of residues at the bottom of the bath indicates that, as might be expected from their densities, some of the conglomerates leave the surface and settle, at a rate determined by their form and composition.

The tapping method selected—either decanting or bottom tapping—depends on whether experience confirms that the undesirable oxides are retained at the surface, or penetrate the skin and enter the melt. The practice favoured in the authors' works consists of bottom tapping to discharge the metal, coupled with the use of low temperatures and adequate surface fluxing. The exigencies of production have not always permitted a detailed study of these inclusions, and their composition and origin may be other than those suggested above, as is demonstrated by the fact that considerable difficulties have been encountered from time to time with the products of low-frequency furnaces.

An outstanding variation which has been noted is the presence of manganese carbide in a manganese-rich alloy, the carbide originating in the manganese metal, which was produced by a thermal-reduction process. Because of the physical characteristics of the carbide, its presence gives rise to all the undesirable features commonly associated with inclusions of the spinel or corundum type.

The preparation of metal free from inclusions has been dealt with at some length because no single in-line technique for controlling quality is known, and use must therefore be made of basic production methods for the successful elimination of these harmful constituents.

(b) Control of Gas Content

A review of experience covering melting in furnaces of the crucible, electric-resistance and electric-induction, coal-fired, coke-fired, oil-fired, town-gas, and producer-gas-fired reverberatory types, indicates that metal with a low gas content can be produced independently of the heating medium employed, the governing factor being the attainment of metal/gas equilibrium at the casting temperature. As in general the melting temperature must be significantly higher than the casting temperature, an adequate holding period at the latter temperature is essential, 1-1½ hr. being normally sufficient.

Here again, control is not aided by any laboratory test, once the melting and holding practice has been established, such methods as the Straube-Pfeiffer test being insufficiently critical to discriminate between metal which in its ultimate form will give rise to troubles associated with gas content, and a cast metal that will be trouble-free. In view of the known accuracy of such tests, it is probable that many of the defects, particularly of the final product, commonly attributed to gas, are not to be related to the gas content of the molten metal. If suitable holding conditions are provided, equilibrium gas contents can to a large extent be assured, and if the direct-chill-casting process is adopted, then the content will be further reduced by the automatic rejection of excess gas required to fulfil equilibrium conditions at the freezing temperature. In the direct-chill process, using open moulds, the molten pool above the near-horizontal freezing plane is so shallow that little resistance is offered to the escaping gas. In view of these easily applied controls, there is no necessity to carry out degassing, which offers little advantage when large volumes of metal, up to 20 tons, are being handled. On the contrary, turbulence resulting from degassing would have the undesirable effect of entrapping all types of oxide particles.

(c) Alloying

When alloying aluminium with a metal of high melting point, special techniques are necessary, if troubles due to high-temperature oxidation are to be avoided. Further, the fact that the alloying metals tend to have densities markedly different from that of aluminium leads to practical difficulties which must be solved if uniform quality of the product is to be ensured. The alloying elements can be divided into two groups: (i) those having densities lower than that of aluminium, viz. magnesium and silicon; and (ii) those having higher densities, the chief of which are copper, manganese, nickel, iron, zinc, and chromium. With the exception of magnesium, which is added in the pure state, these elements are pre-alloyed with aluminium in a separate operation to form binary or ternary alloys of sufficiently low melting point to allow of their introduction into aluminium at a temperature of approximately 750° C. As this pre-alloying must be carried out at a high temperature,

special furnaces must be used, in which the melts are adequately protected by surface flux.

Since no true refining process to eliminate impurities can readily be introduced in aluminium smelting, the purity of the original ingredients is of the utmost importance, if the purity and cleanliness of the final product is to be maintained. In discussing general alloying practice it should be pointed out that, while the introduction of a high percentage of clean scrap and/or secondary ingot is also determined by economic considerations, it is a common observation that furnace charges on this basis produce material which in casting and working gives a more consistent performance than that produced from melts made up of virgin aluminium and hardeners. This holds good despite the fact that no chemical or metallographic controls indicate any imperfections in the alloying and melting techniques employed for material from virgin melts.

2. FURNACES

(a) *Induction Furnaces*

Success in alloying, even with the most diverse additions, can be assured by using induction furnaces for melting. For bulk production of aluminium the low-frequency loop-type furnace is generally used. For alloys this type of furnace is unsurpassed, and when used in conjunction with resistance-heated holding furnaces, is capable of providing material of the highest possible quality. Its use does not, however, necessarily solve many of the fundamental problems confronting the fabricator; hence the decision to install such equipment is normally based either on economic or general practical considerations, e.g. under the latter head, cast sections and process scrap may be of such large dimensions that direct introduction into the melting unit is physically impossible. The logical use for these furnaces in the wrought alloy industry is for the recovery, with low melting loss, of light scrap and fines, i.e. sawing, scaling, and milling swarf, scrap foil, &c.

(b) *Duplex Reverberatory Furnaces*

Present-day fabricating plant and techniques call for large cast blocks, which can be produced economically only by using furnaces capable of melting up to 2 tons/hr. and with a hearth capacity of 10-15 tons. With such a quantity of metal melting and alloying become major physical and mechanical operations. Rabbling, necessary to achieve alloying, and fluxing, necessary to minimize oxidation, must be carried out at temperatures higher than those required for casting; the preparation of the melt should therefore be divided into two stages, alloying and holding, the latter being regarded as the refining process. A double-hearth furnace makes it possible to combine continuous melting at a steady rate with an alternate holding and casting cycle.

3. MELTING TECHNIQUES FOR THE PRINCIPAL ALLOYS

(a) *Group 1: Commercially Pure Aluminium*

The influences exercised by impurities on the properties of any pure metal are experienced to the full with aluminium. In order to satisfy the wide diversity of applications to which the material known as "commercially pure aluminium" is put, it is therefore necessary to select the raw material carefully, or to alloy on a scale that is significant in the pure metal range.

Material of 99.99% purity is prepared by a special process, and if the standard is to be maintained, furnaces with suitable linings must be used for melting and processing. Lower grades (99.8, 99.7, and 99.6% purity) are not the product of any electrolytic refining process, but are prepared by the remelter selecting pig of appropriate composition. Furnaces with clean hearths, if necessary washed out with aluminium of lower purity, are essential; and during melting the unnecessary introduction of furnace tools must be avoided, owing to the rapid solution of iron that takes place despite protective wash coatings. Pick-up from refractories is not normally serious, as a lining of aluminium oxide forms on the hearth during working. If metal of such purities is melted in solid-fuel-fired reverberatory furnaces, the silica contained in the ash may be carried over in the products of combustion and contaminate the melt. No such effects have been noted with oil-fired or washed producer-gas-fired furnaces.

A random melting of Canadian pig with process scrap will yield a purity of the order of 99.5%. The preparation of metal of this grade calls for the minimum control in the melting operation, other than the general precautions already stated. However, the change-over from 100% pig to a mixture containing pig and scrap demands plant control for the segregation of process scrap, and an analytical checking of the molten metal to confirm the absence of contaminants, or their presence within acceptable limits. In a foundry handling the full range of aluminium alloys for working, contamination by a number of elements may be expected. If virgin metals only are involved, these are likely to be confined to magnesium, copper, zinc, silicon, iron, manganese, nickel, titanium, and chromium, all of which are standard alloying elements. If secondary ingot or dealers' scrap is concerned, then a check must also be made for such elements as lead, tin, and antimony.

Aluminium of purity lower than 99.6%, although commonly known as "pure aluminium", should more accurately be described as aluminium-iron-silicon ternary alloys, since iron and silicon are deliberately added to achieve specific properties. The system falls into two subdivisions: (i) alloys intended for tube manufacture, in which the purity is held at an average of 99.2% to obtain a fine grain-size and an adequate strength; and (ii) alloys used

for sheet manufacture, where in order to avoid the formation of needle-like crystals of $AlFe_3$, the iron and silicon are deliberately added in a ratio of 4 : 1, so that a complex is formed which will spheroidize at $570^\circ C$. In the preparation of all grades of pure aluminium, especially when casting the larger sections, addition of a grain refiner is desirable, if not essential. The most suitable refining agent is a proprietary one, based on boron and titanium salts, plus a percentage of hexachlorethane which provides nascent carbon as an end product of decomposition. Its high reactivity enables adequate grain refinement to be effected with trace quantities only of boron and titanium, which do not affect the general purity.

(b) Group 2: Al-Mn Alloys

As already stated, the first step to ensure satisfactory final quality in this material is care in selecting the manganese metal, as any carbide contained in it cannot be removed. Freedom from carbide is essential, as drawing operations can be adversely affected by the presence of these hard insoluble particles.

Melting is complicated by the fact that even when a 5 or 10% hardener is used, the rate of solution in aluminium is relatively slow at the normal melting temperature. It is therefore usual to increase the working temperature by $50^\circ C$., to approximately $780^\circ C$., unless the holding time can be prolonged. Solution of the manganese can be aided by gentle rabbling.

When first introduced, this alloy was probably regarded as binary. Casting by the direct-chill method revealed a proneness to hairline cracking, difficult to avoid owing to the limits of operational control. It was therefore decided to alter the composition of the alloy and to improve its fluidity by increasing the iron content from the variable amount present in virgin aluminium, typically 0.2%, to a controlled amount of 0.4%. The addition of a grain refiner is essential, as the alloy shows a pronounced tendency to form large grains during casting.

(c) Group 3: Al-Mg Alloys

The aluminium-magnesium group, with its wide solid-solution range, permits the preparation of a series of alloys having satisfactory mechanical properties combined with high corrosion-resistance and good workability.

Their melting gives rise to a problem not so far discussed, namely, that of loss of the alloying constituent through preferential oxidation. Although it becomes more marked with larger amounts, the effect is not strictly related to the magnesium content, the extent of loss being determined more by the type of material charged and the method of working the bath. Preferential oxidation results in the formation of thin oxide films which are extremely difficult to remove from the liquid metal, and an attempt is

generally made to suppress its occurrence as far as possible. Of the many liquid covering fluxes used, that based on magnesium chloride and free from sodium salts has proved the most effective. To prevent flux particles being carried over, the last operation before casting is the careful removal by skimming of the contaminated flux.

The preferential formation, during the direct-chill-casting operation, of magnesium nitride results in an irregular cast surface which must be completely removed before rolling. The introduction of 0.001% beryllium into the melt suppresses this effect completely and, incidentally, appears to improve the hot workability of the alloys.

When melting metal for direct-chill casting some attention must be paid to the iron content, as there is a tendency for the iron-rich fraction to be rejected from the magnesium-rich solution at the moment of freezing. As a consequence, the surface where exudation occurs, becomes enriched by particles of iron aluminide. These act as stress-raisers in the cast edges, themselves highly stressed in the rolling operation, and lead to failure by cracking. The alloy in which this has most significance is the 4% magnesium alloy used for ships' plates, and the iron content is here controlled to a maximum of 0.2%.

A phenomenon observed by the present authors more than once, which has defied explanation, is the exhibition by the 3 and 5% magnesium alloys of hot-shortness at normal rolling temperatures, if the copper content exceeds 0.07%. On the first occasion in which this was noted, a content of 0.07% appeared to be critical; the material with 0.06% rolled satisfactorily, whereas that containing 0.08-0.10% consistently failed by surface shattering. As the observation was made during actual production, adequate samples of other casts were available to confirm that casting and preheating techniques were not at fault.

Because of the high annealed strength of the 5 and 7% magnesium alloys, these are used where strong welded joints are required. It has been demonstrated⁵ that the gas content of the parent metal plays a significant part in determining behaviour during welding, and in consequence it is usual to degas these materials to a degree not normally necessary in preparing a sound casting. In order to achieve this low gas content various techniques, both preventative and curative, have been explored. On the preventative side the present authors have established by experiment that the magnesium itself is the main source of gas. This can be explained by the high solubility of hydrogen in pure magnesium, and further by the presence on the surface of present-day magnesium ingots of considerable amounts of corrosion product. The need to treat corroded ingot is not unusual, but whereas in the case of aluminium alloys the adverse effects can be minimized by preheating on a forehearth to $400^\circ C$., this is not practicable in the case of magnesium. The industry would no doubt be glad to see a re-introduction of the pre-war method of packing used by the Japanese, in

which the ingots were wrapped in waterproof paper and sealed in metal containers.

The high gas content introduced by the magnesium means that at the beginning of melting the metal is supersaturated and thorough degassing is necessary. The best method is the use of a magnesium-chloride-base, liquid flux, which permits the free escape of gas; this is accelerated by maintaining an inert atmosphere over the melt, and by gentle rabbling to facilitate diffusion within the molten metal. By this means it has been possible to prepare casts which seem to be perfectly sound under the Straube-Pfeiffer test.

It is fortunate that the limitation of iron and copper content which has to be imposed in order to ensure good hot-working properties, is consistent with the high corrosion-resistance required in the finished product. Specifications call for the control of zinc, but there appears to be little justification for this, except in the broadest terms, as evidence favours, rather than condemns, the presence of a certain amount of this element.⁶ At various times the desirability of controlling the alkali-metal content of these alloys has been discussed, trace quantities of these metals being absorbed from the covering fluxes used. Further evidence as to the necessity or otherwise of controlling these impurities would be welcome.

Manganese is normally added, in order that the iron-manganese compound may be formed in preference to the iron-aluminium compound. Its introduction does not, however, present any problems in the percentages used.

(d) *Group 4: Al-Mg-Si Alloys*

If the compositions in this group are studied, it will be seen that only minor differences exist between one alloy and another. This is because the alloys are assessed on the basis of their characteristics in the wrought and heat-treated condition, when small changes in content of individual elements, or in the element ratios, play a major part in determining the ultimate behaviour. These variations are, however, of interest only to the fabricator, and at the melting stage few problems exist, other than that of maintaining precise control of composition.

(e) *Group 5: Al-Cu-Mg Alloys, and Group 6: Al-Cu-Mg-Si Alloys*

For these alloys to fulfil their functions in carefully designed, highly stressed structures, such as aircraft frames, a consistent performance must be assured. To achieve this, each of the elements in the quaternary alloy must be controlled within very precise limits indeed, and it is the usual practice to use a charge make-up into which a high percentage of secondary ingot of known analysis is introduced, or alternatively, clean scrap of definite composition. This practice also meets the economic necessity of re-introducing the high percentage of fabrication scrap, but quite apart from that aspect, the technique is preferable to

the handling of virgin charges, if reverberatory furnaces are employed. The existence of an enormous amount of scrap in these alloys has made it possible to demonstrate on the largest scale that metal, correctly handled, can be remelted many times without impairing any of its specific qualities.

The fact that this material is finally employed in thin, highly stressed sections means that metal cleanliness must be impeccable. The first control designed to this end is to ensure that no component of the charge is metallurgically unsatisfactory. Therefore no swarf is charged directly into these alloys; light scrap is baled and checked for freedom from moisture, oil, and other foreign matter; if secondary ingot is used, then its production from scrap is carried out under close supervision, utilizing flux-washing processes. The introduction of hardeners does not present a very serious problem, because the quantity introduced at any one time is limited by the high percentage of pre-alloyed material that it is possible to use in preparing a charge. Nevertheless, it has been found desirable to raise the temperature of the melting bath to ensure the complete solution of the hardener elements, aided by rabbling; the bath is then held at this higher temperature to facilitate the settling of non-metallic impurities in accordance with Stokes' law. At the end of this operation the melt is dressed with a cryolite-base flux and all floating drosses carefully removed. In the case of a single-hearth furnace, the metal is allowed to reach its correct tapping temperature and is then covered with a fresh liquid protective flux. With duplex furnaces, the metal is tapped into the second hearth after the first skimming treatment, and reskimmed to remove any oxide film formed during transfer. The clean metal is allowed to stand under a low flame and falling temperature for 1½ hr., while degassing takes place. Successful degassing depends entirely upon a correct initial temperature, for if the holding bath has to be reheated, the metal again becomes supersaturated with gas. As in practice it is almost impossible to observe these conditions, the ideal holding bath would incorporate muffle arches or resistance heating. Holding in the second hearth serves a dual purpose, as it not only degasses the metal but also permits further settling of non-metallics.

(f) *Group 7: Al-Zn-Mg-Cu Alloys*

Although the attractive properties of this group of alloys have long been known, successful production has had to await the development of suitable melting and casting techniques which allow of the preparation of cast blocks, sound and free from segregation. Because of the close relation of mechanical properties and of freedom from stress-corrosion to composition, emphasis at the melting stage will be upon uniform alloying. Using furnaces other than those of the induction type, zinc must be introduced as a 25% hardener; melts of uniform analysis can thus be prepared without excessive rabbling or a prolonged mixing time.

The strength of these alloys in their final form is one-third greater than that of the alloys of Groups 5 and 6, and in addition there seems to be some increase in notch sensitivity. In utilizing these alloys designers must be fully confident that premature failure will not occur, as a result either of mechanical fault associated with lack of cleanliness of the metal, or of stress-corrosion arising from segregation effects. Cleanliness must be carefully watched, as the alloys in the semi-fabricated state are prone to superficial corrosion; hence process scrap should be re-used immediately, or, if this is not possible, stored under good conditions or ingotted. In the melting operation proper, covering fluxes are used to prevent the preferential oxidation of magnesium and of zinc. The technique adopted is that already outlined for the aluminium-magnesium alloys of Group 3.

The fact that in these alloys requirements for working and those for casting probably diverge to the greatest extent, has led to a very detailed exploration of the influence on casting behaviour which the composition can exercise, while at the same time remaining within the prescribed limits. This problem has been very fully discussed by Cook, Chadwick, and Muir,⁷ and in more general terms by Pumphrey and Moore.⁸

(g) *Group 8: Al-Cu-Ni-Fe-Si Alloys*

These alloys are chiefly used for forging into components working at elevated temperatures in internal-combustion engines. Although complex, their melting presents no serious problems, if normal procedures are carefully used. To ensure uniform properties and ease of working, grain-refining treatment is standard practice. Titanium was formerly introduced as an alloying addition for this purpose, but better results are now obtained by using the proprietary agents based on titanium and boron which are added to the melt some 10-15 min. before tapping.

(h) *Group 9: Al-Si-Cu-Ni-Fe Alloys*

Metallurgically, this system is of considerable interest, because it has a eutectic and, further, because the production of material suitable for working depends upon its correct modification by supercooling in the presence of sodium, which suppresses the formation of primary silicon. For this purpose the melt must be raised considerably above the normal temperature; in practice 780° C. is found desirable. At this high temperature there is a natural tendency for gas to be picked up, and some degassing treatment should therefore follow. Immediately before casting, sodium metal, wrapped for convenience in aluminium foil, is added, and the metal is allowed to stand for a critical time which depends on the production conditions obtaining. Casting must then be carried out as speedily as possible. In selecting the composition of this alloy, the absence of primary silicon will most readily be ensured if the silicon content is reduced to the minimum compatible with meeting all other requirements.

III.—METAL TRANSFER

Control in the melting process is concerned with the elimination of oxides introduced from the stock and with avoiding the formation of hard inclusions arising from thermit reactions on the surface of the melt. However, preventative measures during melting can be completely nullified if adequate care is not taken in tapping the furnace and transferring the metal to the casting mould.

The method of metal transfer will depend on the unit volume and rate of production. For small quantities hand lading is favoured, as this has generally given better results than decanting from the furnace or bottom tapping, when comparative production trials have been conducted. This technique has proved satisfactory for castings up to 300 lb., although to counter the fall in temperature occurring in this slow process, it is necessary to raise the bath temperature higher than would be considered ideal. Its success appears to depend on the avoidance of turbulence created by bottom tapping of the bath, and of the splashing effects inevitable with any method of filling the crucible by means of a continuous discharge of metal from the furnace. However, the undesirable effects of a continuous stream can be reduced by tilting the crucible back towards the furnace. As throughput rates increase, more complicated methods, such as siphoning, can be employed, but in the absence of outstanding advantages the simpler methods are best for routine production.

Following this argument, it will be seen that in single-hearth melting the ideal would be a short launder, linking the furnace spout to a lip-axis tilting mould. It is not, however, possible to employ a transfer launder of this simple channel construction, as some oxide formation is inevitable, and a reservoir to reduce the velocity must be incorporated. The aim of the whole transfer operation is to preserve an absolutely steady flow of metal, so that the initial protective oxide film formed on the metal surface remains intact. Failure to do this leads to fresh oxide being formed and to broken particles of oxide film being entrained in the metal stream.

With static furnaces and fixed moulds such as are used in direct-chill casting, a permanent launder installation can be employed. However well the launder may be designed, two points of weakness remain: these are the point of entry of the metal into the launder from the holding bath and the efflux from the launder to the mould. Successful tapping of a bath is a problem that still awaits an ideal working solution. Because of this, every foundry is continuously engaged on minor modifications to equipment and the introduction of remedial measures, such as filtering with porous refractories and glass-wool compacts inserted in the launder. No general recommendation can be made, as the measures which give success vary according to the rate of flow and the heat loss that can be tolerated in the launder. Because of the impossibility, for the reasons already

stated, of employing sharp gradients in the launder, low gradients and slow rates of flow have to be adopted, but as these are associated with unacceptable heat loss, heating or insulation of the launder becomes essential. Whether good pre-heating or continuous heating during casting is chosen, some undesirable temperature variations are inevitable. The importance of this must be examined in relation to the high chilling rates employed in the direct-chill process, and the critical heat balance which must be maintained if the selected freezing conditions are to be ensured.

The mechanical construction of the launder and its ancillary equipment merits some attention. Three aspects in particular must be watched, the most important being to avoid the inclusion of refractory particles arising from spalling or from collapse of the lining. If internal gas heating of the launder is employed, moisture pick-up from the products of combustion may cause gassing of the metal. The varied contours normal to launder design make uniform heating a matter of considerable technical difficulty. A complete solution must be found, since the temperature of the initial flow of metal in the continuous-casting method can determine success or failure in obtaining a sound casting. Few more pertinent controls can be exercised than those of good original design and good maintenance during use of the metal-transfer system.

In analysing the requirements of any laundering system consideration must be given to the statement, already made, that the freezing equilibrium must be maintained within very close limits. A major factor influencing the rate of chill is the amount of metal in the mould. Therefore, if the metal level must not fluctuate, a constant rate of flow from the launder is necessary. In securing such a flow, allowance must be made for the density of aluminium, which renders the significance of the head of metal in the launder greater than would at first appear. The problem may be approached in two ways, either by direct control of the level in the launder by regulation of the flow from the furnace, or by automatic control of the level in the mould by float-valve distributors. In either case, whether running from the furnace to the launder or from the launder to the mould, the ideal is to discharge the metal through the bottom of the furnace and launder so that the formation of oxide skin is prevented. Such principles are not generally applicable to pouring into tilting moulds, unless heavy castings are being considered. In the continuous process, downward discharge from the launder can be accomplished if sufficient attention is paid to nozzle design. If a vortex is created in the reservoir, or if suction effects arise owing to the bore of the vertical tube being larger than is required for the rate of flow, thus permitting air induction, then bubbling will occur and will give rise to the continuous formation of oxide with disastrous results.

Bottom vertical tapping from large-capacity, stationary furnaces has not been adopted, primarily because of the practical problems involved. These

difficulties are resolved in the design of the fully continuous Junghans-Rossi casting machine, where the metal-dispensing system is reduced to one vertical tube fixed in the bottom of a tilting furnace. The base of the furnace is of a shallow V form and the discharge tube is inserted normal to the plane of one half of it. This construction permits the metal to be withdrawn from above the discharge tube, in the event of a failure in the control system. The stopping and starting of the flow, as well as the regulation of the rate, are accomplished by the insertion of a cone valve into the top of the tube. Undesirable suction effects are avoided because the high speed of casting permits the maintenance of an adequate fluid head in the mould, thus ensuring that the lower end of the tube is completely submerged at all times.

IV.—CASTING

1. GENERAL CONSIDERATIONS

The methods of casting now employed are the outcome of years of empirical work in evolving reliable techniques to permit the production on a large scale of castings having a wide diversity of freezing characteristics and of varying liability to segregation, stress-cracking, and other effects. Very precise determination of the ideal conditions has been necessary, because only the highest-quality material is satisfactory in the working processes.

In the preparation either of cylindrical extrusion billets or of rectangular slabs for rolling, by the older methods employing complete moulds, much of the success is dependent upon the skill of the operative, who has to vary the rate of flow in such a way that constant freezing conditions are maintained, since constant pouring gives rise to variations in freezing rates greater than are compatible with the preparation of completely sound castings. When casting alloys of Groups 1 and 2, satisfactory results can be obtained only if a hot mould is used. As this precludes water-cooling, the production technique for these materials is to work a number of moulds consecutively, the rhythm of production thus ensuring that the mould starting temperature is that required. The obvious drawbacks of such methods have encouraged the development of many casting procedures having as their objective the extraction of heat across the minimum section. The nearest approach to success has been achieved in the direct-chill or continuous-casting process, which has also the advantage of enabling large sections to be prepared in any desired length.

At the risk of over-simplification, the principle relating freezing range to cooling rate may be stated as follows: as the freezing range increases, from pure metals and eutectic alloys to more complex systems having a progressively greater difference between the liquidus and solidus temperatures, so the temperature of the mould must be reduced.

The initial approach to solving this problem was to

reduce the size of the casting and, where necessary, to use a heavier mould with a greater capacity for heat absorption. The limits of these possibilities were soon reached, and higher rates of heat extraction had to be employed. This led to the development of, first, the water-cooled cast-iron mould, then the water-cooled copper mould, and finally the direct-chill process, in which the metal is cast into a shallow water-cooled mould or form of the required cross-section, and quenched by water sprays impinging on the solidified shell of metal as it is withdrawn from the mould by mechanical means at controlled casting speeds.

The direct-chill process, in any of its modifications, is sufficiently versatile to permit satisfactory castings to be made in any of the alloys of the groups mentioned, whatever their freezing characteristics. As might be expected, however, the process has problems peculiar to itself. These problems, and the controls necessary to overcome them, are discussed below for the various groups of alloys, the older processes still in use being also examined. Freezing ranges for typical compositions in each of the groups of wrought aluminium alloys are as follows :

Alloy Group	No.	Representative Freezing Range, °C.
C.P. Al	1	30
Al-Mn	2	20
Al-Mg	3	35
Al-Mg-Si	4	40
Al-Cu-Mg	5	130
Al-Cu-Mg-Si	6	130
Al-Zn-Cu-Mg	7	170
Al-Cu-Ni-Fe-Si	8	90
Al-Si-Cu-Ni-Fe	9	20

2. CASTING TECHNIQUES FOR THE MAIN ALLOY GROUPS

(a) Group 1 : Commercially Pure Al, and Group 2 : Al-Mn Alloys

The metallographic structures obtained by the older methods of casting these alloys are so satisfactory that a change-over to the direct-chill method has been delayed until it can be adapted to produce equally good results.

Figs. 1 and 2 (Plate LIV) are photomicrographs typical, respectively, of materials of Groups 1 and 2, cast in hot solid cast-iron book moulds. In neither case was a grain refiner used, and the structure is that resulting from the casting conditions adopted. Longitudinal sections (not shown) confirm the general freedom from preferred orientation. Figs. 3 and 4 (Plate LIV) and Figs. 5 and 6 (Plate LV) illustrate transverse and longitudinal sections of continuously cast rolling slabs. In this case a grain-refiner has been used for the Group 2 alloy (Figs. 4 and 6). The longitudinal sections show that, despite the generally fine grain in the cross-section, there is a pronounced tendency for the grains to be columnar in form, thus imparting undesirable directionality to the material. Figs. 7-10 (Plate LV) are photomicrographs of the

same materials. The coarser precipitates occurring in the hot-mould castings are seldom of practical significance. The precipitates within the grain parameter, seen in the direct-chilled material, occasion more concern owing to the directionality thereby perpetuated.

In actual casting the only method of controlling the quality of the final product lies in the choice of the casting method. With rolling slabs, some opportunity to exercise control arises at the scalping operation, where cold shuts, dross inclusions, hot tears, and surface cracks are revealed. For this reason scalping may be regarded as one of the main inspection methods operating in the foundry. The attribution of the causes of such defects is in some degree a matter of experience, but as they are generally traceable to shortcomings either in equipment or personnel, cause and effect can be rapidly correlated. The 100% inspection at the scalping stage may, however, be later proved to have been ineffective by failure of material at the hot mill, due to unexpected shrinkage effects, or at the final sheet-inspection stage, where heavy rejections due to blisters may occur with annealed sheet produced from stock which would otherwise have been regarded as normal.

Casting of slabs in solid moulds is liable to produce central weakness, if there is any slight departure from standard practice. In order to detect the occurrence of such defects at an early stage, the product of each mould is sampled in turn by taking sections from the centre of the slab, which are fine machined and etched. This type of defect is, however, more often related to the control of temperature and pouring speed in casting than to the condition of the mould. The life of solid cast-iron moulds is limited by the onset of heat-crazing of the surface and by graphitization, with consequent loss of heat conductivity. When serious cracks and non-uniform chilling become evident, the mould faces are reconditioned by planing.

As a result of the low alloying contents of these materials, few segregation effects arise which can be regarded as controllable. In the case of direct-chilled pure aluminium, bands rich in iron and silicon occur at regular intervals across the face of the slab. A similar general enrichment occurs in the slabs from solid moulds, but the enriched layer is not so thick. Figs. 11 and 12 (Plate LV) show microsections through the surface layers on material produced by the two methods, and the iron and silicon contents are given below :

	Fe, %	Si, %
Produced in cast-iron book mould (Fig. 12) :		
Surface	1.20	0.15
Interior	0.29	0.12
Direct-chill-cast (Fig. 11) :		
Surface	3.45	0.92
Interior	0.25	0.12

As this banding persists and can be detected in the partly processed sheet, and even in the finished sheet, if a sufficiently critical survey is made, scalping has to be applied more generally than would be the case

if soundness and cleanliness of appearance were the sole criteria of quality in slabs.

The casting of pure aluminium rolling slabs, even in the largest sections, by the direct-chill process has not proved unduly difficult in practice. In the casting of other solid sections, such as wire-bars and extrusion billets, serious trouble is encountered owing to the enormous shrinkage that takes place on freezing. In the case of wire-bar of approximately 4-in. Gothic section, the intensity of chill is so great that

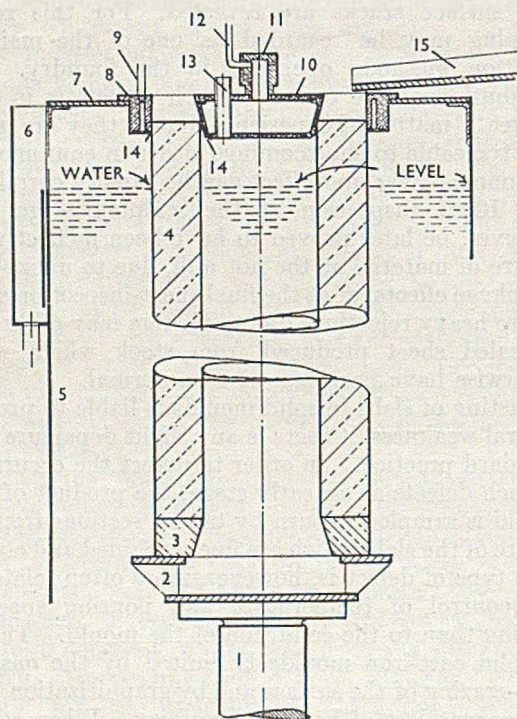


Fig. 17.—Equipment for Direct-Chill-Casting a Hollow Billet 20 in. in Outside Dia. × 10½ in. dia. Bore.

- KEY.
- 1. Ram for lowering billet.
 - 2. Stool plate.
 - 3. Stool.
 - 4. Hollow billet.
 - 5. Water casing.
 - 6. Weir to drain.
 - 7. Top-tinged plate.
 - 8. Die.
 - 9. Water pipe to die.
 - 10. Mandrel.
 - 11. Water box on mandrel.
 - 12. Water pipe to mandrel.
 - 13. Steam escape pipe.
 - 14. Cooling-water jets.
 - 15. Launder from furnace.

star-cracking due to shrinkage is present to a high degree (Fig. 13, Plate LVI). The intermediate sizes, approximating to 6-, 9-, and 12-in.-dia. extrusion billets, call for freezing rates which can readily be provided within the limits of the method. Large cross-sections tend to show unsound centres at the finish of casting, unless precautions are taken to prevent severe piping and possible cracking. The obvious remedy of casting more slowly is not always a practical one, owing to the probable occurrence of cold shutting.

Whilst the casting of large solid sections presents a problem, hollow billets for the manufacture of tube blooms can be cast fairly easily, owing to the absence of a focal point for shrinkage effects. Fig. 14 (Plate

LVI) illustrates the largest hollow billet so far cast, viz. 20-in. outside dia. × 10½-in. bore. Fig. 17 shows schematically the casting arrangement for this billet; while the casting conditions can be noted from the Standard Practice Sheet shown in Fig. 18. Inspec-

Standard Practice Part II—Foundry		Index No. :	
		Date :	
Alloy : PA	Product Size : 20 in. outside dia. × 10½ in.-dia. bore	Furnaces Concerned : No. 6	
Product Type : C.C.P. Hollow			
Melting Bath		Holding Bath/Pot	
Fluxing : Flux No. 5—6 lb.		Fluxing :	
Melting Procedure : Bring Melt up to 730° C. Rabble for 5 min. Add Flux No. 5—Dry off Skim Clean—Allow Temperature to rise to 740°-745° C.			
Furnace Temp. : 740°-745° C.			
Melting Part Charges	Weight of Metal : 500 lb.	Bath Temp. : 740°-745° C.	
Fluxing : Flux No. 5—6 lb. per Shift		Holding Time of Bath : 20 min.	
Part Charge Procedure : After addition of part charge rabble for 2 min. At end of shift add Flux No. 5. Dry off—skim clean		Recharging : 500 lb. after each drop	No. of Operators : Firemen : 1 Casting : 2
		Tapping Temp. : 740°-745° C.	
Plant		Casting	
Type of Unit : C.C.P.	Baffles : Nil	Casting Temp. : 690°-695° C.	No. Cast/Drop : 1
Die Type : C, 20 in.; B, 3½ in.	Mandrel Type : K	Length of Cast : 44 in.	Casting Speed : 3-3½ in./min.
Launder Type :	Launder Cap :	Die Water : 16 gal./min.	Mandrel Water : 9 gal./min.
Stool Shape : Concave		Height of Pit Water : 5 in. below die skirt	Height of Metal in Die : 1½ in. from top
Basic Output/Shift :		Weight of Product/in. : 20-18 lb.	
Other Plant Remarks :		Other Remarks on Casting Technique :	

Fig. 18.—Specimen Standard Practice Sheet.

tion control for such castings is concerned with bore finish, chemical composition, and accuracy of dimensions. As the casting conditions are critical, little deliberate modification of the macrostructure is possible.

(b) Group 3 : Al-Mg Alloys

Of the non-heat-treatable range of alloys the aluminium-magnesium group offers those having the greatest strength in the wrought state. These alloys are therefore of considerable value, and are likely to assume still greater importance as production techniques overcome the problems set by their manufacture.

The relative difficulty of casting can be illustrated by the fact that while solid-mould techniques have been developed which permit 2% magnesium alloy

to be cast into slabs up to 250 lb. in weight, the 3% alloy cannot be cast into slabs weighing more than 1 cwt., and pre-extrusion has to be employed in the preparation of rolling blanks in the 5 and 7% magnesium alloys. Even with modern direct chilling, no satisfactory technique is available in the United Kingdom for the casting in 7% magnesium alloy of a slab capable of being directly rolled, though it is understood that this is being done on the Continent.

If the equilibrium diagram is considered, it will be seen that of the four commercial alloys produced, only the 2% alloy is single-phase. The presence of the second phase is of no practical significance in the 3% alloy, but considerable attention must be paid to its control in the 5 and 7% alloys. For successful rolling, with freedom from crocodiling, edge-cracking, and surface crazing, an increasing rate of chill in relation to the alloying addition must be employed in casting. If this rate changes significantly, from such a cause as variation in the level of the metal in the mould, shrinkage or a coarse β phase will result and lead to surface breaking when rolling. The occurrence of a dross-film inclusion at the slab face can similarly upset the rate of heat extraction at the instant of solidification, and occasion notable departures from the ideal cast state.

The lack of sufficient eutectic in the 2% magnesium alloy shows itself by a tendency to fail by hot tearing, if slight stresses are set up as a result of the mould face being imperfectly dressed, or owing to the mould becoming slightly distorted. Cracks of this nature are in the horizontal sense, and tend to occur at the slab edges. Another indication of the same tendency is the formation of vertical surface cracks due to irregular cooling, such as might result from a blocked spray hole.

It has already been mentioned, when dealing with melting and alloying, that a trace addition of beryllium is made to alloys containing 3% or more of magnesium. Using the direct-chill process, the observed effect of this addition is to produce slabs and billets having cast skins freer from exudation effects than if no beryllium is added. The reduction of exudation to a minimum makes casting easier, in that the metal/mould-face relationship is kept more nearly constant. The economy effected by the addition of this costly element is, however, to be found less in the improvement of the cast face, than in the avoidance of the small surface imperfections that appear in the scalped face of hot-rolled metal not so treated. In certain cases, also, the addition of beryllium will obviate the milling of slab edges, the necessity for which arises from the fact that exudations break off during hot rolling and are rolled into the main faces of the plate, with consequent damage to the surface.

Emphasis has been placed upon the preparation of these alloys in slab form, because the hot-rolling operation is more sensitive to faults in material than is the extrusion process. Unquestionably the preparation of cast blanks for forging and pressing also calls for material of the highest quality; forging is,

however, such a limited field that it is not sufficiently familiar to serve as a general illustration.

Extrusion billets can be satisfactorily and economically prepared in a completely water-jacketed mould, in which case control will be concerned almost entirely with the production of billets free from central weakness. This is ensured by careful selection of method and by seeing that it is scrupulously followed, particularly as regards casting temperature, speed, and the topping operation. If the direct-chill process is adopted perfect soundness can be obtained, but the difficulties inherent in the alloy system, already discussed in connection with the casting of rolling slabs, are again encountered.

A sufficient demand for tubing exists to justify the casting of special hollow billets in the 2% magnesium alloy, a typical size being 9-in. outside dia. \times 2-in. bore. Defects met with are those associated with the difficulty of starting to cast successfully, and with maintaining the metal at a constant level, so that hot-tearing effects are avoided. It has not been found possible to suppress exudation either in the bore or on the outer surface, and the bores are machined to a depth of $\frac{1}{8}$ in. on the radius before extrusion into bloom. The preparation of hollow billets in the 3, 5, and 7% magnesium alloys has not yet been attempted.

(c) Group 4: Al-Mg-Si Alloys

Owing to the great difficulties of casting this group of alloys by the direct-chill process, it is not employed except for some major economic or other reason. Consideration of the alloy system will show that little is to be expected metallurgically of the direct-chill method in suppressing segregation effects or in giving greater soundness. In fact, because of the tendency towards preferentially orientated structures, the use of cast blank so prepared can prove an embarrassment.

All sizes of extrusion billets can be satisfactorily produced; using either solid iron or water-cooled moulds. Rolling slabs up to $30 \times 25 \times 5\frac{1}{2}$ in. can also be made in solid cast-iron moulds. No points arise regarding the technical control of these methods of production which have not already been discussed. In using the direct-chill method, however, control of casting practice becomes more critical, as the alloys are extremely prone to shrinkage, which can be exaggerated by stress arising from the heat-treatment effect to which they are subject. Successful casting, therefore, depends upon obtaining the nearest possible approximation to the ideal of vertical heat extraction from a horizontal cooling face. Cooling in this manner is initiated by using a stool cooled by internal sprays. The general direction of chilling is further established by immersing the solid cast section in water almost immediately below the mould. To minimize the inevitable side-chilling effects through the walls of the box mould, the flow of water is reduced to a volume sufficient only to prevent the mould from over-heating. In addition, the water passing through the mould is discharged to waste,

instead of being directed on to the casting by suitably inclined jets. To encourage the formation of a horizontal freezing plane, distributors can be used which direct the incoming hot metal to the extremities of the mould, thus countering to some extent the adverse effects of side chilling. It follows, from the well-known fact that the depth of the freezing cusp is directly determined by the speed of casting, that these alloys must run at a slow rate.

Correct indication of the speed selected and its steady maintenance throughout the entire casting operation are therefore factors of major importance in maintaining control. Instruments of sufficient accuracy for this and other control purposes in the chill-casting process are not readily available. Given efficient equipment, which enables precise standard practices to be observed, the present authors are of the opinion, contrary to that expressed by Thomas and Fowler,⁹ that good castings can be produced consistently in these and any other alloys, and that it is shortcomings in this direction, rather than undefined variation in metal quality, that cause failure.

From the foregoing it will be seen that in the casting of these alloys quality control is concerned less with the metallurgical characteristics than with the mechanical means necessary to produce sound castings. Of some metallurgical interest is a feature observed very noticeably in the alloy containing 0.7% manganese, but also seen in the 1¼% manganese alloy of Group 2, namely the profound effect which the direct-chill process has on the subsequent recrystallization behaviour of the material in the wrought state. This is of considerable importance economically, as extensive homogenization has to be undertaken before the material will respond freely and uniformly to annealing treatments.

(d) *Group 5: Al-Cu-Mg; Group 6: Al-Cu-Mg-Si; Group 7: Al-Zn-Cu-Mg; and Group 8: Al-Cu-Ni-Fe-Si Alloys*

The successful casting of slabs for direct rolling in most of the alloys of Groups 5-8 has been made possible only by the direct-chill process. The general difficulty of casting these complex alloys in such a way as to refine their structure sufficiently to make them acceptable for direct working, is enhanced by the fact that all the alloys are heat-treatable and that complicated stress systems are set up as a result of the solution effects of direct chilling. Precise control of every stage of the operation is therefore essential. Severe exudation, which is a result of the complexity of the systems, necessitates deep scalping in the case of rolling slabs and machining in the case of extrusion billets.

Segregation, other than that associated with surface exudation, is not a matter for routine control, and defects are confined to cracking in its various forms. Types encountered include: central delayed-stress cracking in the low-copper alloys of Groups 5 and 6;

vertical cracking in the same groups, associated generally with too slow a casting speed; and "trouser-leg" splitting in Group 7, which is the resultant of the high heat-treatment response of this alloy system in conjunction with the low hot strength. Most of these defects are self-evident, but 100% macro-inspection or examination by ultrasonic means is carried out to ensure that no material is processed which is unsound in any degree. Fig. 16 (Plate LVII) is a photograph of a 6-in.-dia. billet cast in one of the alloys of Group 6; perfectly sound as cast, it cracked in the manner shown during preheating for extrusion.

(e) *Group 9: Al-Si-Cu-Ni-Fe Alloys*

Whilst this billet alloy presents no serious problems during casting by any method, the following experience may be of interest. The successful production of 12-in.-dia. billets by the direct-chill process could at one stage not be reproduced in the authors' works owing to failure eventually traced to the type of mould lubricant used. Based on evidence gained from comparative trials, a general change had been made in the foundry from simple mineral oils and greases to a proprietary silicone-bearing mixture. While this was successful with all the company's other alloys, and has been retained for use with them, it proved to be reactive with the alloy of high silicon content and gave rise to intense shutting effects which rendered the billets useless. A return to ordinary mineral oil produced the smooth surface commonly obtained with this alloy.

V.—APPLIED CONTROLS

1. CHEMICAL COMPOSITION

The techniques outlined above should yield cast blocks having the minimum variation in composition due to segregation. Some variation associated with these effects must be accepted, but successful production will depend upon the attainment of the desired mean composition.

The preparation of casts to give a correct target composition, involving in many cases four or five alloying elements and three or more impurities, calls for comprehensive sampling schemes and adequate analytical facilities. Most of the material to be examined is in the molten state, and liquid samples may be taken and cast into the most convenient form. Considerable care must be used in selecting the precise method to be adopted if misleading values are not to be obtained. If tapping is protracted, samples should be taken at least from the beginning and the end of the run, and more samples should always be cast than are normally required, so that the existence of faults may be confirmed and the seat of any trouble located.

The methods of analysis vary considerably, but any control laboratory has available bench equipment for gravimetric determinations, and some type of colorimeter, polarograph, and spectrograph. This diversity

of equipment has been necessary in the past owing to the difficulty of analysing aluminium alloys, which made it essential, if results were to be obtained in the minimum time, to adopt the method of determination most appropriate to each element. Fortunately, the direct-reading spectrograph now gives results for the majority of the elements in a few minutes, and permits a high order of control checks and release analyses to be made while melting is in progress.

2. MELTING

In earlier sections an attempt has been made to summarize the main sources of trouble and causes of defects in each of the groups of material commonly handled, and to indicate the principles to be observed if a consistently satisfactory quality is to be attained. In practice, a specific interpretation of these principles must be applied to each individual class of product. For the purpose of shop control, all the information relevant to a certain type, based on experimental work in the foundry culminating in trial production runs, is assembled on one or more sheets known as "Standard Practice Sheets." Part, or the whole, of these data are then passed to the key personnel. A typical form is shown in Fig. 18 (p. 386). The quality of the material produced in the trial runs is subjected to close laboratory control, both at the foundry and at the fabricating plant. Moreover, no standard is accepted as final until normal or improved yields are obtained.

On the Standard Practice Sheet temperatures are specified for each stage of the operation. This calls for suitable pyrometric equipment. As the typical furnace unit is large, and the cycles in consequence protracted, continuously recording instruments are favoured. Instruments of robust design, and possessing open scales that can be read with ease, should be employed, and each one should be installed, if possible, adjacent to the charging station, where the furnaceman may have it under constant observation. The industry finds difficulty in obtaining a suitable material for thermocouple sheaths, capable of withstanding immersion in molten aluminium for long periods. No refractory sheath has been found entirely satisfactory, failures being due to mechanical or thermal weakness. Sheaths of heat-resistant cast iron are therefore used, but a reasonable life can be assured only if they are given a refractory wash after each shift. Whilst the accuracy of modern instruments leaves little to be desired, a false confidence will be gained unless due consideration is given to the many factors determining the actual temperature recorded. Amongst these are the heavy nature of the sheaths and the fact that the couple is normally protected from mechanical damage by being located in the furnace lining. Both these factors cause considerable lag. The position of the hot junction of the thermocouple needs to be carefully selected in relation to the depth of the melt, as with reverberatory furnaces a 40° C. gradient between the melt

surface and the hearth floor has been observed in baths of 18-in. working depth. This accounts for the apparently anomalous fact that rabbling causes a rise in the temperature indicated. The siting of the thermocouples in the bath is decided when the original design is completed. The site, or sites, selected can seldom be related to the points of thermal significance, as other considerations prevail and the thermal behaviour is thus to some degree a matter of conjecture. This is nowhere more obvious than at the beginning of melting; until a completely molten pool is obtained the pyrometric installation is useless, and the avoidance of overheating becomes a matter for personal control by the operative.

In casting, there are also considerable limiting factors in determining temperature. If casting direct from the holding bath is practicable, the minimum temperature at which tapping can successfully be undertaken becomes *ipso facto* the general tapping temperature. The temperature of the metal at the time of tapping can be widely altered. Excessive preheating of the launder may cause over-heating of the initial stream; more frequently, however, the low temperature of the launder results in the metal being too cool. In the case of transfer of metal by ladle some heat loss is inevitable, and allowance must be made for this.

For a battery of small reverberatory furnaces working on the continuous-melting principle with ladle transfer of the metal, a multiple-station temperature-indicating system has been found satisfactory. The system is so devised that the operator has only a thermocouple to handle. When this is lifted from its hook the circuit peculiar to the furnace is isolated, and without any further action on his part, the temperature of a thermocouple permanently immersed in the bath is indicated on a 24-in.-dia. illuminated dial (Fig. 15, Plate LVI). Meanwhile, if the operative so wishes, he can immerse the hand-thermocouple in the melt in the ladle and this temperature will be indicated 10 sec. after lifting the couple from its hook. A permanent record of all temperature measurements from this battery of furnaces is made on a master recorder installed in the Superintendent's office.

Where the melting unit is large enough, efficient combustion of fuels will be aided by installing flue gas CO₂ recorders and by fitting pressure indicators to the heat-exchange chamber. In all cases, however, the necessity of opening doors for charging, fluxing, skimming, &c., renders any continuous record of little use.

3. CASTING

If casting is to be reliably executed, the following controls are necessary in addition to those regulating metal temperature. The temperature of the cooling water must be kept constant within 1° or 2° C., and suitable mercury-in-steel indicating thermometers should be fitted. Provision of a means of adjusting

the cooling-water temperature is, of course, assumed. Of equal importance is the rate-of-flow indicator, which ideally should be provided for regulating the supply of water to each mould. Control of speed of casting is of vital importance, both as regards correct indication of speed from the instant when initial movement begins, and sensitivity to changes in speed. The ideal may be a combination of good instrumentation and mechanical regulation.

A non-standard requirement is the automatic control of the height of the metal in the mould, which becomes progressively more desirable as the number of feed points increases beyond the possibility of manual control. This can be achieved within very close limits by means of a float-operated valve distributor in the mould.¹⁰

In the case of castings of smaller cross-section, where the introduction of a float is not feasible, constant orifices fed from a fixed head provide a simple means of control.

4. INSPECTION AND TESTING

(a) *Physical Inspection*

An adequate method of identification must be operated, if location of faults is to be made easy. Although an onerous task, it is well worth while to preserve the identity of the material in batches related to the basic production-process unit, throughout all the various operations.

The general dimensions of the cast product are determined by those of the moulds and dies employed, and the successful attainment of correct dimensions depends on adequate allowance being made for shrinkage and contraction effects. If scalping and turning are required, the size of the finished product should be checked, to ensure that the full amount of material to comply with metallurgical requirements has been cut away.

(b) *Visual Inspection*

Most of the defects to which rolling slabs and extrusion billets are prone can be detected by systematic visual inspection. This operates at several levels, the operative and foundry supervisors carrying out a general check on their own work, and a final inspection being made by a special staff. Typical defects are cold shuts, hot tears, surface-oxide inclusions, longitudinal, transverse, and central cracks. If machining is carried out, these defects will be revealed more clearly, although in some cases the machining operations eliminate the more superficial examples.

(c) *Non-Destructive Testing*

Whatever method may be employed, visual inspection cannot concern itself with more than the immediate surface layer of the material. Inspection is not complete unless some assurance of central soundness is also obtained. An important aid in

this respect is the ultrasonic flaw detector, which enables a check to be made for relative freedom from shrinkage, central cracks, or random inclusions. Depending upon the use for which the material is intended, this inspection may be applied at various rates up to 100%. It is particularly suited to the examination of extrusion billets, as defects arising from this processing method are not self-revealing in the early stages as are those occurring in the rolling of slabs.

(d) *Destructive Testing*

Whatever the method of casting, the bases and tops of billets and slabs are non-uniform with the bulk of the material. When any critical application is involved, therefore, it is common practice for an appreciable discard to be made from each end, at the most convenient stage in processing. The consistency of the macrostructure of the most critical alloys, cast as extrusion billets, is checked by inspection of a slice cut for this purpose from each cast length, and prepared for examination by fine machining and etching. This type of inspection is not so extensively used for rolling slabs, because scalping serves as a general inspection, and few major defects pass through the hot mill unnoticed.

VI.—ORGANIZATION OF CONTROL

In reviewing the factors significant in the melting and casting of aluminium alloys for working, the conclusion must be reached that quality can be maintained only by the simultaneous operation of a multiplicity of indirect controls. Departures from standard practice can accordingly take place without the cause being obvious. To ensure that information concerning cases of failure is made widely known and that adequate remedial action is promptly taken, presents a considerable problem in organization. In the authors' works, in addition to the direct supervision exercised by the production staff, an inspection staff operates during the whole of the twenty-four hours. Members of this staff report major defects as soon as found and summarize their findings at the end of each working shift. Each morning the findings on the material inspected during the preceding twenty-four hours are summarized and placed before the Foundry Superintendent. Similarly, summaries are prepared covering each week's work on one furnace for any one product, and in this case a sub-analysis against shifts is shown. This analysis is kept as far as possible up to date, and is available for scrutiny by the production staff.

In order to arrange suitable and co-ordinated action, a weekly meeting is held, attended by representatives of the production, inspection, and metallurgical staffs. At these meetings the inspection department table their findings, summarized for the week, and the metallurgical department present any complaints regarding material which have arisen in the main or sub-plants. The Standard Practice

Sheets already mentioned, are based on this information, and the committee decides when a Standard Practice has been established. The yield values obtained in producing any particular run of material provide a means of assessing both its quality and the efficiency of the controls applied, thus providing target values for action.

The general success of the control measures outlined in the present paper is considered to be proved by the fact that, although the works handles a wide diversity of materials, 90% or more of the gross production weight cast is forwarded to the rolling and extrusion mills.

Confirmation of the success of the foundry techniques has, however, to await the processing of the material to its final stage in the fabricating plants, where the more subtle variations in quality of the material tend to be revealed.

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THE CONTROL OF QUALITY IN MELTING AND CASTING MAGNESIUM ALLOYS FOR HOT WORKING *

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SYNOPSIS

A description is given of present practices in the control of quality and inspection in the melting and casting of the three principal types of magnesium alloy used for wrought purposes, viz. magnesium-manganese, magnesium-aluminium-zinc-manganese, and magnesium-zirconium-zinc. The zirconium-containing alloys are considered separately, not only because special procedures are involved in their melting, but also because they are always cast by the semi-continuous direct-chill process.

Except on a laboratory scale, rolling, extrusion, and forging are not carried out in the authors' works, and thus the use of commercial-scale hot working as a running routine "inspection" method is not possible. The inspection processes applied before the cast stock is sent out to other works are therefore crucial.

I.—INTRODUCTION

BEFORE the commercial introduction of the new high-strength magnesium-zirconium-zinc alloys some years ago, the wrought alloys produced in Great Britain were restricted to the "classical" magnesium-manganese and magnesium-aluminium-zinc-manganese types. These alloys were—and in general still are—melted and alloyed in holding crucibles of 2 tons capacity, before being decanted into 300-lb. crucibles and chill cast into extrusion billets and rolling slabs in "book" moulds. When operated by reasonably skilled labour, this procedure gives cast stock of a quality acceptable for most purposes and, since operating costs are not unreasonable and because production volume has not justified the capital outlay for more modern plant, the installation still remains in use for the bulk of the output in the older alloys.

When the zirconium-containing alloys were being commercially introduced, the semi-continuous direct-chill (D.C.) casting process was being developed, and, after this had been thoroughly proved on all types of alloy, the D.C. casting machine was devoted to the production of the new materials and of certain especially critical items, e.g. forging stock, in the older alloys.

Although a small rolling mill and extrusion press are available for research and test purposes, no rolling, extrusion, or forging on a commercial scale is carried out at the authors' works, and therefore any defects in the cast stock are not disclosed on a day-to-day, or even week-to-week, basis in full-size hot-working operations. In these circumstances control of quality and the application of rigorous inspection processes

before the stock is sent out to other companies are matters of prime importance. In practice the steps described in the present paper have proved over a long period of years to be successful in maintaining rejections at the very satisfactorily low level of considerably less than 1%.

II.—THE CLASSICAL ALLOYS: Mg-Mn (AM503) AND Mg-AL-ZN-MN (AZM AND AZ855)

1. MELTING AND CASTING PROCEDURE

These alloys, the nominal and specified compositions of which are given in Table I, are produced in cast-steel melting and holding crucibles of 2 tons capacity, heated in pit-type producer-gas-fired furnaces. The charge normally consists of large "cheeses" of virgin magnesium (crudely cast directly from the output of the electrolytic cells), together with process scrap, but in certain cases small additions of secondary ingot are also made. Alloying constituents, aluminium, zinc, and/or manganese (the latter introduced in the form of manganous chloride), are added by an alloying bucket and the melt is plunged thoroughly. Throughout the melting and alloying operations a fluid ("Z") flux rich in magnesium chloride is used to protect the metal from oxidation, and at subsequent stages of the operations an inspissated flux ("E"), producing a stiff protective cover, is also applied.

When alloying has been completed, the crucible is transferred to a tilting furnace which will maintain a metal temperature of about 750° C. The crucible is then used as a reservoir of molten metal for filling a series of fabricated mild-steel crucibles of 300 lb. capacity. These crucibles, after filling, are taken to

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producer-gas-fired furnaces, and the melts are there refined by stirring-in the inspissated "E" flux whilst the temperature is brought up to about 800° C. The melts are then ready to be taken to the billet- or slab-pouring points, each crucible being transported by crane to the gas-heated holder of the pouring machine.

The moulds are installed in wheeled carriages, and can therefore be brought up on rails in succession to a

essentially upon accurate weighing. Thus, control of this factor is vested almost wholly in the reliability of the operator.

A sample in the form of a "Churchill block" (Fig. 1, Plate LVIII) is taken from each 2-ton melt by a ladle, precautions being taken against contamination (see Appendix, p. 400), and this is analysed¹ for the elements covered in the particular specification, some

TABLE I.—Designations and Compositions of Magnesium-Base Wrought Alloys.

Elektron Alloy Designation	Wrought Form	D.T.D. Specification No.	Nominal Composition and Normal Manufacturing Limits				D.T.D. Specification Requirements										
			Al, %	Zn, %	Mn, %	Zr, %	Al, %	Zn, %	Mn, %	Zr, %	Cu, % max.	Si, % max.	Fe, % max.	Ni, % max.	Ca, % max.		
AM503	Sheet Extrusions Tubes	118A 142A 737	}	...	1.5 (1.0-2.0)	}	...	0.05 max.	0.03 max.	1.0-2.0	}	...	0.02	0.02	0.03	0.005	0.02
AZM	Extrusions " Tubes Forgings	259A 749 348A 88C																6.0 (5.5-6.5)	1.0 (0.7-1.2)	0.3 (0.2-0.4)	7.5-5- 8.5 15.5- 16.5	1.5 max. 0.5-1.5	0.2- 0.4	0.03	0.05	0.03	0.005	...
AZ855	Press forgings	88C	3.0 (2.5-3.5)	0.4 (0.3-0.5)	0.3 (0.2-0.4)	...	7.5-8.5	1.0 max.	0.2-0.4	...	0.03	0.05	0.03	0.005	...		
AZ31 ° (High Purity)	All wrought forms	Specifications under consideration	3.0 (2.5-3.5)	1.0 (0.7-1.2)	0.3 (0.2-0.4)	...	2.5-3.5	0.6-1.4	0.2 min.	...	0.05 Total of Other Elements	0.3	0.005	0.005	0.3 max.		
ZW3 †	Sheet Extrusions Press forgings Impact forgings	626 622 619 729	}	...	3.0 (2.7-3.3)	}	...	0.02 max.	2.5-4.0	0.15 max.	0.5-1.0	}	0.03	0.01	0.01	0.005	...
ZW1 °	Fully argon-arc-weldable sheet, extrusions, and tubes	Specifications under consideration															

° The specification requirements quoted are those under consideration.

† The D.T.D. specification details and requirements quoted are those under consideration for revised issues.

position in which the runner of each mould is aligned with the lip of the crucible.

The crucible holder is fitted with lip-axis tilting gear, and pouring is controlled by hand winding. At the start the mould is tilted at an angle of approximately 15° to the horizontal, the axis of tilt being through the mouth of the runner, and is allowed to come back to the vertical position as it is filled with metal. When the mould is full, a red-hot cast-steel "top-hat", heated in a muffle furnace, is placed on the top. The crucible is then lifted a few inches in a vertical direction and the casting is fed through the open top of the heated ring.

Finally, when the billet or slab has solidified and cooled for a short time, the mould is opened and the casting removed, melt and cast identification numbers being marked on it with crayon.

2. CONTROL OF COMPOSITION

Control of composition presents few difficulties. For each melt a Melt Control Card is issued which specifies the charge in terms of the weights of the various constituents and serves as the record of all other essential details. Given raw magnesium of constant impurity content from the electrolytic cells, reliable segregation of process scrap, and the known analysis of any secondary ingot used, the ensurance of correct composition of the melt depends

of which are determined spectrographically and others by wet methods. Internal and A.I.D. inspection procedures are normal and need not be detailed.

3. CONTROL OF VOIDS

Although it cannot be claimed that book moulds are capable of producing castings of the same density as those made by the D.C. process, they do give billets and slabs of acceptable quality when proper attention is paid to the control of the pouring operation. The moulds (see Fig. 2, Plate LVIII) are designed to have a varying section giving a heavier chill at the base and, with a side runner and slot gate, they give a good degree of directional solidification.

The moulds are heated by gas torches before being brought into operation, and, in most cases, the first one or two billets or slabs cast in each are scrapped. However, the moulds quickly develop a favourable temperature gradient from top to bottom, the magnitude of which varies with the diameter, but which is always at least 50° C. and may in some cases reach 150° C. A typical range is 200-300° C. For the AM503 alloy, which has a great tendency to piping, both the moulds and the "top-hats" are fitted with gas-rising heaters for use during the actual casting operation. In all cases special attention must be paid to adequate feeding of the solidifying metal, and it is usually necessary to feed more than once.

Careful observance of correct pouring temperatures and speeds is all-important for the production of sound stock. Details of these are given in Table II.

TABLE II.—Pouring Temperatures and Times for Billets and Slabs Cast in Book Moulds.

Billet Size, mm.	Pouring Temperature, °C.		Pouring Time, min.
	AM503	AZM and AZ855	
73	790	760	1
106	770	750	1½
112	770	750	1½
133	760	740	2
175	750	730	2½
246	750	730	3½
295	750	730	5
Slab 16 × 24 × 3 in.	780	...	3

Throughout all alloying, refining, and casting operations mild-steel-sheathed pyrometers are used in the molten metal and are coupled to a system of 6-point potentiometric recorders. In D.C. casting a pyrometer may also be used in the metal reservoir. The thermocouples are of Chromel/Alumel, insulated by means of porcelain beads.

The AM503 alloy is distinctly prone to the formation of internal shrinkage, or "bridging", cavities (Fig. 4, Plate LIX), which are totally enclosed by metal and do not outcrop to the surface. Every care is taken to minimize the frequency of their occurrence, but in practice it seems that they weld up satisfactorily in the extrusion or rolling operation. This alloy never contains micro-porosity.

The AZM and AZ855 alloys are susceptible to both macro- and micro-porosity (Fig. 5, Plate LIX), and control of casting conditions is very important in minimizing these defects. Rolling slabs are not made in these alloys because they are not normally used in sheet form. Inspection for internal cavities in billets by means of routine "cut-up" tests is automatically supplemented by periodic reports from the various mills where the billets are normally cut into lengths before extrusion.

4. CONTROL OF NON-METALLIC INCLUSIONS

Cleanliness of the castings depends upon proper treatment of the melt and good pouring practice. The standard fluxing procedures, which have been fully described as to both practice and function by Emley,^{2,3} can always be relied upon to ensure that clean metal is available for casting, and then only tranquil pouring in a sulphur atmosphere is required.

In melting and alloying, protective "Z" flux (dyed pink) is used to prevent burning of the charge, and a small quantity is sprinkled on the bottom and around the inside of the crucible before the solid metal is added. The operators then add the flux as required, so that when the metal is fully molten there is a fluid protective cover over the whole surface.

It will be recalled that 2-ton crucibles are used as

reservoirs for the filling of 300-lb. crucibles in which the refining is carried out and from which the metal is poured. Before each 2-ton crucible is taken from the melting furnace to the tilter, the melt is given a good cover of inspissated "E" flux (grey) to form a stiff crust from beneath which the metal can be poured into the smaller refining crucibles. This cover is repaired after each tilt.

When refining the alloy, "E" flux is sprinkled on to the surface of the melt and allowed to fuse. At a temperature of about 760° C. this flux is then stirred through the metal until the surface appears bright and silvery. This constitutes the refining operation, after which the melt is given a stiff cover of "E" flux before heating up to 800° C. as a preliminary to taking the crucible to the casting machine. At the casting machine the flux cover is repaired and the crucible tilted in its lip-axis container to the pouring position, the cover again being repaired if necessary.

Now that clean metal is available at the mould, the vital factor in avoiding oxide inclusions is the prevention of contact between the molten metal and the atmosphere during the pouring operation by ensuring that there is continuous chemical or physical protection of the metal, and by minimizing turbulence. The flux cover is very carefully drawn back from the crucible lip, which is itself scraped clean, and at the same time a sprinkling of sulphur is applied so that the small area of exposed metal is protected from oxidation. The interior of the mould is dusted with sulphur (from a muslin bag) before pouring begins, and it is important that throughout the casting operation the exposed metal surface in the crucible and the pouring stream are both dusted with sulphur continuously.

In pouring, the crucible and mould lifting and tilting gear must be operated very smoothly, so that the initial protective oxide skin formed as a "tube" around the metal stream remains unbroken from start to finish. With the mould tilted at 15° to the horizontal, pouring is started by tilting the crucible until the rate of pour in the early stages is such that the metal stream flows gently down the runner of the mould in a straight line and strikes the bottom with the minimum turbulence. The runner is separated from the main cavity of the mould by a narrow (¼–½ in.) slot which prevents oxide skins formed during pouring from entering the billet. Pouring is continued at this rate until the metal reaches within ½ in. of the top of the mould, when lowering of the mould is begun. The latter operation must be carried out as gently as possible to prevent breakage of the protective oxide skin.

When the mould is full, a red-hot "top-hat" is placed in position, the crucible raised vertically, the metal surface skimmed, and the feeding operation carried out with due care. Finally, the surface is dusted with sulphur and a plate placed over the "top-hat" to exclude air during the final stage of solidification.

Flux inclusions in the billets or slabs occur very

rarely, but if careless operation does result in this trouble it is readily evident in the machining operation and the stock is scrapped (see Fig. 6, Plate LIX).

5. CONTROL OF GRAIN-SIZE

(a) *Magnesium-Manganese Alloy (AM503)*

Alloy AM503 is notorious for possessing an extremely pronounced tendency to develop a very coarse and columnar grain structure which, in rolling, can give rise to severe surface and edge cracking at worst, and, at best, a noticeable, but not serious "orange peel" effect on the blank in the breaking-down operation. (In the U.S.A. it is normal practice to add 0.1-0.2% calcium to the alloy to produce a reasonably fine equi-axed structure in the slab, but in Great Britain calcium is strictly controlled as a trace impurity in the interests of good gas-weldability.) The grain-size of AM503 is indeed one of the most difficult quality factors to control, and it must be said that to obtain a reasonably uniform and not excessively coarse-grain structure is more of an art than a science; however, adherence to the pouring temperatures and speeds (Table II, p. 395) established from experience gives acceptable slabs and billets (see Fig. 4, Plate LIX). It is of interest to note that the "diagonal" mode of growth of columnar crystals in D.C. cast AM503 slabs was found in early tests to be associated with poor rolling properties.

(b) *Magnesium-Aluminium-Zinc-Manganese Alloys (AZM and AZ855)*

As has been remarked previously, only extrusion billets are book-mould-cast in these alloys, and no special care is needed to control the grain-size, because this is not critical, and it is in any case reasonably fine (Fig. 7, Plate LX).

6. CONTROL OF GAS CONTENT, CRACKING, AND SEGREGATION

Magnesium melts do not readily absorb hydrogen from the melting atmosphere, but strict precautions are necessary in the avoidance of contact with moisture, as, for example, in corroded scrap or wet flux. It is also essential that clean, dry crucibles are used and that mould dressings* are dried very thoroughly.

Only AM503 alloy is sensitive to contraction cracking. The avoidance of this defect rests solely on a suitable design of the mould to eliminate "holding". On rare occasions when such cracks have appeared—always when new moulds have been put into use—they have proved extremely troublesome to detect before the rolling or extrusion operation. The cracks are very fine, and it is difficult, even after machining and macro-etching, to differentiate between them and the grain boundaries and other purely structural markings.

In both Mg-Mn and Mg-Al-Zn-Mn alloys there is no serious tendency to either normal or inverse segregation when cast in book moulds.

7. CONTROL OF SURFACE QUALITY

All magnesium alloy extrusion billets are supplied to the mills fully machined, and the AM503 alloy rolling slabs are scalped on the two major surfaces. Control of surface quality therefore lies in the hands of the machining operator, who normally works to depths of skim of $\frac{1}{8}$ – $\frac{3}{16}$ in., only increasing these in cases where surface defects such as "cold shuts" are encountered.

III.—MAGNESIUM-ZIRCONIUM-ZINC ALLOYS (ZW3 AND ZW1)

1. DEVELOPMENT OF THE ALLOYS

The compositions of these alloys are given in Table I (p. 394). In the early stages of development of the wrought magnesium-zirconium-zinc alloys, rolling slabs and extrusion billets were cast in the normal chill moulds which have been described, and with certain exceptions the results were reasonably satisfactory. However, there were some serious troubles, for example the incidence of outcropping micro-porosity resulting in internal oxidation and nitride formation at the high pre-heating temperatures (450°–520° C.) used for rolling slabs. This was especially deleterious to the rolling properties, and could naturally be expected to result in unreliable sheet. Another major trouble which arose was segregation of zirconium-rich particles during the solidification of the largest sizes of billet. In 1944 Magnesium Elektron, Ltd., designed and constructed a small plant for D.C. casting, and there followed a period of intensive development to work out suitable conditions for the casting of slabs and billets in all types of alloy. The magnesium-manganese alloy AM503 and the magnesium-aluminium-zinc-manganese alloys AZM and AZ855, particularly the former, were quickly found to present few problems, and once the right casting conditions had been firmly established it was decided to concentrate the use of the machine on the zirconium-containing alloys both for development and production.

With the commercial launching of ZW3 alloy, the outstanding feature of which is its remarkable hot workability combined with high strength,⁴ the Company was naturally anxious to send out to the rolling and extrusion mills, and to the forging shops, cast stock representing the very highest quality possible. The policy of especially rigorous control and inspection has been justified by results and, although the production tonnages of the alloy have so far been substantially lower than for the old-established alloys, rejections over the period have been very much lower than 1%.

* The mould dressing consists of 80% French chalk and 20% boric acid, well mixed in water to give a paste sufficiently thin for use in a spray gun.

2. CASTING BY THE D.C. MACHINE

The D.C. machine (Fig. 3, Plate LVIII) consists essentially of three units for pouring, controlling, and casting the metal, respectively. There is a heated, lip-axis, tilting container for a 300-lb. crucible, the inside being fitted with a refractory lining incorporating a gas burner of sufficient capacity to maintain the metal at any desired temperature up to 780° C.

The metal is poured from the crucible into the mould either via a reservoir, for rolling slabs and the larger size of billet, or down a simple launder for the smaller billets. The reservoir is held in a gas-heated refractory-lined container, the heat applied being sufficient to maintain a metal temperature of up to 720° C. The metal enters the reservoir down a very short launder and leaves at the other end through a valve which controls the flow of metal into the mould.

From the reservoir outlet, the metal flows through a funnel into a "tundish", or distribution vessel, of similar shape to, but of smaller cross-section than, the billet or slab being cast, this tundish being supported centrally at the top of the mould. The metal leaves this vessel through a number of narrow slots in its sides. The level of the metal in the mould is maintained at such a height as just to cover the tops of the slots, and the funnel mouth is always kept submerged. The purpose of this tundish is to act as a combined metal distributor and oxide trap.

For smaller-diameter billets (6 in. and less), the reservoir is replaced by a simple straight launder with a pouring funnel attached. The launder is heated by gas burners in order to prevent freezing of the flowing metal. No tundish has been found necessary for these smaller billets, the metal entering the mould through the mouth of the funnel itself, the tip of which is kept immersed.

Multiple casting of the smaller billets has been developed, but is not normally used in production.

The moulds are of the "collar" type, cooled by external spray rings, one or two in number, according to the depth of the mould. An additional lower spray is used for cooling the emerging billet.

The ram of the D.C. casting machine is hydraulically operated, and is of the double-acting type giving a positive downward pull during casting. The flow of oil also drives an electric tachometer indicating the speed in in./min. Frequent checks are made on the calibration of this instrument by actual timing of the casting operation.

The ram is fitted with a tray surrounding the head to collect water which will act as a douche in the event of a "run-out" of molten metal. Although there should be no danger from such a "run-out", provided that sufficient water is present, it is deemed an essential safety precaution for the operating platform to be sealed off from the cooling chamber in which the emerging billet comes into contact with water.

Melting on a 2-ton scale is not carried out in the D.C. foundry, and the 300-lb. charges generally

consist of refined magnesium ingot (rather than crude cell metal), process scrap, and zinc, with the addition of a zirconium "master salt". The scrap and ingot are melted using a special "HE" flux (dyed blue) to prevent burning. When all the metal has been charged, the requisite quantity of master salt is added and the whole mass melted and brought up to a temperature of 700°–750° C. After the zinc addition has been made, the temperature is raised to and held at 800° C. The melt is then puddled with a preheated plunger in such a way that the master salt at the bottom of the crucible is brought into thorough contact with the metal. During this operation, "HE" flux is used to prevent burning.

A sample of the melt is then taken in a clean, red-hot ladle and poured into a small die-mould. This sample bar is fractured and the zirconium content is assessed from the grain-size. If this is satisfactory, a Churchill block sample (Fig. 1, Plate LVIII), is taken, again with a clean, red-hot ladle. If, however, the zirconium content is judged to be low, the melt is puddled again and the sampling procedure repeated.

The sides of the crucible above the metal level are then scraped clean and the flux cover is renewed. It is generally unnecessary to refine the melt after the puddling operation, but this may be done if any burning has been seen.

The crucible is taken by crane from the producer-gas-fired furnace and placed in the preheated tilting container of the D.C. machine, where it is allowed to settle for 10–20 min., during which period it is brought to the correct pouring temperature of 750°–780° C., depending upon the type and size of the product (see Table III).

TABLE III.—Essential D.C. Casting Conditions for ZW3 and ZW1 Alloys.

Billet Size, mm.	Ram Speed, in./min.	Water Flow, gal./min.			Crucible Temp., °C.
		Top	Middle	Bottom	
73	6.3	20	...	...	780
92	6.2	30	...	5	775
106	4.5	20	...	20	770
133	4.2	40	...	20	770
175	4.0	40	...	20	770
220	3.8	40	...	40	760
246	3.5	40	30	15	760
295	2 → 3.5 → 2	40	30	15	760
Slab 14½ × 4½ in. section	3.5	40	20	10	750

Immediately before pouring, the flux round the wall of the crucible near the pouring lip is cut away with a clean spoon and the surface of the metal dusted with sulphur. The sulphur bag is used continuously from now until the casting is complete. Pouring is begun, either into the reservoir or, for the smaller billets, into the long launder. Protection of the molten metal throughout the pouring system is effected by means of powdered sulphur or jets of sulphur dioxide.

3. CONTROL OF COMPOSITION

The nominal and specified compositions of ZW3 and ZW1 alloys are given in Table I (p. 394). Control of the zinc content presents little difficulty, since process scrap is carefully segregated and any zinc additions required are weighed out accurately. Greater care is, however, required in controlling the effective "soluble" zirconium content^{5,6} at the required level of 0.5-0.9%. The critical test for this is the examination of the fractured die-bar sample, and an experienced observer can readily estimate the success of the alloying operation by visual observation of the fracture grain-size in the centre of the bar. (Reference standards are, of course, available in cases of doubt.) If the fracture is not satisfactory, the puddling operation is repeated, or in very rare cases a further addition of master salt may be required. When the zirconium content is judged satisfactory—and in practice one puddling usually suffices—a Churchill block sample is taken and analysed for zirconium, zinc, and the specified impurities (Table I).

4. CONTROL OF FLUX INCLUSIONS

It is now well known that many years of research were required to develop a process for the introduction of zirconium via a reducible salt, while avoiding the presence in the alloy of corrosive flux inclusions.⁵⁻⁷ The master salt, which has been in commercial use since 1946, is in fact foolproof from this point of view when used with a proper technique in conjunction with the special "HE" flux. This flux is "weighted" with barium chloride and is a dual-purpose flux combining the functions of protecting against burning in melting and alloying and providing an efficient cover for the melt. In practice, it has been found that there is no danger of flux inclusions being present in the main bulk of the billet or slab, and it is only necessary to be vigilant against this defect at the end of the pouring operation when, with a careless operator, there is a possibility of some of the residual fluid alloying mixture at the bottom of the crucible passing into the mould with the last metal poured.

When the billet or slab has been removed from the machine and has cooled, it is taken to the machine shop and short "discards" are cut off at the base and top. As a matter of routine, the top discard (which varies in length according to the diameter of the stock) is subjected to exposure in a "humidity chamber" as a routine inspection for flux inclusions. A 1-in. section is cut from the lower surface of this discard, i.e. that surface which coincides with the top surface of the billet proper, and, after milling, it is exposed for 48 hr. in an atmosphere of 80% relative humidity,* care being taken to protect the newly machined surface from finger marking, dust, or other contamination in transit to the test chamber. After this period, any flux inclusions, even those of a

very minor character, will be clearly visible. If the test section is of a satisfactory standard, it can be confidently assumed that the whole of the billet or slab is free from flux inclusions, or, for the smaller sizes, in which a number of billets are successively cast from the one melt, that all are clean. If, however, there are significant signs of flux in the section from the discard, further test samples are cut and exposed until the defect has been eliminated.

5. CONTROL OF OXIDE AND NITRIDE INCLUSIONS

Assuming that the fluxing has been properly carried out in the melting and alloying operations, and that clean metal is brought to the reservoir of the casting machine, freedom of the cast stock from oxide and nitride inclusions naturally depends on minimizing turbulence in the pouring system and on the effectiveness of the protection provided by the sulphur and sulphur dioxide atmospheres. It is also vital that all components of the system should be free from moisture.

Both top and basal discards of each casting are acid pickled and examined for oxide inclusions (Fig. 8, Plate LX). It is the unavoidable turbulence which takes place at the beginning of each pour that makes it necessary for a basal discard to be taken. However, this discard is small because at the beginning of the pour the mould "stool" at the head of the ram is brought to within 2 in. of the top of the mould.

It should be mentioned that routine examination (for cracking) of the billets and slabs by the ultrasonic flaw detector also gives a reliable indication of freedom from oxide inclusions.

6. CONTROL OF VOIDS AND CRACKS

The D.C. casting process normally provides an almost completely automatic insurance against the occurrence of voids. Throughout the authors' experience the worst defect of this nature has been the presence of extremely light, distributed, and quite insignificant micro-porosity. The castings are not, therefore, inspected for voids.

D.C. casting does not, however, provide an insurance against cracking. Although there is now a substantial body of theoretical knowledge of the D.C. process, it is not possible to lay down, in advance of *ad hoc* trials, precise casting conditions for the avoidance of cracking. In practice reliance is placed upon the strict observance of casting temperatures, speeds, water-flow figures, water-distribution characteristics, &c., established in trials. The basic conditions for the zirconium-containing alloys are given in Table III (p. 397).

Inspection for cracking is straightforward. Any outcropping cracks are easily discernible during machining and/or pickling, and the supersonic flaw detector is used as a matter of routine for the internal cracks.

* The atmosphere in a closed chamber containing a saturated solution of sodium thiosulphate.

7. CONTROL OF SURFACE CONDITION

All D.C. cast billets and slabs are machined on all surfaces, with normal depths of skin of $\frac{1}{4}$ – $\frac{3}{8}$ in., to remove all traces of inverse segregation and surface folds. After machining, rolling slabs (for which surface condition is critical) are acid pickled and examined by an experienced inspector to ensure that no traces of surface defects remain. In certain cases where residual portions of any particularly deep folds are evident, these may be removed by local dressing.

Whereas the magnesium–manganese (AM503) and magnesium–aluminium–zinc–manganese (AZM, AZ855, &c.) alloys—especially the former, which has a very narrow freezing range—invariably give little surface trouble in D.C. casting, ZW3 and ZW1 alloys are prone to the occurrence of surface folds. In practice these defects are kept to the minimum by strict observance of standard casting conditions; maintenance of a uniform metal level in the mould is especially important. A mould vibrator has been tried experimentally, but was found to result in an interesting, but highly deleterious, side effect of “banded” zirconium precipitation and associated β -phase formation (see Fig. 9, Plate LX).

8. CONTROL OF METALLOGRAPHIC STRUCTURE

Reference has already been made to the die-bar fracture test applied after the alloying operation to check that the melt contains a fully effective zirconium content giving a correspondingly fine grain-size. Final reliance is not, however, placed on this, and every billet and slab is metallographically examined on samples taken from the top discard (last metal poured) as a check on the effective zirconium content, as evidenced not only by the grain-size, but more particularly in this case, by freedom from undue quantities of β phase. (It is to be noted that one of the primary effects of the zirconium addition to a magnesium–zinc binary alloy lies in its power to inhibit the formation of magnesium–zinc compound which—the binary eutectic temperature being 341° C.—would ruin hot workability at the much higher temperatures used. With a “full” zirconium content, the solidus temperature of ZW3 is about 590° C.)

These factors are naturally of fundamental importance in rolling, which is normally carried out at 480°–500° C. In extrusion, at lower temperatures, it is equally essential to have a fully effective zirconium content to achieve maximum mechanical properties.

Fig. 10 (a), (b), and (c) (Plate LXI) shows the standards of metallographic structure which have been established from experience. It can be seen that the “good” structure, with an average grain-size of 0.055 mm., shows straight boundaries enclosing grains with pronounced zirconium coring. The “weak” structure has a grain-size of 0.10 mm., shows “wandering” grain boundaries with little or no sign of an effective zirconium content in the crystals, and contains significant quantities of β phase. The “satisfactory” structure, with a grain-size of 0.065

mm., represents the border-line case, and is intermediate in characteristics.

It is of interest to note that although normal (as opposed to inverse) segregation effects are rare in D.C. casting, one interesting example has been encountered in ZW3 alloy. This is illustrated in Fig. 11 (Plate LXI), and takes the form of a continuous concentration of β phase which has been found to result from mal-positioning of the tundish.

9. CONTROL OF HOT-ROLLING AND MECHANICAL PROPERTIES

Small sections are taken from the top discard of every slab and, after preheating to the normal temperature of 500° C., they are broken-down under careful observation for cracking tendencies or surface defects such as oxide skins.

It has been noted that the mechanical properties of ZW3 and ZW1 extrusions depend very largely upon the effective zirconium content, and therefore in any doubtful cases short, 3-in.-dia. extrusion billets may be cut from the top or the bottom of the casting and extruded under standard conditions on the laboratory 400-ton extrusion press. Using a standard billet temperature of 300°–320° C. and a speed of 1 ft./min., ZW3 billets are rejected unless tensile properties exceeding 18.5 tons/in.² 0.1% proof stress, and 23.0 tons/in.² ultimate stress are obtained from standard $\frac{3}{4}$ -in.-dia. bar. Slightly lower properties are acceptable in the case of ZW1 alloy.

IV.—OTHER D.C. CAST PRODUCTS

Brief mention must be made of some products in the older alloys which are D.C. cast to obtain maximum soundness and structural homogeneity for critical hot-working operations.

1. AZM ALLOY BILLETS FOR FORGING

Whereas billets in the magnesium–aluminium–zinc–manganese alloy (AZM) cast in book moulds possess very poor forgeability as a result of the existence of some micro-porosity and large pools of β phase, billets cast by the D.C. process may be satisfactorily forged after a homogenization heat-treatment. In addition to being extremely sound, the D.C. billets show excellent β -phase dispersion.⁴

The billets are cast by the same D.C. casting equipment as that employed for the zirconium-containing alloys, the metal being melted in 300-lb. crucibles by a technique similar to that already described for AZM alloy (Section II, 1). One essential difference in casting procedure is that whereas the zirconium-containing alloys are cast at comparatively high temperatures, AZM alloy is poured at the lowest possible temperature consistent with satisfactory flow of metal into the mould (approximately 690° C.). This is necessary to avoid “sticking” of the metal to the mould wall, with consequent tearing of the billet, a tendency to which AZM alloy is somewhat prone. Special care must be taken with this alloy to ensure that no water or steam enters the gap between the

emerging billet and the mould, since this has been found to be a source of oxide inclusions in the stock.

The inspection procedure for AZM alloy forging billets consists in examination for cracks and oxide inclusions by means of the ultrasonic flaw detector, and in fracturing a section cut from the top of the billet. This latter procedure provides a useful method of checking the presence of skins resulting from incursion of water into the mould; if present they show as brown or black markings in the fracture. The sections are also metallographically examined before and after homogenization.

2. ROLLING SLABS IN HIGH-PURITY AZ31 ALLOY

Since this alloy, the composition of which is given in Table I (p. 394), is normally required to a high standard of purity, with a maximum iron content of 0.005%, a special melting procedure is necessary. The metal in the crucible is not allowed to exceed a temperature of 760° C., the melting process is carried out as quickly as possible, and the holding period after alloying and refining is strictly curtailed in order to minimize pick-up of iron from the crucible.

Casting and inspection procedures closely follow those employed for AZM alloy.

V.—CONCLUSION

It will be evident from this paper that, as in many other industries, control of quality of magnesium-alloy cast stock rests very largely upon the employment of experienced and conscientious operatives, and that the retention of key foremen and charge-hands and the maintenance of good labour relations are correspondingly important. All operatives concerned are paid on time rates only.

It has already been emphasized that, since the cast stock is worked elsewhere, control and inspection are especially rigorous and exhaustive, and this applies particularly to the relatively new zirconium-containing alloys. Naturally the procedures are subject to continuous review in the light of experience and in relation to production costs.

The functions of control and inspection are the responsibility of the Metallurgical Research Department, which maintains a special team of melting and casting observers and inspectors who work in close collaboration with foundry personnel. This system, in addition to other merits, is essential for successful production development of new alloys.

ACKNOWLEDGEMENTS

The authors are indebted to the Chairman and Directors of Magnesium Elektron, Ltd., for permission to publish this paper, and to many of their past and present colleagues who have helped to develop the procedures described. Special thanks are due to Mr. L. Lasch and Mr. J. H. T. Petch for assistance in the preparation of the tables and figures.

Acknowledgements are also due to the various companies who have collaborated in the establish-

ment of standards in extrusion, rolling, and forging behaviour of the cast stock.

APPENDIX

NOTES ON SAMPLING THE MELT AND ON THE SPECTROGRAPHIC TEST-PIECE MOULD

(a) *Sampling*

A clean iron ladle, holding about 1 kg. of metal, and kept for the sampling of one particular alloy type alone, is first "washed" in the melt for not less than 30 sec. The ladle is then half filled with metal, care being taken that no part of the flux cap is swept into it, and this is quickly poured into the spectrographic test-piece mould (see Fig. 1, Plate LVIII). The cast test-piece is stamped on the side with the alloy type and melt number. It is then placed in a wooden sample container in the foundry, with other samples to await analysis.

The metal sampler is required to observe the following points:

1. The ladles used for sampling must be kept free from adhering metal scraps of the previous melt.
2. The copper baseplate of the mould should be previously heated, and kept in a thoroughly clean condition.
3. The "washing" of the ladle in the melt must be strictly adhered to.
4. The test block must be free from flux, oxide inclusions, and gas holes.
5. The test block must be correctly marked with the steel punch stamps by the person who cast it.

(b) *Details of the Mould*

The spectrographic test-piece mould (see Fig. 1, Plate LVIII) is a metal frame fitted with asbestos-covered handles and hinged at one side to facilitate removal of the test block after solidification. The lining of the mould consists of two hard amorphous carbon sections, which when placed together form a cylinder about 2 in. in dia. and $3\frac{1}{2}$ in. in height, and have a tapered cavity in the centre into which the molten metal is poured. It should be noted particularly that the carbon sections protrude below the metal framework of the mould, so that good contact is made with the copper plate, and therefore no metal leaks out during casting.

The copper plates used are approximately $12 \times 8 \times \frac{1}{2}$ in. and are fitted with handles for carrying.

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4. R. G. Wilkinson and F. A. Fox, *ibid.*, 1949-50, 76, 473.
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6. C. J. P. Ball, *Chem. and Ind.*, 1948, (34), 531.
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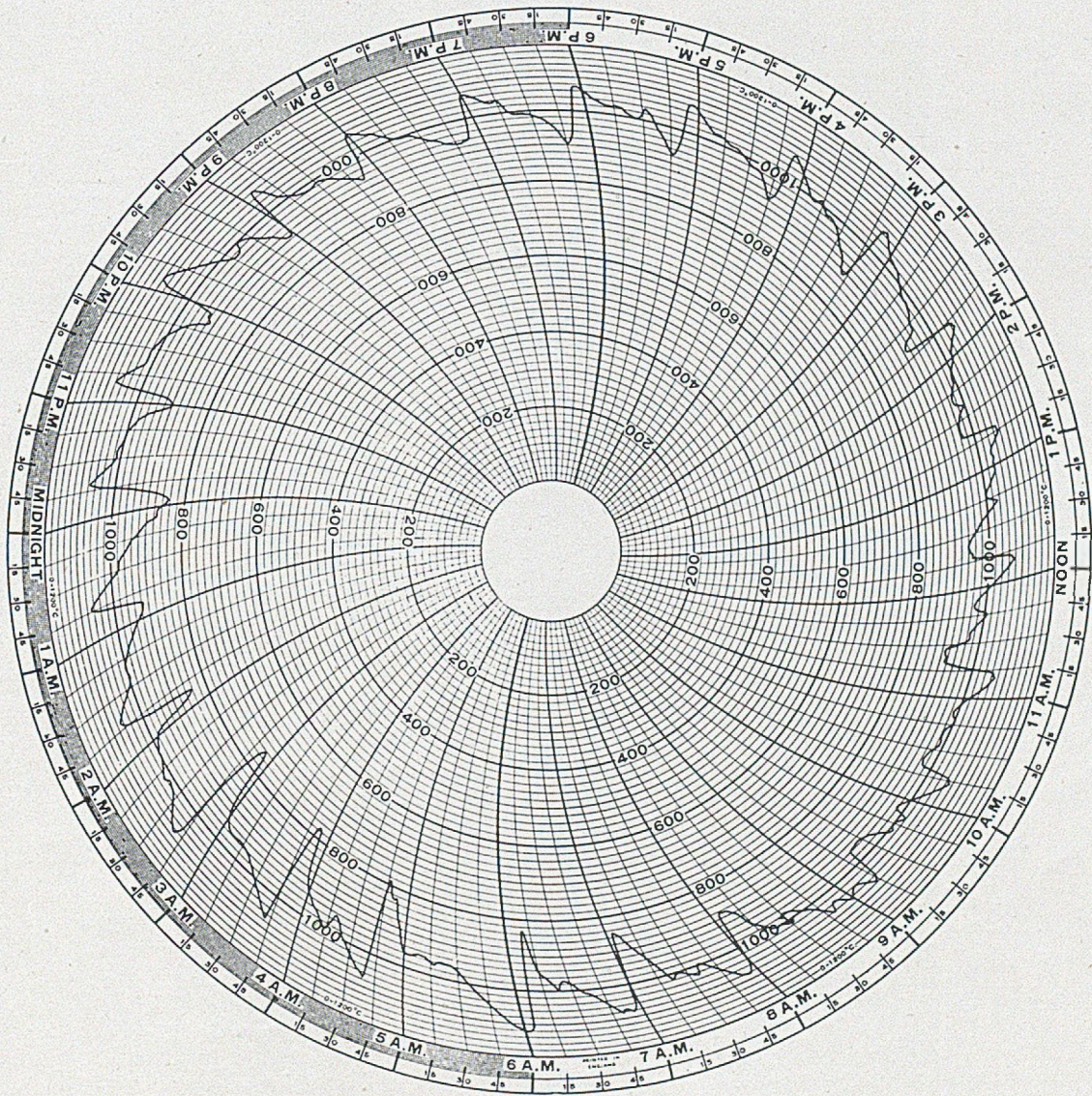


FIG. 2.—Chart Showing Record of Pouring Temperature.

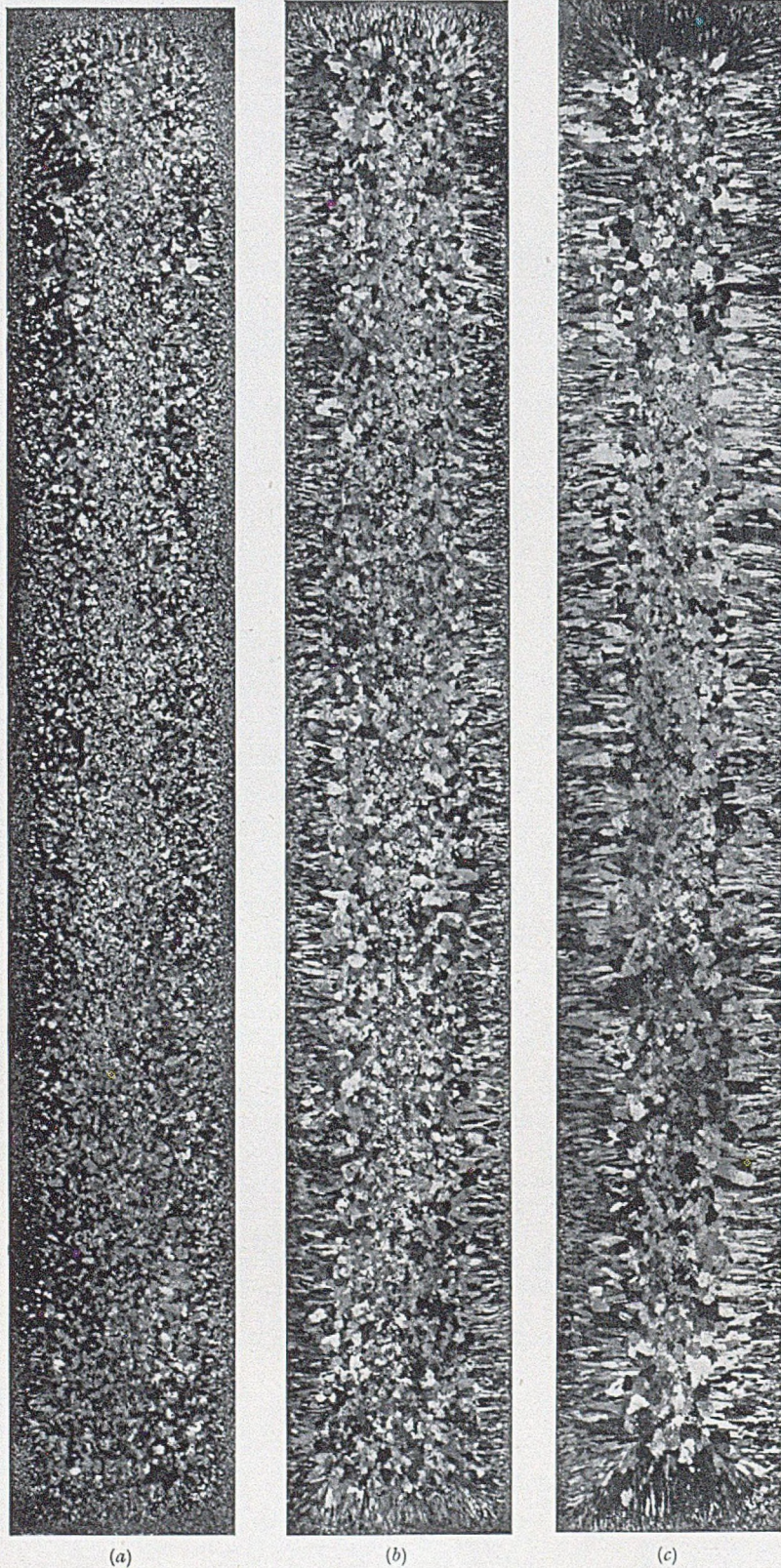


FIG. 3.—Transverse Medial Cross-Sections of 67 : 33 Brass Rolling Slabs Cast in Water-Cooled Moulds. $\times \frac{1}{2}$. Casting temperatures : (a) 980°, (b) 1000°, and (c) 1020° C.

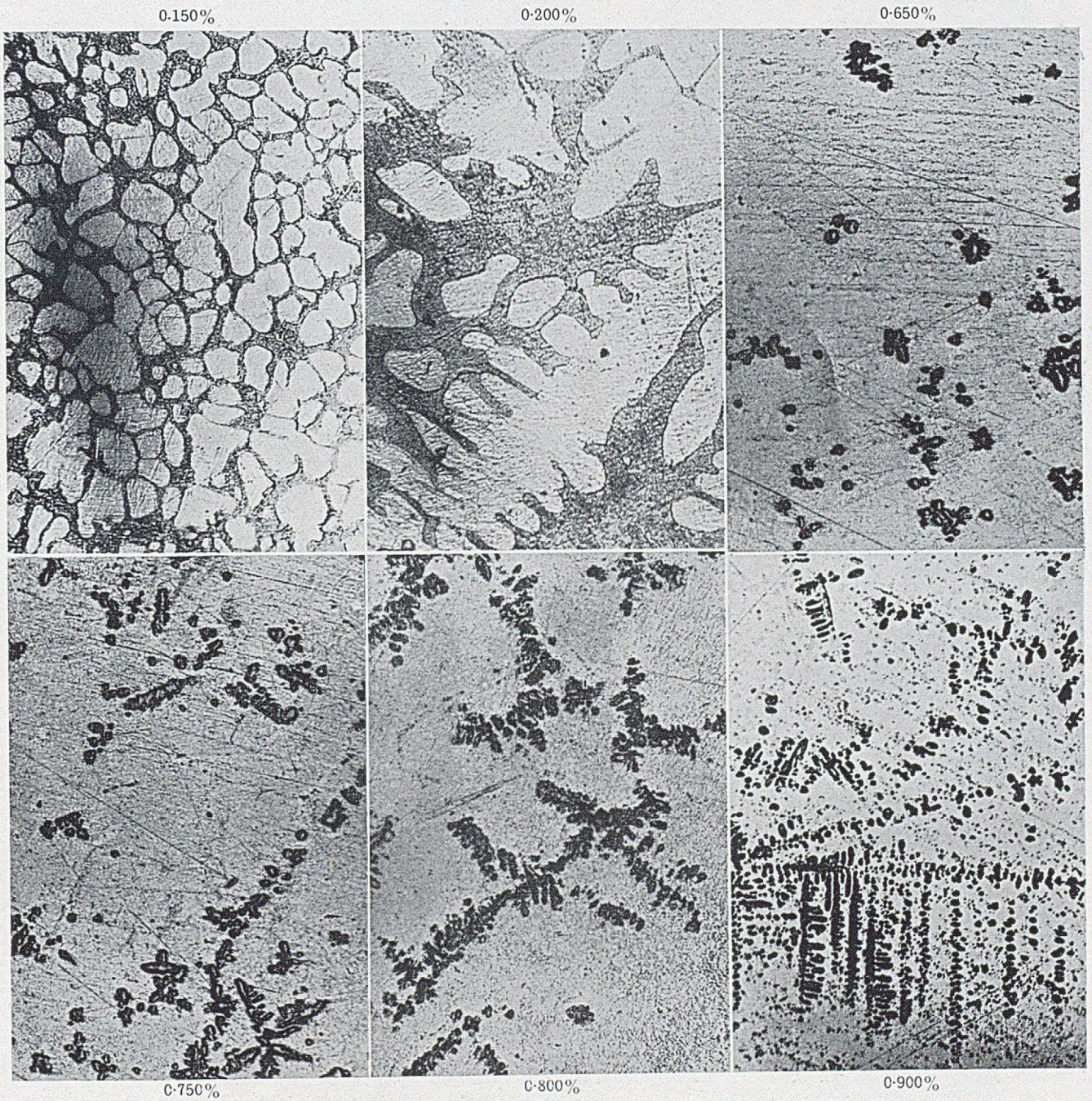


FIG. 4.—Structures of "Low-Set" Copper Buttons Containing Various Percentages of Oxygen. $\times 100$.

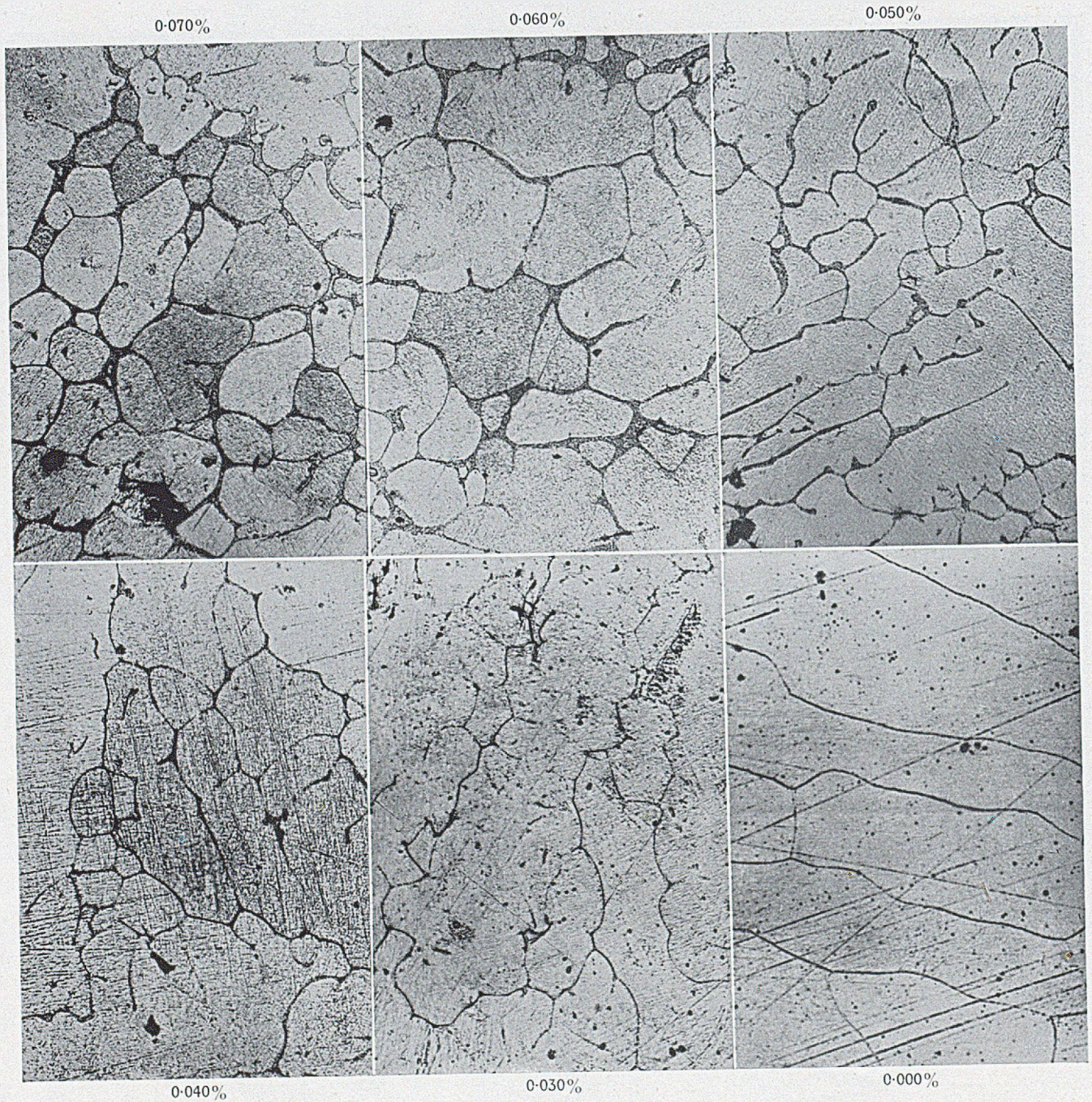


FIG. 5.—Structures of Tube Samples of Copper Containing Various Percentages of Oxygen. $\times 100$.

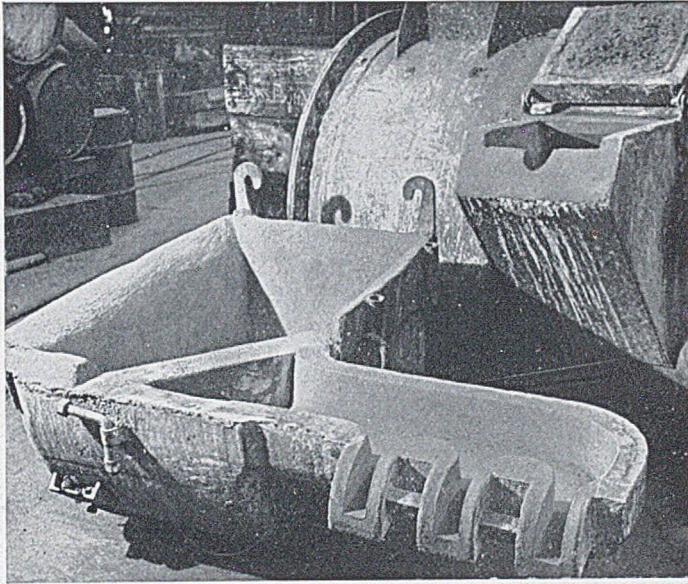


FIG. 6.—A Pouring Ladle Used in the Production of Horizontally Cast Wire-Bars.

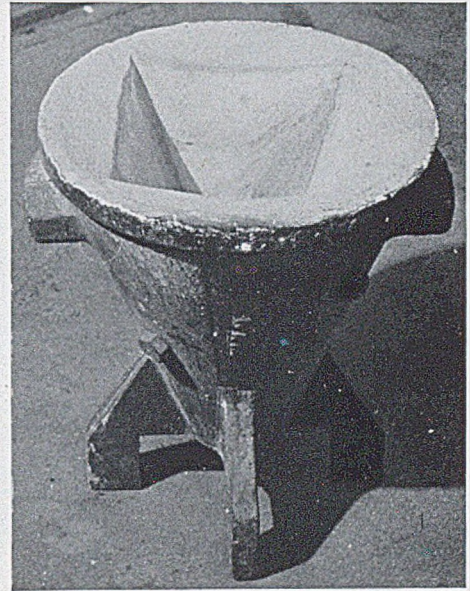


FIG. 7.—A Funnel Used to Pour Vertically Cast Billets.

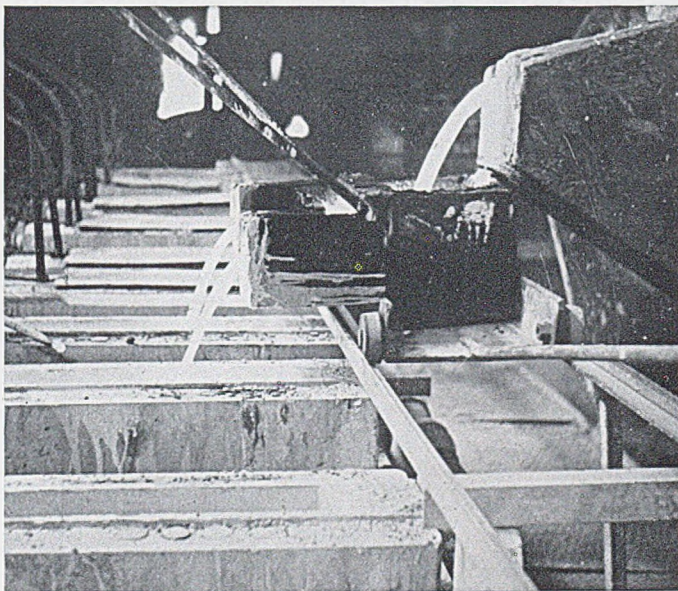


FIG. 8.—The Simultaneous Casting of Two 1000-Lb. Rolling Slabs from a 5-Ton Portable Furnace.



FIG. 9.—A Pelican Ladle Used for "Floating" Vertically Cast Cakes.

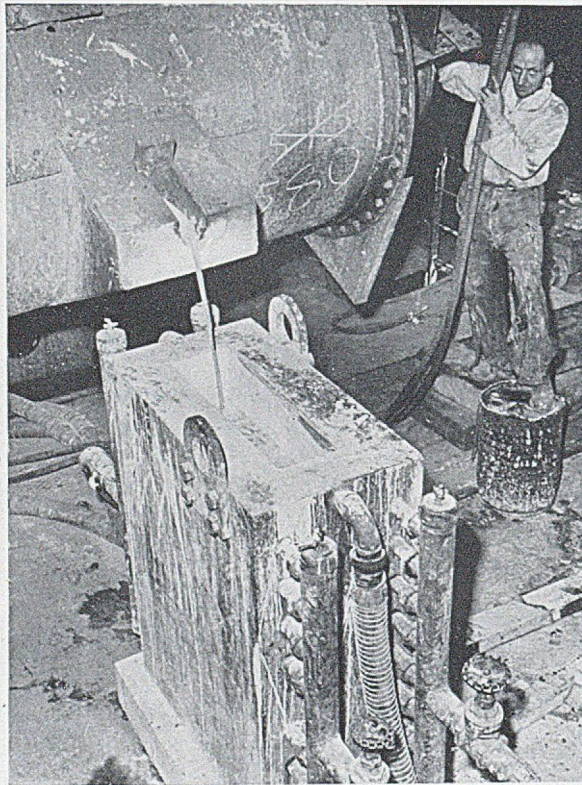


FIG. 10.—A 3000-Lb. High-Conductivity Copper Cake Being Vertically Cast into a Water-Cooled Copper Mould.



FIG. 4.—Radiograph of Zinc Rolling Slab Containing Interdendritic Shrinkage. $\times 1$.



FIG. 6.—Radiograph Showing Large Gas Cavity in Zinc Rolling Slab. $\times 1$.



FIG. 5.—Photograph of Vertical Section through Area Covered by Fig. 4. $\times 1$ approx.

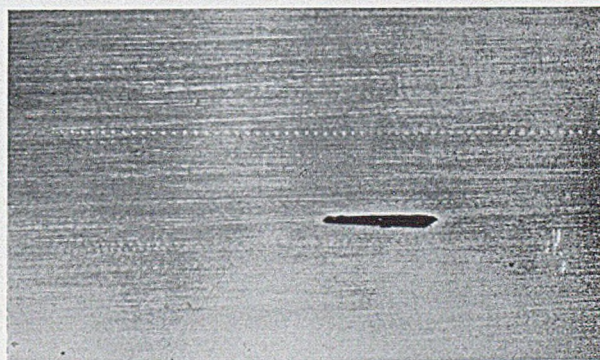


FIG. 7.—Photograph of Horizontal Section through Gas Cavity Shown in Fig. 6. $\times 1$ approx.



FIG. 8.—Macrostructure of Vertically Cast Zinc Rolling Slab. $\times 1$ approx.

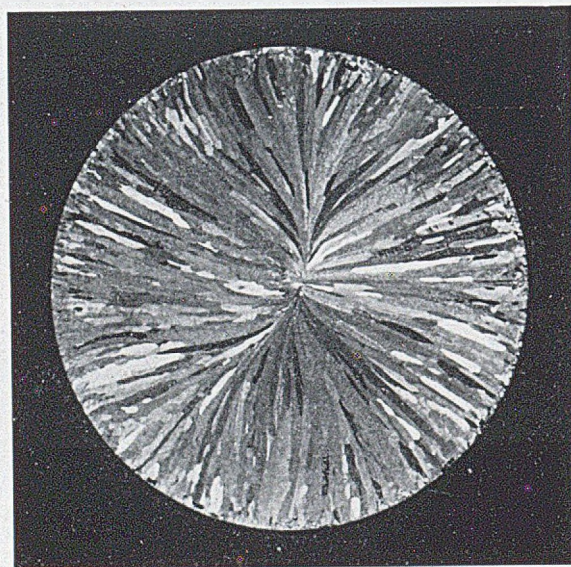


FIG. 9.—Macrostructure of Vertically Cast Zinc Extrusion Billet. $\times \frac{1}{2}$ approx.

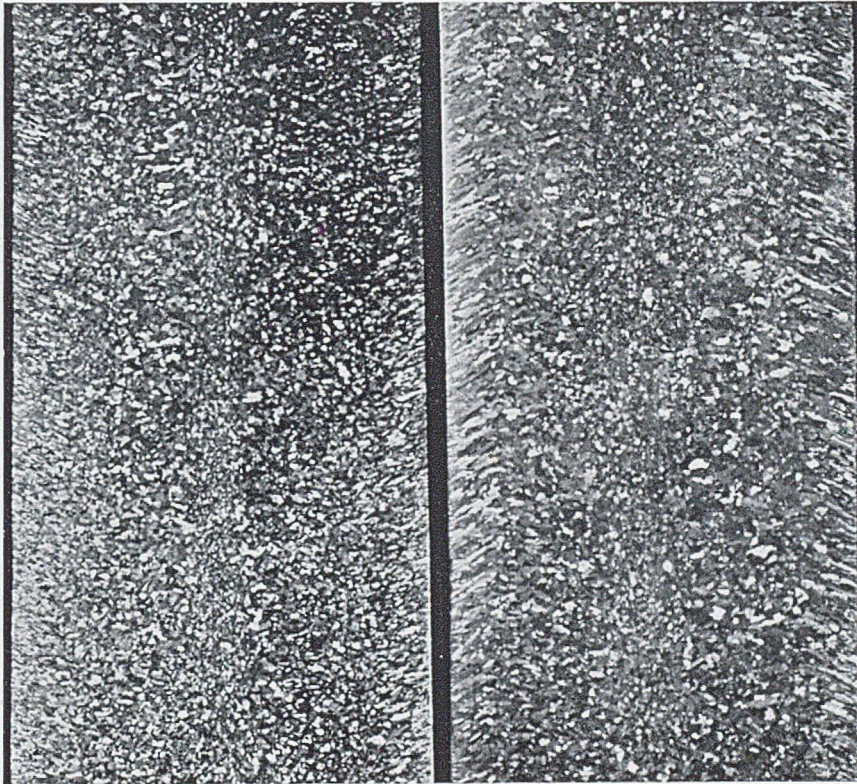


FIG. 1.—Transverse Section of Commercially Pure Aluminium Rolling Slab, Cast in Solid Cast-Iron Book Mould. Etched. $\times \frac{1}{2}$ (reduced by $\frac{1}{2}$ in reproduction).

FIG. 2.—Transverse Section of Aluminium-Manganese Alloy Cast in Solid Cast-Iron Book Mould. Etched. $\times \frac{1}{2}$ (reduced by $\frac{1}{2}$ in reproduction).

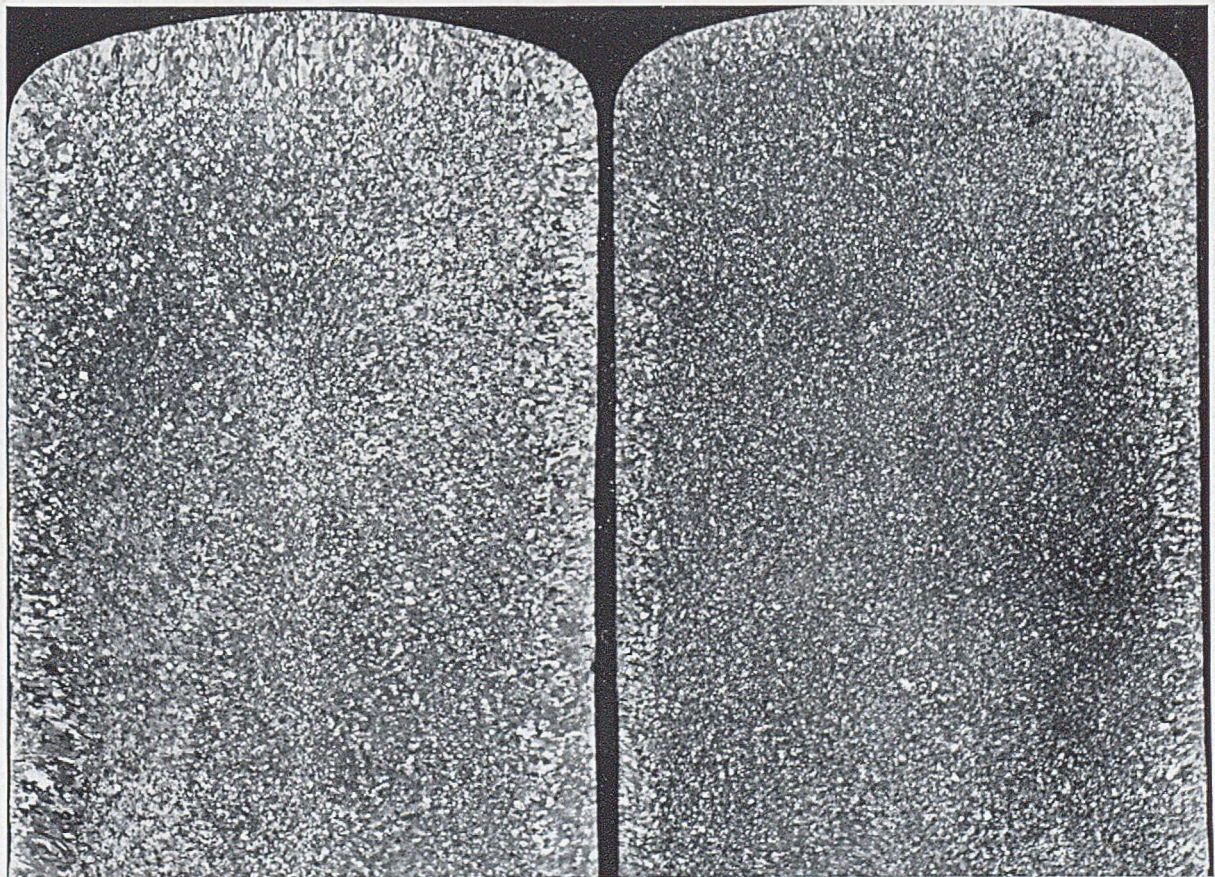


FIG. 3.—Transverse Section of Commercially Pure Aluminium, Direct-Chill-Cast. Etched. $\times \frac{1}{2}$ (reduced by $\frac{1}{2}$ in reproduction).

FIG. 4.—Transverse Section of Aluminium-Manganese Alloy, Direct-Chill-Cast. Etched. $\times \frac{1}{2}$ (reduced by $\frac{1}{2}$ in reproduction).

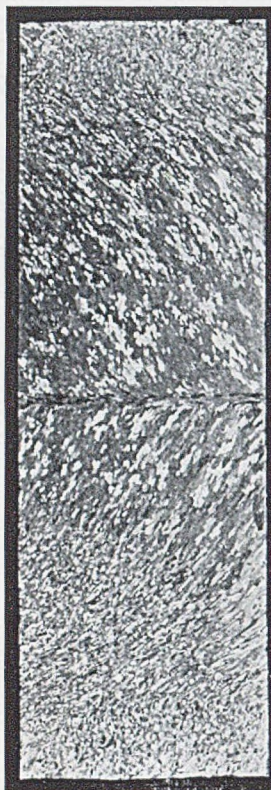


FIG. 5.—Longitudinal Section of Commercially Pure Aluminium, Direct-Chill-Cast. Etched. $\times \frac{1}{4}$.

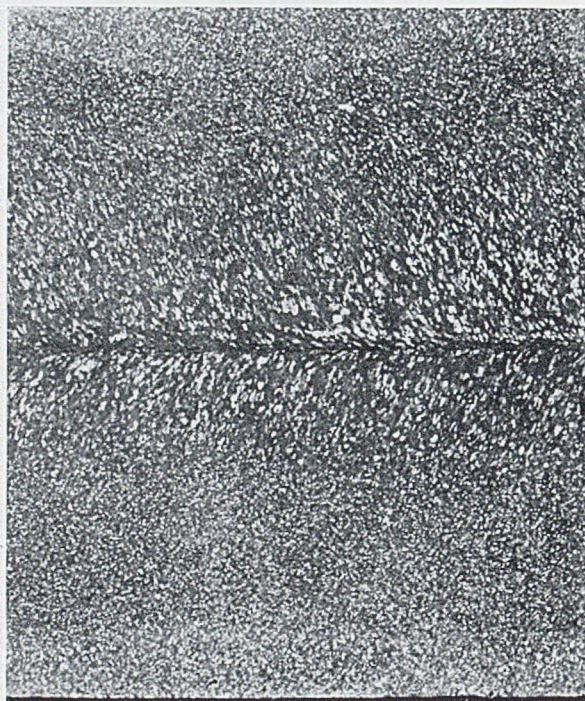


FIG. 6.—Longitudinal Section of Aluminium-Manganese Alloy, Direct-Chill-Cast. Etched. $\times \frac{1}{4}$.

FIG. 7.—Commercially Pure Aluminium Cast in Solid Cast-Iron Book Mould.

FIG. 8.—Aluminium-Manganese Alloy Cast in Solid Cast-Iron Book Mould.

FIG. 9.—Commercially Pure Aluminium, Direct-Chill-Cast.

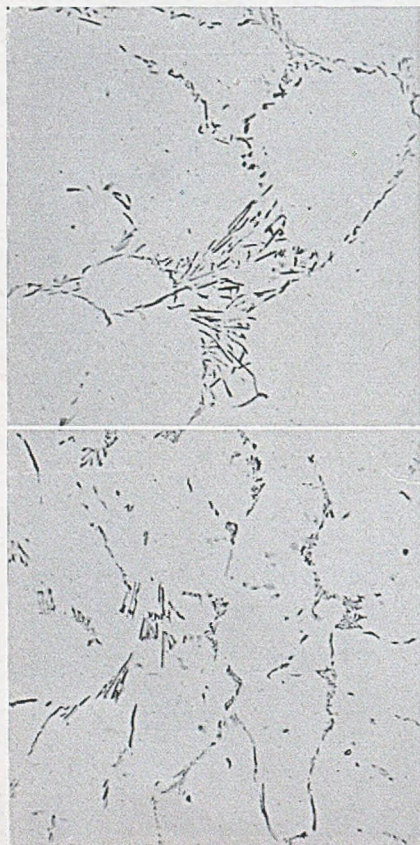


FIG. 10.—Aluminium-Manganese Alloy, Direct-Chill-Cast.

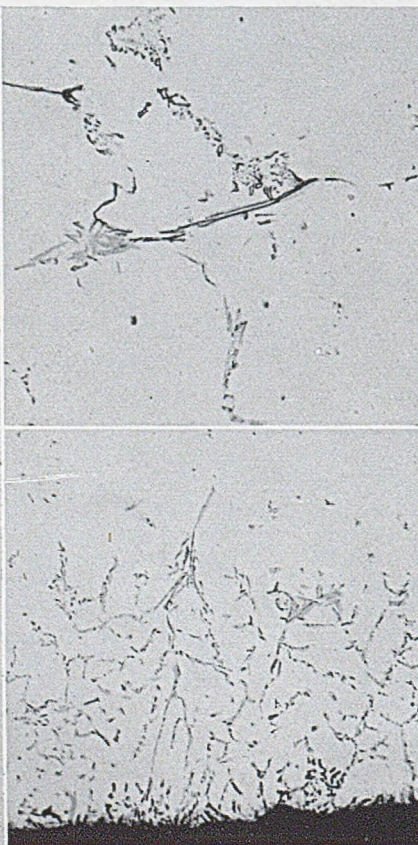


FIG. 11.—Structure at Surface of Commercially Pure Aluminium, Direct-Chill-Cast.

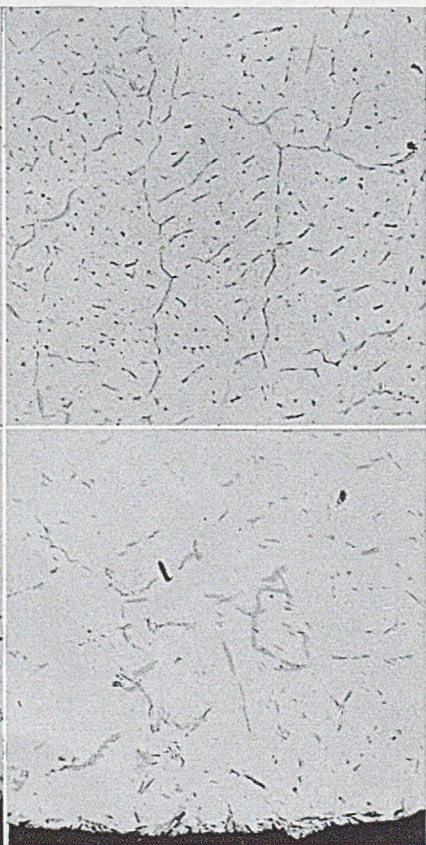


FIG. 12.—Structure at Surface of Commercially Pure Aluminium Cast in Solid Cast-Iron Book Mould.

All $\times 100$. Unetched.



FIG. 13.—Structure at Centre of Transverse Section of 4 × 4-in. Gothic Wire Bar, in Commercially Pure Aluminium Direct-Chill-Cast. Etched. × 2.

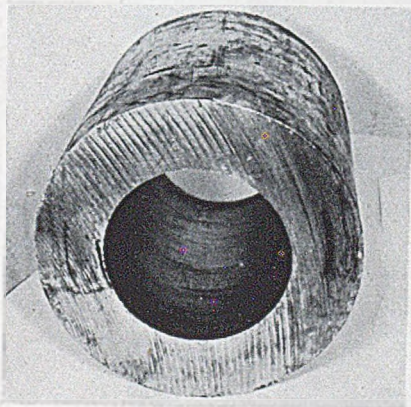


FIG. 14.—Hollow Billet, 20-In. Outside Dia. × 10½-In. Bore, in Commercially Pure Aluminium, Direct-Chill-Cast.

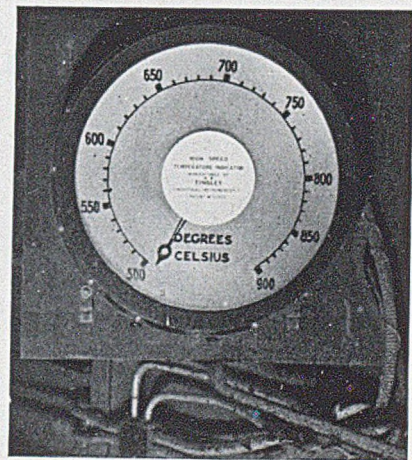


FIG. 15.—20-In.-Dia. Illuminated Dial of Temperature-Indicating Apparatus.

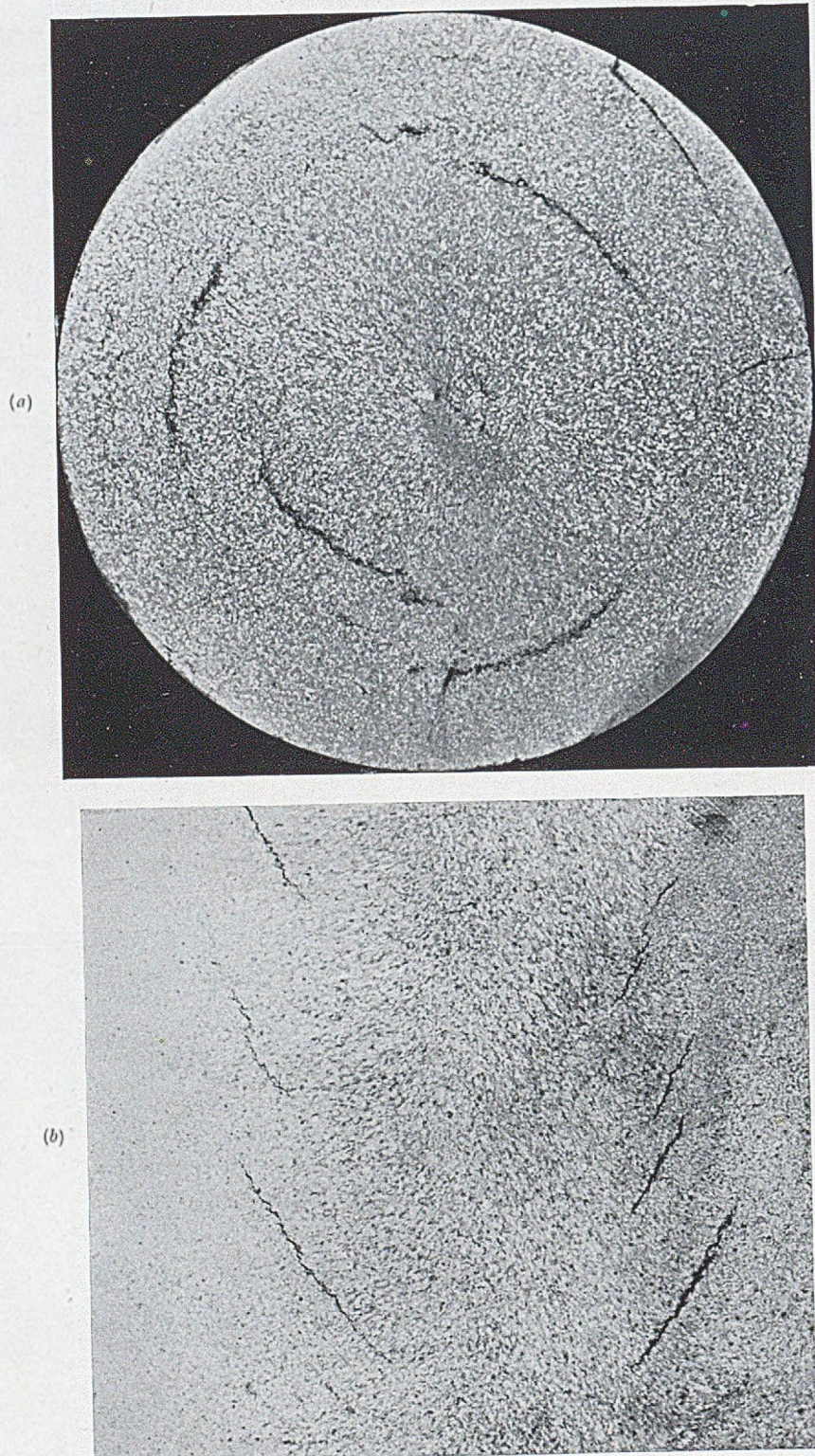


FIG. 16.—(a) Transverse and (b) Longitudinal Section of 6-In.-Dia. Billet in Material of Group 6 (Al-Cu-Mg-Si), Direct-Chill-Cast, Showing Cracks Developed During Homogenizing. Etched. $\times \frac{1}{2}$.

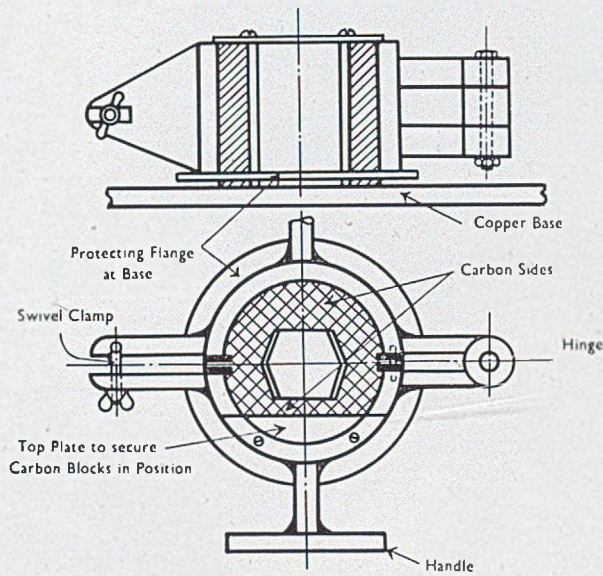


FIG. 1.—Spectrographic Test-Piece Mould for Casting a "Churchill Block". Size of test-piece $3\frac{1}{2}$ in. high, $1\frac{1}{4}$ in. wide, and $2\frac{1}{2}$ in. broad.

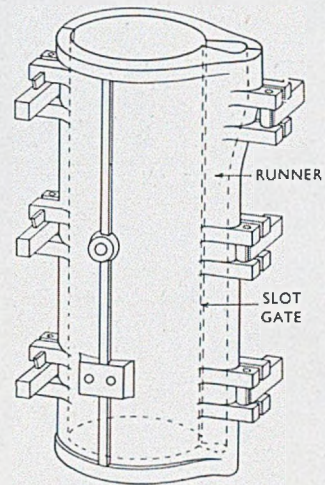


FIG. 2.—Typical Book Mould for Extrusion Billets in the "Classical" Alloys.

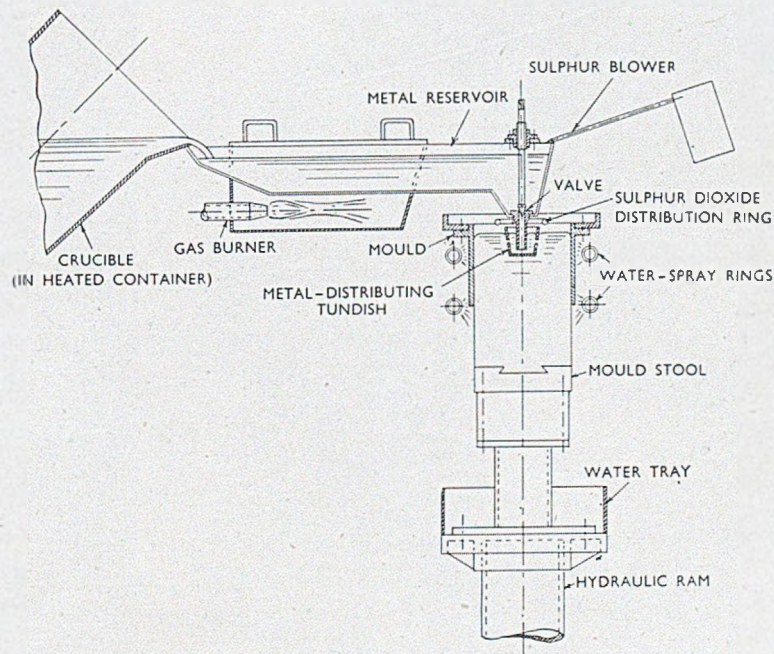


FIG. 3.—The Essential Components of the D.C. Casting Machine.

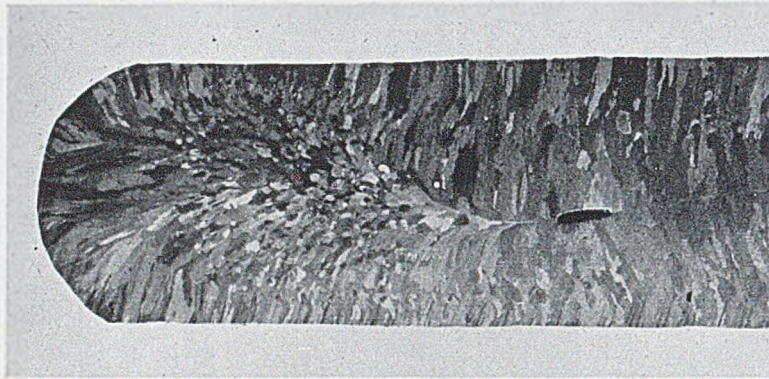


FIG. 4.—Part of a Macro-Etched Transverse Section of an AM503 Alloy Rolling Slab Cast in a Book Mould Showing " Bridging " Cavity and Normal Grain-Size. Approx. $\frac{1}{2}$ size.

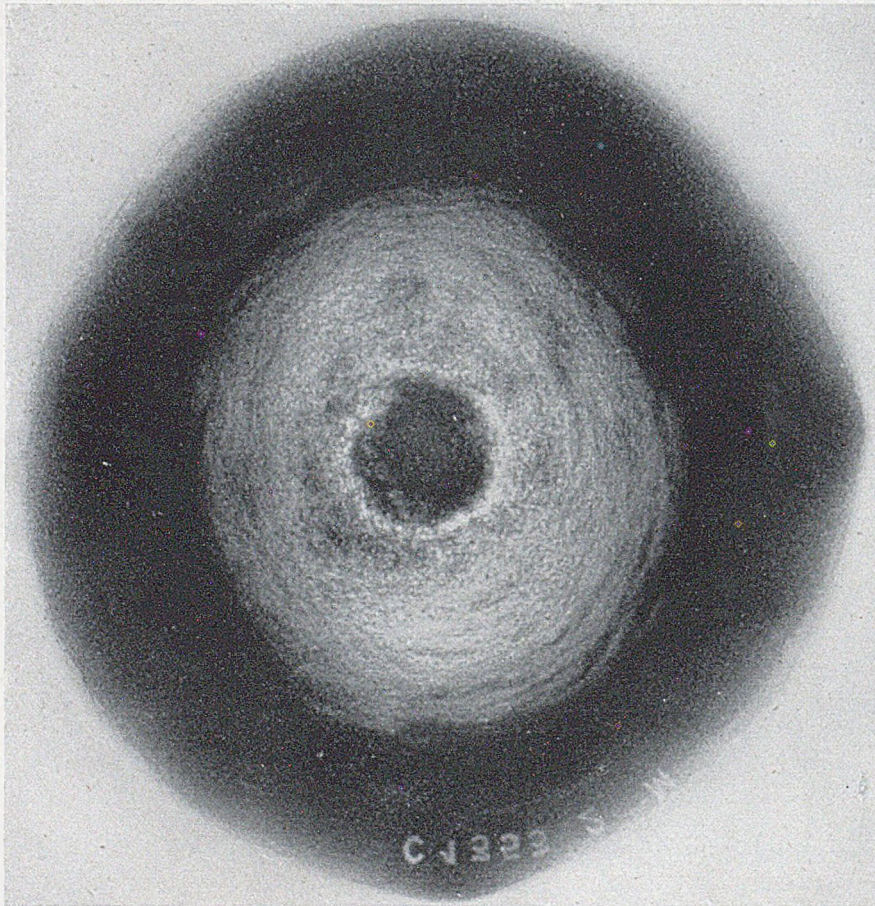


FIG. 5.—Radiograph of Section from AZM Alloy Billet Showing Macro- and Micro-porosity.

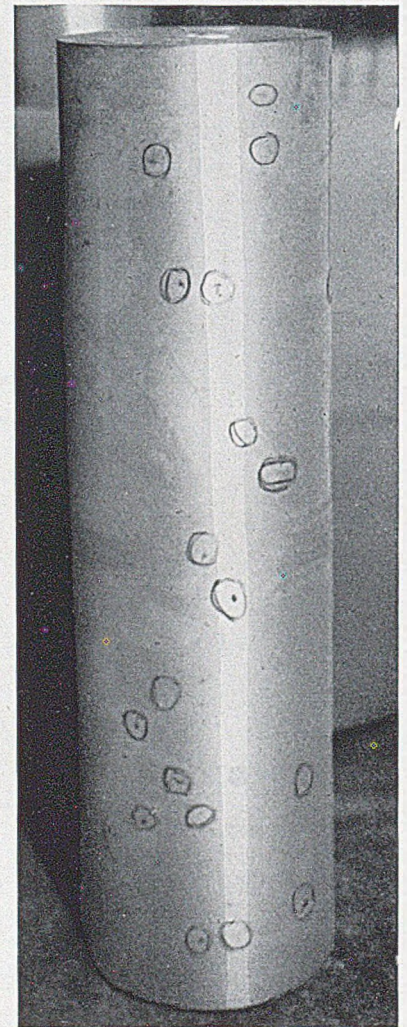


FIG. 6.—Flux Inclusions in a Billet of AZ855 Alloy Disclosed in Machining.

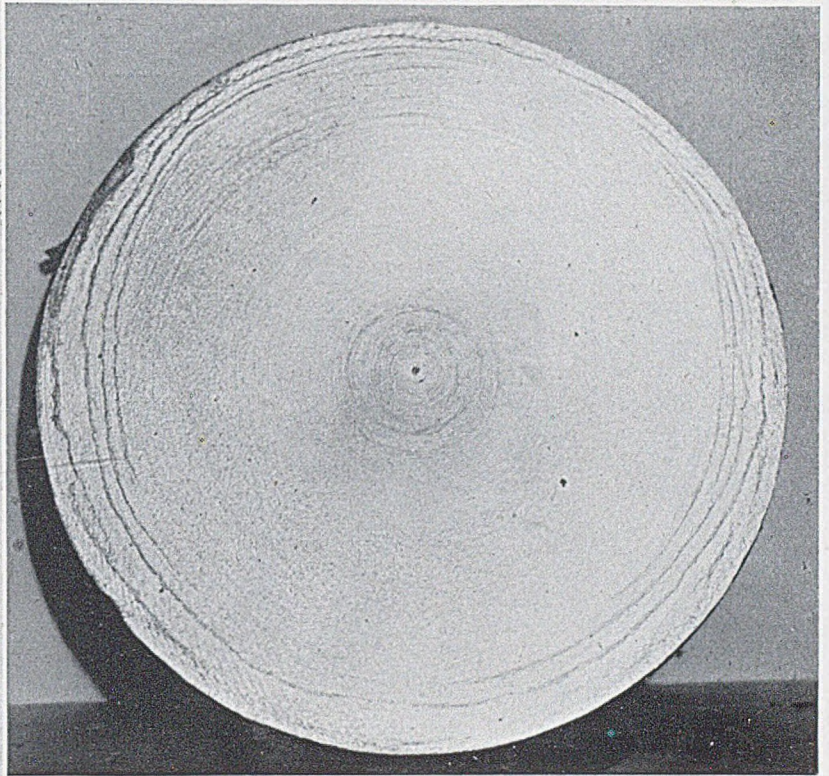
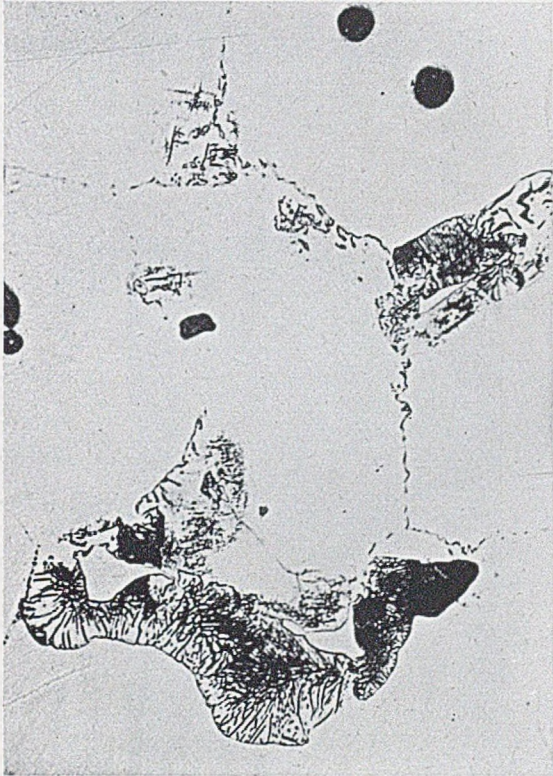


FIG. 7.—Typical Microstructure of AZM Billet Cast in a Book Mould. As cast. $\times 250$.

FIG. 9.—Sectioned ZW3 Alloy Billet Showing Banded Zirconium Precipitation and Associated β Phase Resulting from the Use of a Mould Vibrator.

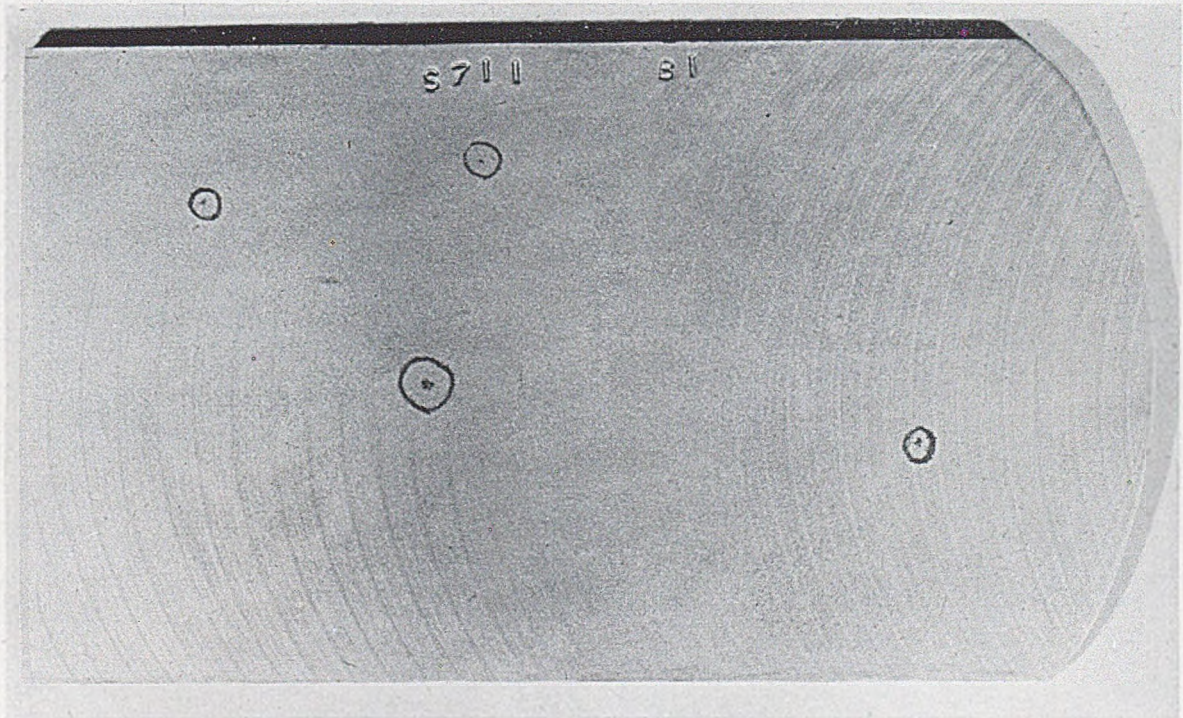


FIG. 8.—Etched Section from Direct-Chill-Cast Slab Showing Oxide Inclusions.

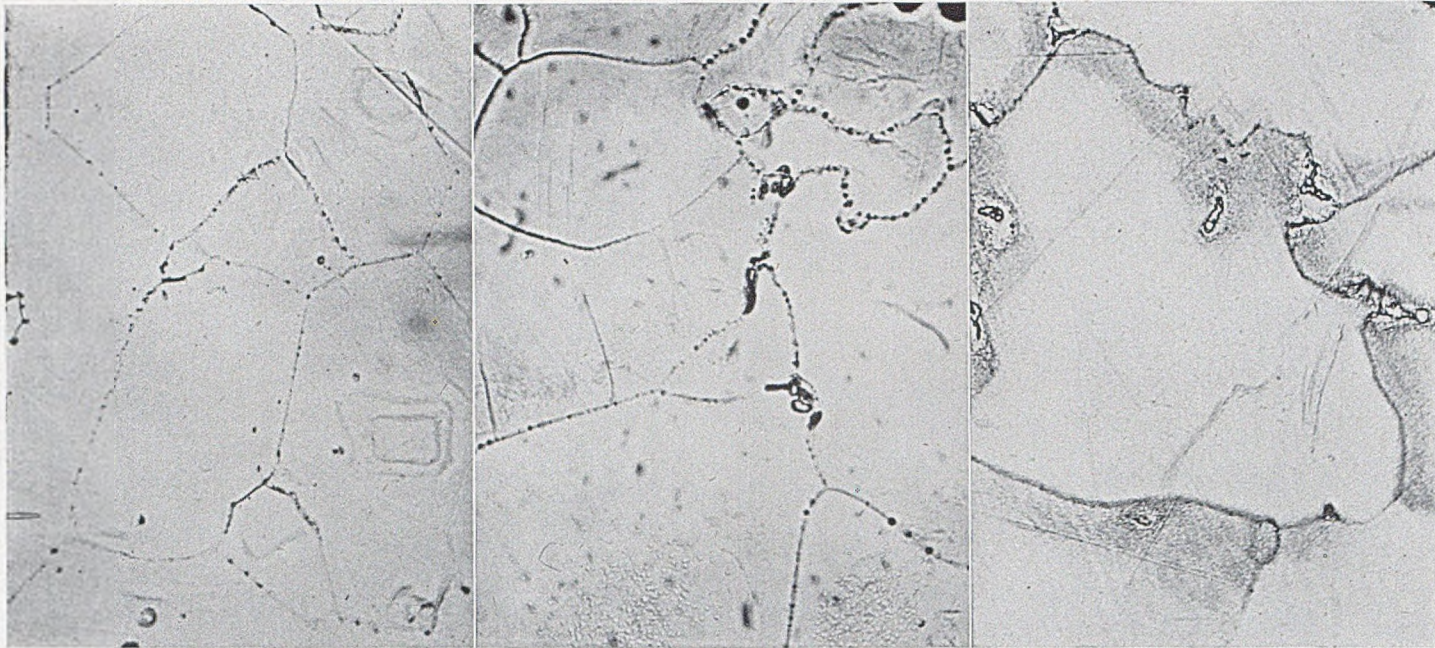


FIG. 10.—Microstructures of ZW3 Alloy Direct-Chill-Cast Billets and Slab. $\times 500$.
 (a) Good structure. Grain-size: 0.055 mm. (b) Satisfactory structure. Grain-size: 0.065 mm. (c) Weak structure. Grain-size: 0.10 mm.

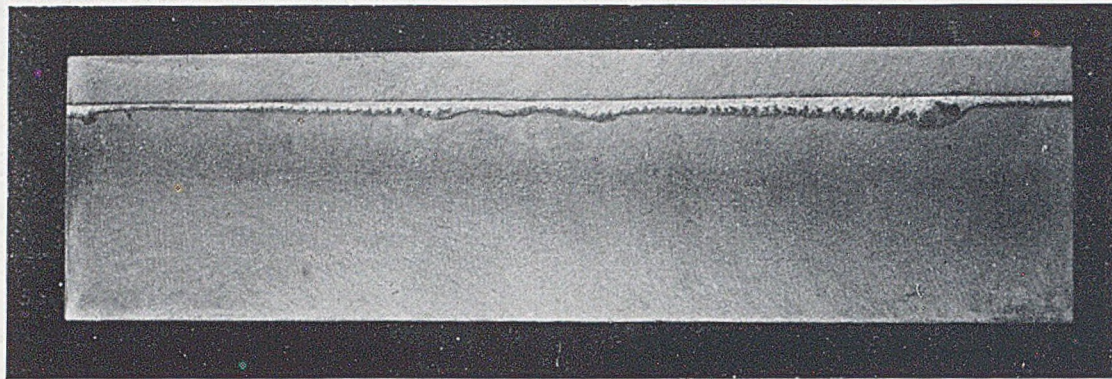


FIG. 11.—ZW3 Alloy Direct-Chill-Cast Slab, Sectioned Vertically, Showing Massive Concentration of β Phase Resulting from Mal-Positioning of the Tundish.

METALLURGICAL ABSTRACTS

GENERAL AND NON-FERROUS

VOLUME 20

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PART 7

1 — PROPERTIES OF METALS

*Effect of Annealing on the Creep Properties of 2S-O Aluminium Alloy [Commercially Pure Aluminium]. O. D. Sherby and J. E. Dorn (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 954-963; discussion, 977-980).—Creep tests were carried out on 2S-O Al sheet after annealing for 1 hr. at (a) 650° F. (345° C.), (b) 950° F. (510° C.), and (c) 1150° F. (620° C.) and air cooling. Treatments (a) and (b) did not cause recrystn., the original grain-size being retained, but after treatment (c) large grains were produced. Tests were carried out at 90°, 212°, 300°, 400° F. (32°, 100°, 150°, 205° C.), and within the ranges of temp. and stress investigated the creep rate decreased with increasing annealing temp. It is suggested that the improved creep-resistance generally reported for coarse-grained materials at elevated temp. may be attributable to greater grain perfection rather than the grain-size *per se*. The results are said to be in qual. agreement with concepts of the role of dislocations in the processes of creep. 10 ref.—P. T. G.

*Determination of the Tensile Strength of [Aluminium and] Aluminium Alloys from Their Hardness. (Meincke). See col. 461.

*Influence of Small Amounts of Impurities in High-Purity Aluminium on the Dielectric Film of Electrolytic Condensers. II.—Effect of Mg, Zn, Mn, and Ti. Namio Kawashima, Yuzo Nakamura, and Takuji Okugawa (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (5), 278-281).—[In English]. Among the many factors affecting the dielect. properties of an electrolytic condenser, the impurities in Al may be considered important. Results of experiments on the influence of 0.02-0.5% Mg, Zn, Mn, and Ti showed that: (1) <0.1% Mg and <0.4% Zn improve the properties; (2) <0.05% Mn is beneficial, but >0.05% is harmful; (3) Ti is undesirable; (4) hard-rolled Al is better than annealed Al; and (5) annealing at higher temp. gives rise to inferior properties. Generally, K., N., and O. found that impurities in solid soln. are not deleterious, whereas impurities present as precipitates or compounds are.—S. R. W.

*The Allotropy of Cobalt. A. G. Metcalfe (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 717-731).—Dilatometric measurements on 99.9% Co revealed a transformation on heating between 1119° and 1145° C., which showed considerable hysteresis on cooling. It is concluded that it corresponds to a reversion to hexagonal Co, and support for this view is given by the results of thermally etching pure Co at 1135° and 1175° C., dilatation measurements on Co-Cr-Mo alloys, and previous X-ray work. The transformation is compared with that occurring at low temp., and a possible mechanism is discussed. 27 ref.—D. M. P.

*Mechanical Properties of Copper at Various Temperatures. W. H. Munse and N. A. Weil (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 996-1019; discussion, 1019-1022).—The Y.P., U.T.S., reduction of area, elongation, and modulus of elasticity were determined at temp. ranging from -321° to 400° F. (-196° to 205° C.) for: (i) electrolytic tough-pitch Cu,

(ii) deoxidized high-P Cu, and (iii) O-free high-conductivity Cu. The materials were tested in 2 thicknesses ($\frac{1}{8}$ and $\frac{1}{4}$ in.) and 2 tempers (annealed and cold-rolled 5-7%). Tests were also carried out on cold-rolled material (ii) at temp. up to 1200° F. (650° C.). The property most affected by variation in temp. was the U.T.S., which increased from ~5000 lb./in.² at 1200° F. to ~50,000 lb./in.² at -321° F. The rate of change was, however, greatest at temp. below atmospheric. The Y.P. also increased as the temp. was lowered, but the rate of change decreased as the temp. fell below atmospheric. The reduction in area increased gradually as the temp. was increased, except in the region 300°-700° F. (150°-370° C.), where there was a drop of 10-15%. Elongation was not greatly affected by increase in temp. up to 500° F. (260° C.), when a considerable increase started to occur. Cold rolling increased the Y.P. approx. 150%, but the U.T.S. only 4-7%. Simultaneously the elongation decreased and the reduction of area remained almost const. Reduction in thickness increased the Y.P. 12-30%, while the U.T.S. was increased to a smaller extent, the elongation was decreased, and there was little effect on reduction of area. Rolling direction had no effect on the annealed Cu, but with the cold-rolled materials there was a greater strength and lower elongation for specimens || the rolling direction than for those ⊥. The differences in mech. properties of the 3 types of Cu were in general negligible. The results obtained are correlated with previously published results for the same and similar materials. 30 ref. —P. T. G.

*The Reflectivity of Copper Electrodeposits. W. H. Gauvin and C. A. Winkler (*J. Electrochem. Soc.*, 1952, 99, (11), 447-449).—It is shown from measurements of the specular reflectivity of Cu electrodeposits, that any change in deposition conditions leading to increased polarization, increases the reflectivity. Decreased metal ion content of the soln. and increased acidity have the same effect. Larger increases in reflectivity were obtained when the apparent c.d. was increased or the temp. lowered. Addn. of gelatin to the electrolyte caused considerable increase in the reflectivity of the deposit. Addn. of binardine gave a smaller increase. It is concluded that reflectivity measurements can be used for controlling the concentration of glue or gelatin in the electrolyte, but not that of binardine. 16 ref.—G. T. C.

*A Theoretical Estimate of the Effect of Radiation on the Elastic Properties of Simple Metals [Copper and Sodium]. G. J. Dienes (*Phys. Rev.*, 1952, [ii], 86, (2), 228-234).—An approx. theoretical treatment is given of the effect of a small fraction of vacancies and interstitial atoms produced by irradiation, upon the elastic const. of Cu and of Na. The calculations, which employ a simple exponential atomic interaction potential for Cu and a Morse function for Na, assume that the inhomogeneous lattice is equivalent to a homogeneous one, modified to allow for the number of contacts formed and broken by the creation of vacancies and

* Denotes a paper describing the results of original research.

† Denotes a first-class critical review.

interstitials. Atomic position relaxation effects are insufficient to prevent interstitial atoms from increasing the elastic const. of Cu considerably, but in Na relaxation reduces the effect to approx. a bulk one. The effect of vacancies is of the same magnitude as a bulk effect in both metals. Since approx. equal numbers of interstitial atoms and vacancies should be produced by irradiation, a net increase in the elastic const. of Cu should result. A 10% increase in the Young's modulus of Cu was found after heavy cyclotron irradiation.

—P. C. L. P.

***The Heat Capacity of Gallium from 15° to 320° K.: The Heat of Fusion at the Melting Point.** George B. Adams, Jr., Herrick L. Johnston, and Eugene C. Kerr (*J. Amer. Chem. Soc.*, 1952, 74, (19), 4784-4787).—Heat-capacity data for Ga in the range 15°-320° K. are tabulated, and a curve obtained on plotting the results from four samples of 99.75-99.99% purity is presented. A λ point in the curve for the solid at 292.4° K. was caused by eutectic melting, and was not observed with the sample of 99.99% purity, though subsequent runs with this sample gave heats under the λ proportional to contamination of the Ga by Sn dissolved from soldered joints in the calorimeter. The heat capacity of the liquid decreased with increasing temp. over the range observed (303°-320° K.), as has been reported for Hg and liq. Na and K. The heat of fusion for pure Ga was 1335 ± 1.0 cal./g.-atom, and the entropy of fusion was 4.407 ± 0.004 e.u. at the m.p.—J. R.

***The Vapour Pressure of Germanium.** Alan W. Searcy (*J. Amer. Chem. Soc.*, 1952, 74, (19), 4789-4791).—Tabulated data from vapour-pressure detn. on liq. Ge by the Knudsen effusion method lead to the equation $\Delta F = 87,490 + 2.0 T \ln T - 45.5 T$, where ΔF is the free energy of vaporization and T is the abs. temp. Consideration of the results in conjunction with estimated heat-capacity and heat-content data give 84.0 ± 1.5 kg.cal./mole for the heat of sublimation of Ge at 298.15° K. X-ray-diffraction photographs of some Ge films on the heated Pt collector plates indicated reaction between Ge and Pt.—J. R.

***Specific Heat, Latent Heat of Fusion, and Melting Point of Germanium.** E. S. Greiner (*J. Metals*, 1952, 4, (10), 1044).—An A.I.M.M.E. Research in Progress summary. The following phys. properties of Ge have been determined: (1) sp. heat (of metal having an elect. resistivity of 10 Ω -cm. at 25° C.) 0.080 cal./g.°C. at 600° C., rising to 0.085 cal./g.°C. at 900° C.; extrapolation of these data to lower temp. shows agreement with results for the range 0°-300° C. reported by other workers; (2) latent heat of fusion 8100 ± 800 cal./g.-atom; and (3) m.p. and f.p. (of metal having an elect. resistivity of >20 Ω -cm. at 25° C.) 936 ± 1 ° C. 3 ref.—E. N.

***The Specific Heats of Germanium and Grey Tin at Low Temperatures.** R. W. Hill and D. H. Parkinson (*Phil. Mag.*, 1952, [vii], 43, (338), 309-316).—The sp. heats of high-purity Ge and grey Sn have been measured in the temp. ranges 4°-170° and 2°-110° K., resp. The results for grey Sn agree with those of Lange (*Z. physikal. Chem.*, 1924, 110, 343; *J. Inst. Metals* (Abstracts), 1924, 32, 521), which extend down to ~ 18 ° K. A smaller sp. heat and no peak is shown for Ge, in disagreement with Cristescu and Simon (*ibid.*, 1934, [B], 25, 273), whose specimen may have been impure. Values of the thermodynamic functions of both substances are calculated, and a discussion is given of the reason why the Debye characteristic temp. show an abnormally large variation, qual. similarly to that shown by diamond and Si. The behaviour is thought to be a characteristic of the crystal structure, but the possibility of a sp.-heat contribution from some unknown excitation process is also considered.—P. C. L. P.

***Diffusion of Donor and Acceptor Elements into Germanium.** Calvin S. Fuller (*Phys. Rev.*, 1952, [ii], 86, (1), 136-137).—A letter. The diffusion of As and Sb into p -type Ge was investigated by following the position of the p - n junction with a W probe. The results fit the equation: $D_{As} = D_{Sb} = 0.71 \exp(-51,000/RT)$. The diffusion const. of In and Zn in n -type Ge at 775° and 845° C. were also determined; both gave an activation energy of $\sim 50,000$ cal./mole.—P. C. L. P.

***Measurement of Diffusion in Semi-Conductors [Germanium] by a Capacitance Method.** K. B. McAfee, W. Shockley, and

M. Sparks (*Phys. Rev.*, 1952, [ii], 86, (1), 137-138).—A letter. The change in the capacity of a p - n junction in Ge on heat-treatment is used to determine the change in concentration gradient of a non-uniformly distributed impurity and hence its rate of diffusion. The result for the diffusion rate of As in Ge at 800° C. is several orders of magnitude less than that determined by Fuller (preceding abstract). A discussion is given of the advantages of the technique, which include the elimination of the necessity to determine the initial concentration of solute atoms at the surface required by most conventional methods.

—P. C. L. P.

*** p - n Junction Method for Measuring Diffusion in Germanium.** W. C. Dunlap, Jr., and D. E. Brown (*Phys. Rev.*, 1952, [ii], 86, (3), 417-418).—A letter. The rate of diffusion of radioactive Sb¹²⁴ in Ge, as measured by following the position of the p - n junction, agrees satisfactorily with that determined by direct measurement of the activity at different depths below the surface. The results indicate an activation energy of 57,000 cal./mole and a value for D_0 of 10 cm.²/sec.—P. C. L. P.

***Probing the Space-Charge Layer in a p - n Junction [of Germanium].** G. L. Pearson, W. T. Read, and W. Shockley (*Phys. Rev.*, 1952, [ii], 85, (6), 1055-1057).—The extent of, and potential distribution within, the space-charge region of a p - n junction in a Ge single crystal has been investigated with a sharply pointed W probe.—P. C. L. P.

[Discussion on a Paper by F. H. Buttner, E. R. Funk, and H. Udin:] Viscous Creep of Gold Wires Near the Melting Point. — (*J. Metals*, 1952, 4, (11), 1217-1220).—See *M.A.*, 20, 2.

***Dimensional Changes Normal to the Direction of Diffusion [of Silver in Gold].** R. W. Balluffi and B. H. Alexander (*J. Appl. Physics*, 1952, 23, (9), 953-956).—Ag was continuously evaporated on to Au wires or foils kept at the same temp. as the Ag source, and allowed to diffuse into the Au. There were expansions of several % \perp the diffusion direction; the magnitude of expansion was the same in 2 directions both \perp the diffusion direction. Specks of dirt at the original surface served as markers as diffusion progressed, and these markers occupied a cylinder of increasing radius as diffusion went on in the wires. From measurements of this radius the expansion \parallel the diffusion direction was derived. It was always somewhat larger than the \perp expansion. The results show that Ag diffuses faster in Au than Au in Ag. On a simple vacancy or interstitial diffusion mechanism the expansion should be isotropic. The observed anisotropy is attributed to triaxial stresses set up by diffusion, which lead to a dependence of the efficacy of dislocations as vacancy generators on the directions of their Burgers vectors.—R. W. C.

***Wave-Functions for Excited States of Mercury and Potassium.** Bramananda Mishra (*Proc. Cambridge Phil. Soc.*, 1952, 48, (3), 511-515).—Values of the normalized wave-functions for excited states of Hg and the normalized ($4p$) wave-function for K are calculated and tabulated. Values of the kinetic energy and cross-section of the photo-ionized ejected K atom are also tabulated.—J. S. G. T.

***The Heat of Combustion of Neodymium.** Elmer J. Huber, Jr., and Charles E. Holley, Jr. (*J. Amer. Chem. Soc.*, 1952, 74, (21), 5530-5531).—A note. The heat of combustion of Nd, suitably corrected for impurities present and taking into account the uncertainty in the energy equivalent, was found to be 6252.6 ± 3.5 abs. joules/g. The heat of formation of Nd₂O₃ is given as -432.15 ± 0.24 kg.cal./mole.—J. R.

***Physical Properties of Electrodeposited Metals I.—Nickel: (3) The Effect of Plating Variables on the Structure and Properties of Electrodeposited Nickel.** A. Brenner, Victor Zentner, and C. W. Jennings (*Plating*, 1952, 39, (11), 1229-1230).—Cf. *ibid.*, (8), 865; *M.A.*, 20, 324. A correction.

—G. T. C.

Catalytic Activity of Nickel: Theoretical Aspects. D. A. Dowden (*Indust. and Eng. Chem.*, 1952, 44, (5), 977-985).—Presented at an American Chemical Society Symposium on Nickel. Chemisorption of substrates by metals depends upon the "residual valencies" of the giant-molecule crystallites. These valencies are discussed qual., using band theory and Pauling's resonating-valence-bond theory. Vacant d orbitals appear necessary for rapid, general chemisorption, and there-

fore also for catalytic activity of certain types. The binding potential of the valencies varies inversely as the Fermi energy of the metal electrons and inversely as the ionization potential of the relevant, substrate valence electrons. These concepts are employed in a rationalization of the properties (sp. area and sp. activity) of Ni and its alloys as catalysts in industry and research.—D. P. M.

*Behaviour of the Heat Capacity of Supraconducting Niobium Below 4.5° K. A. Brown, M. W. Zemansky, and H. A. Boorso (*Phys. Rev.*, 1952, [ii], 86, (1), 134-135).—A letter. The heat capacity of a Nb cylinder has been measured in both the normal and supraconducting states. At higher temp. the sp. heat in the supraconducting state follows the relationship $C_s = 464(T/161)^3$, but below 4.5° K. the sp. heat decreases more rapidly than can be given by a T^3 law. The sp. heat in the normal state can be expressed as $C_n = 21.0 \times 10^{-4}T + 464(T/254)^3$, in the range 2.5°-12° K., but above this temp., the observed sp. heat becomes progressively less than that given by the equation. The data are thermodynamically consistent with the behaviour of a metal which is undergoing reversible transitions, and whose critical temp./magnetic field curve obeys a parabolic relationship $H = H_0(1 - T^2/T_c^2)$, where $H_0 = 1960$ Oe. and $T_c = 8.7^\circ$ K.

—P. C. L. P.

*Experiments on the Electrical Resistivity of Metals. [Rubidium.] D. K. C. MacDonald (*Phil. Mag.*, 1952, [vii], 43, (339), 479-481).—A letter. The temp. variation of the elect. resistance of Rb shows a marked increase in slope at 180°-190° K. Rapid cooling to liq.-air temp. from above the transition temp. gives a resistivity greater than that produced by slow cooling. The evidence suggests that an electronic transition, rather than a change of crystal structure, is responsible. This work throws light on the anomalous variation in the apparent Debye temp. of Rb (MacD. and Mendelssohn, *Proc. Roy. Soc.*, 1950, [A], 202, 103; *M.A.*, 18, 88).—P. C. L. P.

*The Optical Properties of Liquid Selenium. E. W. Saker (*Proc. Phys. Soc.*, 1952, [B], 65, (10), 785-787).—Opt. properties of Se have been measured up to 400° C. The absorption edge moves out to longer wave-lengths at higher temp., the change in the energy gap between the electron bands being 1.4×10^{-3} eV./°C. The refractive index decreases with increasing temp.—E. O. H.

*Studies on Selenium and Its Alloys. VI.—Effect of Some Doping and Anti-Doping Elements on the Electrical Conductivity of Molten Selenium. Tomoo Satō and Hideo Kaneko (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 309-312).—[In Japanese, with tables and graphs in English]. The elect. conductivity of molten Se contg. doping agents (Cl, Br, and I) increases exponentially with temp. It also increases exponentially with Cl content, but proportionally with the amount of Br or I. Addn. of anti-doping elements (e.g. Hg, Te, S, and P) have little effect on the conductivity. However, they diminish the doping action of the halogen element, and hence have an injurious effect on the rectifying characteristic of Se.—AUTHORS.

[Discussion on a Paper by M. Balicki and G. Leeds:] Work-Hardening-Reannealing Cycle of Pure Silver. — (*J. Metals*, 1952, 4, (11), 1206).—See *M.A.*, 19, 502.

*The Contamination in Evaporated [Silver and Germanium] Films by the Material of the Source. O. S. Heavens (*Proc. Phys. Soc.*, 1952, [B], 65, (10), 788-793).—Microchem. and radioactive-tracer methods have been used to study contamination of Ag and Ge films by the material used for boats or sources of the metals. A lower limit of a few p.p.m. was found, and it is suggested that this arises from soln. of the boat materials by the molten metals.—E. O. H.

*The Change of Phase on Reflection at a Silver Surface, and Its Dependence on the Angle of Incidence. G. Dörnenburg (née Prost) and R. Fleischmann (*Z. Physik*, 1951, 129, (3), 300-306).—The phase changes produced by the reflections glass/Ag and air/Ag were measured by means of a Jamin interferometer, using polarized light. Anomalies are attributed to surface films on the Ag, and the opt. properties of these are evaluated.—J. W. C.

*Self-Diffusion in Pure Polycrystalline Silver. L. Slifkin, D. Lazarus, and T. Tomizuka (*J. Appl. Physics*, 1952, 23, (9), 1032-1033).—Precision methods have been used to measure the diffusion of radioactive Ag in Ag. The results agree very well with other published data. A least-squares calculation from all these data gives $D = 0.724 \exp(-45,500/RT)$. Grain-boundary diffusion occurs at temp. ≤ 560 -600° C. (as deduced from penetration curves). This limiting temp. is lower than that reported by Hoffman and Turnbull (*ibid.*, 1951, 22, 634; *M.A.*, 19, 102); this is attributed to the greater grain-size in the specimens used in the new work.

—R. W. C.

*The M_3 and M_4 X-Ray Absorption Edges of Tantalum. Donald D. Doughty and J. W. McGrath (*Phys. Rev.*, 1952, [ii], 85, (6), 1040).—A letter. Using a Siegbahn-type vacuum spectrograph, the positions of the M_3 and M_4 absorption edges of Ta were found to occur at a higher wave-length than given by Whitmer (*ibid.*, 1931, [ii], 38, 1164). The positions of the M edges do not agree with those computed from the L lines.—P. C. L. P.

*Elastic and Plastic Properties of Very Small Metal [Tin] Specimens. Conyers Herring and J. K. Galt (*Phys. Rev.*, 1952, [ii], 85, (6), 1060-1061).—Sn whiskers 1.8×10^{-4} mm. in dia. have been found to withstand stresses of the order of tens of kg./mm.² without appreciable slip or creep in a period of 1 week. Where, under higher bending stresses, plastic deformation does occur, sharp bends are found. These mech. properties resemble those to be expected of a perfect crystal.—P. C. L. P.

*The Isotope Effect in Supraconductivity. II.—Tin and Lead. B. Serin, C. A. Reynolds, and C. Lohman (*Phys. Rev.*, 1952, [ii], 86, (2), 162-164).—Cf. *ibid.*, 1951, [ii], 84, 691; *M.A.*, 20, 69. The variation of the critical magnetic field for the destruction of the supraconductivity of 3 samples of Sn of average mass number M of 113.6, 118.7, and 123.8 and purities 99.5, 99.995, and 99.76%, resp., has been measured as a function of temp. The zero field transition temp., T_c , was found to depend on M in accordance with the relationship $M^{0.48} \pm 0.2T_c = \text{const.}$ The results for the 3 samples lay on the same curve when the normalized critical field was plotted against the normalized transition temp., though above 2° K. there was a progressively greater departure from a parabolic relationship. A variation of T_c with M was also found for Pb, but the mass range investigated was only 206.15-207.9.—P. C. L. P.

*Supraconductivity of the Isotopes of Tin. E. Maxwell (*Phys. Rev.*, 1952, [ii], 86, (2), 235-242).—The variation of the supraconducting transition temp. of six large-grained or single-crystal Sn wires of average mass number in the range 113.58 to 123.01, has been measured as a function of the magnetic field. The zero field transition temp., T_c , obeyed the relationship $M^2T_c = \text{const.}$, with $x = 0.505 \pm 0.019$. Although the transition temp./magnetic field curves were not accurately parabolic, they were geometrically similar for the different samples. It is deduced that the thermodynamic functions and the electronic sp. heat in the normal state are independent of the mass number. 29 groups of ref.—P. C. L. P.

*Strain-Sensitivity of Commercial-Purity Titanium. James L. Wyatt (*J. Metals*, 1952, 4, (10), 1050).—The strain-sensitivity, K (defined as the unit change in elect. resistance/unit strain), has been measured, within the range 0-1% total strain, for commercial-purity Ti wire, using a Kelvin double bridge accurate to 0.000001 Ω . A positive value of 0.17 for K was found, compared with values of 2.15 and 3.5 for Constantan and cold-worked Invar, resp., two of the more common strain-gauge materials. A temp. change of 30° F. (16.6° C.) was found to cause the same resistance change as 1% strain. It is considered that Ti would be useful as a strain-gauge material only: (1) if a high degree of const. temp. control could be maintained, and (2) in appn. of very large total strain.—E. N.

*Mechanical Properties and Strain-Ageing Effects in Titanium. F. D. Rosi and F. C. Perkins (*Amer. Soc. Metals Preprint*, 1952, (29), 20 pp.).—The tensile properties of hot-

rolled Ti rod were determined at temp. in the range -196° to 652° C. and at const. strain rates of 0.003 and 0.138 in./in./min. The material used contained Fe 0.10, N 0.08, C 0.05, Si 0.04, and W 0.01%. The usual mech. effects associated with strain-ageing were observed, as was expected in view of the impurities present. The Y.P. phenomenon was observed at temp. between 122° and 232° C.; as usual, this phenomenon disappeared gradually with increasing or decreasing temp. The max. difference between the upper and lower Y.P. was observed at $\sim 232^{\circ}$ C. Serration in the stress/strain curves (discontinuous yielding) was found in the temp. range 432° – 652° C. The occurrence of strain-ageing was also revealed by the effect of temp. on elongation and reduction in area, ductility decreasing with increasing temp. in the range 232° – 452° C. The yield strength does not change with temp. in the range 352° – 552° C.; the effect of increasing strain rate on this property is greatest in the range 27° – 127° C. Ageing at 200° C. of specimens prestrained $\sim 5\%$ produced a Y.P. and a strengthening in the room-temp. stress/strain curve. Ageing at higher temp. caused the disappearance of the Y.P. and softening resulting from a recovery effect. Lüders lines were observed in an extended coarse-grained sheet specimen; these bands consist of fine parallel lines shown by X-ray analysis to be traces of $\{10\bar{1}0\}$ planes. 16 ref.—R. W. R.

***Stress-Rupture Characteristics of Unalloyed Titanium Plotted.** F. B. Cuff, Jr., and N. J. Grant (*Iron Age*, 1952, 170, (21), 134–139).—The creep-rupture behaviour of annealed Ti in air is complex. The effects, on bars of small cross-section, of surface treatment and test atmosphere are important, partly owing to the ease with which Ti combines with O and N. Surface reactions tend to improve the rupture life of Ti at temp. $>900^{\circ}$ – 1000° F. (480° – 540° C.). There is a marked loss of strength as the metal passes through the equicohesive temp. For 75A Ti this temp. varies from 720° F. (380° C.) for a 100-hr. rupture life to 1020° F. (550° C.) for 0.1 hr. Ti undergoes strain-ageing in hot tensile tests at $\sim 200^{\circ}$ – 400° F. (95° – 205° C.).—J. H. W.

[Discussion on a Paper by O. J. C. Runnals and L. M. Pidgeon:] Observations on the Preparation of Iodide Titanium. — (*J. Metals*, 1952, 4, (11), 1180–1181).—See *M.A.*, 20, 326.

[Discussion on a Paper by W. C. Ellis and E. S. Greiner:] Effect of Prior Strain at Low Temperatures on the Properties of Some Close-Packed Metals at Room Temperature. — (*J. Metals*, 1952, 4, (11), 1208–1209).—See *M.A.*, 20, 73.

***Local Deformations in Simple Tension and Their Role in Formation of Necking.** P. Bastien, A. Popoff, and P. Azou (*Rev. Mét.*, 1952, 49, (11), 783–790; discussion, 790).—When a cylindrical specimen is stretched, it first deforms plastically in accordance with its mech. history and the nature of the stress. After further stretching, deformation appears at particular points, since the origin of the displacements of dislocations is localized in disturbed regions, as evidenced by the Lüders lines in steel. Then follows elongation distributed much more homogeneously and characterized by the appearance of necking. The relation of these localized deformations to homogeneous cold working was investigated experimentally, and the results for various metals are described in detail. Necking in all the cases observed appeared before the appn. of the max. stress imposed during the experiments; but this stress does not necessarily mark the cessation of non-localized deformations, which seem to be governed rather by the characteristics of the normal theoretical tensile curves.—J. H. W.

***Electrostatic Contribution to the Elastic Constants of Solids with a Diamond Structure.** E. P. Wohlfarth (*Phil. Mag.*, 1952, [vii], 43, (339), 474–476).—A letter. In an attempt to interpret the recently measured elastic const. of Si and Ge, calculations have been made of the electrostatic interaction of charges in this structure. Neither these interactions, the Brillouin-zone structure, nor non-Coulomb interaction between the ions can explain the stability of the lattice, which, it is concluded, must arise from directed valency bonds.—P. C. L. P.

***Temperature Dependence of the Hardness of Pure Metals.** J. H. Westbrook (*Amer. Soc. Metals Preprint*, 1952, (17), 23 pp.).—W. reviews published information on the variation with temp. of the hardness of pure metals and makes a number of generalizations. The temp. dependence of the hardness, H , is well represented by the relation $H = A \exp(-BT)$, where A and B are const. At low temp., where slip is the primary deformation mechanism, A and B have one set of values; at high temp., where viscous flow or other mechanism predominates, the const. have another set of values. The transition between low- and high-temp. behaviour of the indentation hardness occurs at $\sim 0.55T_M$, where T_M is the m.p. in $^{\circ}$ K. In the low-temp. range, A is simply related to the crystal structure and the thermal energy of melting, here defined as the heat content of liq. metal at the m.p.; for a given thermal energy of melting, A increases with decreasing lattice symmetry. In this temp. range B is related in a complex manner to the rate of change of heat content with temp. The relations given enable the hardness of a pure metal to be calculated approx. as a function of temp. up to about half the absolute m.p., provided the crystal structure, sp. heat, and heats of fusion and transformation are known. 50 ref.—R. W. R.

***A Note on Estimating Yield-Point Loads in a Plastic-Rigid Body.** R. Hill (*Phil. Mag.*, 1952, [vii], 43, (338), 353–355).—Calculations are made of the limits of error introduced when a math. convenient approx. yield function and plastic potential are used to determine Y.P. loads. Illustrations regarding the deformation of Cu and of Al show that the max. error is comparatively small.

—P. C. L. P.

***The Nature of Work-Hardening.** J. S. Kochler (*Phys. Rev.*, 1952, [ii], 86, (1), 52–59).—To explain the initial stages in the work-hardening of metal crystals, the present theory adopts the suggestion that sources of easy glide of the Frank-Read type (*ibid.*, 1950, [ii], 79, 722; *M.A.*, 18, 465) can produce only a finite number of dislocation loops. A reasonable assumption about the distribution of F.-R. sources and the way in which they will be used up, to give "source-hardening", leads to agreement of the predicted low-temp. low-strain stress/strain curve with experiment. At higher temp. the effects of thermal fluctuations are introduced into the theory, and also the observation of Brown (*Met. Appn. of the Electron Microscope (Inst. Metals Monograph No. 8)*, 1950, p. 110; *M.A.*, 17, 812) that sources produce more glide before exhaustion at high temp. than at low temp. The theory correctly predicts the importance of the past history of the specimen to its glide properties. Under higher stresses it is postulated that both source-hardening and hardening by the interaction of crossed dislocations with one another occur. Suggestions are put forward about important experimental work needed. Speculations are made about the reason for sources giving more glide at high temp. and how the interlocking of F.-R. sources can occur. 32 ref.—P. C. L. P.

***Concerning the Law of Static Friction.** S. B. Ratner (*Doklady Akad. Nauk S.S.S.R.*, 1952, 83, (3), 443–446).—[In Russian]. R. suggests that the coeff. of static friction is not const., but varies with the load N thus: $\mu = a + b/N$, where a and b are const. Results obtained for two types of rubber on steel S-25 and on Al alloy AMG-7, at 20° and 80° C., are given in support.—G. V. E. T.

***On the Influence of Surface Films on the Friction of Solids.** F. P. Bowden (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (4), 116–127).—[In German]. Friction between out-gassed metal surfaces was measured *in vacuo*. Most metals welded completely as they touched; with Fe at room temp. a film was formed which lowered the coeff. of friction to ~ 3.5 , but at 300° C. the impurities were driven off and welding occurred. The force required to separate the metals was measured, and the actual area of contact was calculated from micrographs. The mech. strength of the contact welds corresponded to that of the solid metal. Small amounts of H have very little influence, whereas O, water vapour, caproic acid vapour, Cl, and H_2S prevent welding

and gradually lower the coeff. of friction. The friction of steel on Al, and of Zn, Cd, pure Fe, and Mg was studied in air with loads from 10 kg. to several mg.; the electron microscope revealed that plastic deformation, welding, and shearing of the metal had occurred even with the smallest loads. In the case of Cu the oxide prevents welding with small loads and lowers the coeff. of friction, probably because its hardness is similar to that of the metal so that both deform simultaneously. Boundary lubrication cannot suppress local welding completely; the amount of metal transferred from one surface to the other was determined on Cu by electrographic and radioactive methods and found to be of the order of 10^{-10} g./mm.². The influence of temp. on the friction, electron-diffraction work, and experiments with radioactive metals show that phys. adsorption is not sufficient for the most effective boundary lubrication; the formation of a metal soap at the surface is essential, and this reaction appears to be favoured by the presence of an oxide film. The transfer of metals was also studied in the absence of a lubricant, with an oxide film only; between similar surfaces $20-40 \times 10^{-6}$ g./mm.² was transferred, irrespective of the hardness of the metal; with dissimilar metals only 1×10^{-6} g./mm.² was transferred, the particles transferred being appreciably smaller. There is no direct relation between friction and metal transfer, but they always vary in the same sense. The friction of plastics is discussed, and the development of composite materials consisting of sintered Cu and a low-friction plastic or MoS₂ is referred to.—K. S.

***Metal Transfer and Wear.** I.-Ming Feng (*J. Appl. Physics*, 1952, 23, (9), 1011-1019).—A new theory of metallic friction is put forward. At the high points where contact is made, the local stress often suffices to cause intense plastic distortion, leading to exact mech. interlocking. The immediate surroundings are work-hardened, and the high points then separate again not at the original, keyed, interface, but nearby, beyond the hardened zone. At the instant of fracture here, a heat wave is generated, which may suffice to weld the original interface. The essential assumption of this theory—the mech. keying—has been confirmed by sectioning through a pair of brass cylinders held in contact under a known force in a clamp, and taking opt. and electron micrographs. (No sliding of the cylinders took place.) Examination of the slip and annealing-twin markings on the surfaces which had been in contact showed, because of crystallographic inconsistencies, that markings from one surface had been impressed on the other.—R. W. C.

†**The Nature, Origin, and Effects of Residual Stresses.** R. G. Treuting (*Residual Stress Measurements (Amer. Soc. Metals)*, 1952, 1-41).—Residual stresses are stresses produced by, and remaining after, some operation in the metal's history. After a brief discussion of the principles of elasticity, T. reviews the effects of residual stresses on metallic properties, viz. alteration of elect. conductivity, magnetic permeability and magnetostriction, chem. potential and reactivity, phase transformations, pptn., plastic deformation, work-hardening, fatigue, creep, elastic and plastic after-effects, recovery and recrystallization, internal friction and elastic properties, mech. strength and fabrication qualities, and dimensional stability. All these effects are fundamentally attributable to structural changes. Residual stresses are the result of inhomogeneous changes in the metal. In almost all cases of stress-corrosion cracking, failure is intergranular. Transgranular cracking can be produced, in almost any material, with almost any corrosive agent, under the fatigue condition of cyclic loading. 50 ref.—J. S. G. T.

†**Residual Stress States Produced in Metals by Various Processes.** H. B. Wishart (*Residual Stress Measurements (Amer. Soc. Metals)*, 1952, 97-128).—The magnitude and distribution of stresses produced by heat-treating, mech. working, carburizing, and nitriding steel are briefly discussed and illustrated. Changes of compn. and size can materially alter the stress distribution. 17 ref.—J. S. G. T.

†**Relief and Redistribution of Residual Stresses in Metals.** D. G. Richards (*Residual Stress Measurements (Amer. Soc. Metals)*, 1952, 129-204).—The following matters are discussed :

(1) methods used for studying redistribution of residual stresses; (2) redistribution due to thermal action; (3) stress-relief annealing; (4) re-heat-treatment; (5) diffusion; (6) redistribution due to mech. action; (7) machining, grinding, polishing; (8) surface treatments; (9) peening; (10) static stressing, e.g. stretching, bending, straightening; (11) thermal, impact, and cyclic stressing; and (12) redistribution due to chem. action. Many of the processes described refer to workshop practice, in which residual stresses are redistributed during various phases of the fabrication process and during service. The basic causes of stress redistribution are: (a) inhomogeneous plastic deformation due to creep action, heating or cooling, or external forces; (b) inhomogeneous vol. changes associated with chem. or structural non-uniformity, and (c) removal of stressed metal. It is emphasized that redistribution of macro-residual stresses is usually accompanied by changes in the material which may have more effect on the subsequent behaviour of the part than the final residual stresses. 156 ref.—J. S. G. T.

***Vibration Frequencies in Diatomic Molecules and in Solid Metals.** E. C. Baughan (*Trans. Faraday Soc.*, 1952, 48, (2), 121-128).—An empirical expression is derived for the Debye temp., θ_D , of solid metals in the form $\theta_D = 4385 Z^{1/2} A^{-1/2} d_M^{-1/2}$, where Z is the number of outer electrons in the atom of at. wt. A , and d_M the distance of an atom's nearest neighbours in the metal lattice. The expression is derived from that due to Guggenheimer (*Proc. Phys. Soc.*, 1946, 58, 456). Satisfactory agreement is found between calculated and observed values of θ_D for the 22 metals of A sub-groups, the mean value of $\theta_{calc.}/\theta_{obs.}$ for 10 metals, for which an unbracketed value of θ_D can be given, being 0.98. Fairly satisfactory agreement between calculated and observed values of θ_D are obtained for 10 transition metals of group 8, on the assumption that $Z = 6$. Agreement is also satisfactory for the 2-5B groups of metals (comprising 13 metals), except for Ga and Tl. A valency of 3 seems to be the best integer value of Z for Cu and Ag, with a possible increase in the case of Au. 18 ref.—J. S. G. T.

***Contribution to the Study of the Diffusion of Ions Across Metallic Deposits.** Maurice Bonnemay, Helmy Makram, and Jean Royon (*Compt. rend.*, 1952, 235, (17), 955-957).—Metallic deposits are all porous, and the porosity was studied by two different methods: (1) by an electrochem. method, following the course of the potential of a metal electrode covered by the deposit to be studied and immersed in a soln. of a salt of the same metal, and (2) by the use of radioactive tracers. No activity appears for a time, T (*temps du passage*), varying with the properties of the deposit. The activity then rises as the time increases and tends to be proportional to T . $\log T \propto$ thickness of the deposit.—J. H. W.

***A Calculation of the Cohesive Energies and Pressure/Volume Relations of the Divalent Metals [Mg, Ca, Sr, Ba, Zn, Cd, and Be].** S. Raimes (*Phil. Mag.*, 1952, [vii], 43, (338), 327-337).—The method developed by Fröhlich (*Proc. Roy. Soc.*, 1937, [A], 158, 97; *M.A.*, 4, 78) to calculate the energy of the lowest state of the alkali metals without using a Hartree-type field or constructing a semi-empirical field is extended to the divalent metals. The choice of assumptions resulted from experience in prior calculations for Mg by the cellular method; a major one is shown to be true for the divalent metals except Hg. The valence-electron energy terms are evaluated for free electrons except for Be, where the Fermi energy interpolated from the calculations of Herring and Hill (*Phys. Rev.*, 1940, [ii], 58, 132; *M.A.*, 7, 429) is also used. The computed interatomic spacings, compressibilities, and total valence-electron energies are in reasonable agreement with the observed values, taking H. and H.'s results for the Fermi energy of Be, though, as expected, the theoretical and observed cohesive energies sometimes differ considerably. The change in vol. with pressure is calculated for pressures up to 100,000 kg./cm.² and found to be in general agreement with experiment. The approach could readily be extended to metals of higher valency.—P. C. L. P.

***The Absorption of Light by Noble Metals and Its Relation to the van der Waals Contribution to the Cohesive Energy.** J. Friedel (*Proc. Phys. Soc.*, 1952, [B], 65, (10), 769-774).—

The colour of Cu and Au is due to strong absorption in the blue or ultra-violet. It has been suggested that this absorption is caused by an internal photoelect. effect, with the transition of an electron from the $3d$ shell to the conduction band. The hole created is then screened by a $4s$ electron bound to it, and so absorption should begin for the frequency corresponding to this excited state. Experimental work is in agreement with this. In addn., it is suggested that this model should alter the interaction between the d shells and hence the van der Waals cohesive energy term; an estimate of the magnitude of this is given.—E. O. H.

*The Optical Constants of Thin Metallic Films Deposited by Evaporation. P. L. Clegg (*Proc. Phys. Soc.*, 1952, [B], 65, (10), 774-781).—A photoelect. method is described for measuring opt. const. After discussing the influence of the substrate, curves are given for Ag, Au, In, and Sn at different rates of deposition. Agreement with theory is satisfactory.—E. O. H.

*The Influence of Elastic Shear Strains on the Conductivity and Thermoelectric Force of Cubic Metals. J. Smit (*Physica*, 1952, 18, (8/9), 587-596).—[In English]. It is shown that, under the influence of stress, the shape of the Fermi surface will be altered. This alters the energy gap at the boundary of the surface, with a consequent change in conductivity. S. considers this change theoretically, and shows how certain features of the size and shape of the Fermi surface may be deduced from other published data. The change in thermoelect. force is likewise related to the conductivity problem, and is also discussed.—E. O. H.

*Homogenous Thermoelectric Effect in Fine-Crystalline Metal Wires. Isolde Dietrich (*Z. Physik*, 1951, 129, (4), 440-448).—The possible existence of a thermoelect. p.d. in a fine-grained metal wire between two points at the same temp., but with an asymmetric temp. distribution between them, is considered. It is concluded that any such potential (Benedicks effect) must be very small ($< \sim 10^{-9}$ V.). Experiments on pure Au and Pt wires showed that any effect, if it existed, was $< 10^{-8}$ and $< 3 \times 10^{-8}$ V., resp.—J. W. C.

*Electrodynamical Potential in the Extended Phenomenological Theory of Superconductivity. Friedrich Beck (*Z. Physik*, 1951, 129, (3), 233-245).—Math. A development of von Laue's generalized non-linear theory of superconductivity (*Ann. Physik*, 1949, [vi], 5, 197; *M.A.*, 19, 269). The expressions for the force d and the angular momentum are derived.—J. W. C.

Results of the Extended Phenomenological Theory of Superconductivity. Johannes Geiss (*Z. Physik*, 1951, 129, (5), 449-482).—Math. The c.d., J , in the Londons' phenomenological theory is replaced by a vector G , which is a function of J . The current and field distribution for a semi-infinite solid, a plate, and a wire are derived on the assumption that G and J have the same direction, and for a wire when there is a linear tensor relation between G and J .—J. W. C.

*The Quantum Theory of Superconductivity.—[I.]. R. Schachenmeier (*Z. Physik*, 1951, 129, (1), 1-26).—Math. Only degenerate wave-packets may be used to explain superconductivity. In elements of the second group of the Periodic Table, these wave-packets are near the Fermi surface. S. concludes that only metals with 2 valency electrons can become superconducting.—J. W. C.

*Bardeen's Theory of Superconductivity and the f -Sum Rule. E. N. Adams, II (*Phys. Rev.*, 1952, [ii], 86, (2), 258-259).—A letter. A. raises an objection to Bardeen's theory of superconductivity in its present form (*ibid.*, 1950, [ii], 80, 567; 1951, 81, 829; *M.A.*, 18, 757; 19, 174) on the grounds that the magnetic field will not be expelled from the metal, because the Landau-Peierls susceptibility is paramagnetic and not diamagnetic as taken by B.

—P. C. L. P.

*Magnetic Hysteresis in Superconducting Colloids. A. B. Pippard (*Phil. Mag.*, 1952, [vii], 43, (338), 273-284).—The isothermal transition between the normal and the superconducting states caused by a change in the magnetic field,

shows considerable magnetic hysteresis. A simple theoretical treatment is given of the phenomena, termed "superheating" and "supercooling", for colloidal dispersions of a superconducting substance, which shows qual. agreement with the experimental work of Shoenberg (*Proc. Roy. Soc.*, 1940, [A], 175, 49; *M.A.*, 7, 275) on colloidal dispersions of Hg. Quant. discrepancies are found which may be due to an overestn. of the effective Hg content of the colloids. Experimental conditions to give a more critical test of the theory are suggested.—P. C. L. P.

*Secondary Electron Emission of Some Metals Under the Impact of Positive Lithium Ions. Georges Couchet (*Compt. rend.*, 1952, 235, (17), 944-946).—C. describes the experimental set-up for measuring the coeff. of secondary electron emission, γ , under the impact of positive Li ions and gives the variation of γ for Duralumin, stainless steel, and Mumetal. It is an increasing function of the ionic energy and reaches a critical value for energies of some thousands of eV. according to the metal target.—J. H. W.

*The Distribution of Electrons Round Impurities in Monovalent Metals. J. Friedel (*Phil. Mag.*, 1952, [vii], 43, (337), 153-189).—A theoretical study has been made of the method by which the positive charge on the ions of substitutional elements of higher valency in the lattices of the monovalent metals is screened. Where the excess charge on the impurity atom is a multiple of $2e$ (e.g. Ga or As in Cu), all the screening must come from doubly occupied bound states below the level of the Fermi distribution. Where the excess charge is unity, the extent of screening by occupation of a bound state or by redistribution of the Fermi electrons is uncertain. Electrons in bound states have to be subtracted from the Brillouin zone, so there is no difficulty in explaining the Hume-Rothery rules, and possibilities arise of explaining certain anomalies. Discussion of the behaviour of H in soln. in Cu shows that screening of the proton by a bound electron gives a heat of soln. in agreement with experiment, though screening by Fermi electrons would not give a very different result. The heats of soln. of various elements in Cu and Ag, calculated on the assumption of bound states, show reasonable agreement with experiment in view of the neglect of several interaction terms. This agreement also applies to those cases where some Fermi electron screening is expected. The discussion is extended to the magnetic behaviour of Cu, Ag, and Au alloys, to the absorption and emission bands of the alkali metals, and to the opt. absorption of the noble metals. The existence of bound states accounts for certain features of the K emission bands of Al, Zn, and Be in Cu-rich alloys.

—P. C. L. P.

*A Mechanism of Spin-Lattice Relaxation in Ferromagnetic Substances. Tokutaro Hirone and Noboru Tsuya (*Sci. Rep. Research Inst. Tohoku Univ.*, 1952, [A], 4, (3), 261-267).—[In English]. The mechanism of line-broadening in a ferromagnetic resonance absorption spectrum is interpreted on the assumption that the wave number vectors of excited spin waves due to perturbation of the microwave field are distributed through a wide range of the reciprocal lattice space. Line width, τ , is shown to $\propto T^{3/2}$, where T denotes the abs. temp. As this result indicates that τ vanishes at $T = 0$, a result which is contrary to experimental results, it is suggested that there are other mechanisms of line-broadening, e.g. internal stresses, which are independent of T . Calculated values of line widths for Ni at 0° - 400° C. agree well with Bloembergen's data (*Phys. Rev.*, 1950, [ii], 78, 572; *M.A.*, 18, 341).—J. S. G. T.

*Energy of a Bloch Wall on the Band Picture. I.—Spiral Approach. Conyers Herring (*Phys. Rev.*, 1952, [ii], 85, (6), 1003-1011).—Using the collective electron model of ferromagnetism, calculations are made of the energy of the transition region which separates ferromagnetic domains having different directions of magnetization. The electron spin is allowed to precess as it moves through the transition region, so as to keep it in approx. alignment with the magnetization vector. On the assumption that all the spin functions are the same, and by neglecting electron correlation, the calculated Bloch wall coeff. of Ni and Fe is only 3-4

times the observed value. The agreement is satisfactory since the only empirical magnetic const. introduced is the saturation magnetization.—P. C. L. P.

*Solution of the Thomas-Fermi-Dirac Equation. P. Gombás and R. Gáspár (*Acta Phys. Acad. Sci. Hungar.*, 1951, 1, (1), 66-74).—[In German]. The soln. of the fundamental equation of the Thomas-Fermi-Dirac statistical theory of the atom, viz. $\psi'' = x[(\psi/x)^{1/2} + \beta]^3$, where ψ'' is

the second derivative of ψ with respect to x , subject to boundary conditions due to Jonsen (*Z. Physik*, 1934, 89, 713), which attributes a min. value to the energy of the atom as a whole is effected by a perturbation method. The soln. is applicable to neutral free atoms and ions, as well as spherically-symmetrical close-packed atoms. Values of the various parameters entering into the theory are calculated and tabulated for the inert gases and Rn.—J. S. G. T.

2 — PROPERTIES OF ALLOYS

*The Properties of Some Binary Aluminium Alloys at Elevated Temperatures. J. V. Lyons and W. I. Pumphrey (*Metallurgia*, 1952, 46, (277), 219-226).—The high-temp. tensile properties of the binary alloys of Al with Cu, Fe, Mn, and Zn have been determined to obtain knowledge of factors which affect mech. properties at temp. above and below the solidus and which therefore affect their welding and casting properties. An examination has also been made of the effect of the degree of approach to structural equilibrium on the high-temp. properties of certain of the alloys tested.

—F. M. L.

*Determination of the Tensile Strength of [Aluminium and] Aluminium Alloys from Their Hardness. Hermann Meincke (*Z. Metallkunde*, 1951, 42, (6), 175-181).—An attempt has been made to correlate the hardness with the P.S., and the U.T.S. of Al (99.99 and 99%) and commercial Al-Mg-Cu, Al-Mg-Si, Al-Mn, Al-Mg, and Al-Mg-Mn alloys (Bondur, Pantal, Mangal, B.S.S., and K.S.S., resp.). The alloys were processed by rolling, drawing, or extrusion, and were tested in the work-hardened, annealed, soln.-treated, or aged condition; the mech. tests were carried out both \parallel and \perp the direction of working; both spherical and almost unidirectional indenters were used in the hardness detn. The results show that: (1) hardness values increase slightly with increase of indenter load (P) up to 50 kg., and thereafter remain practically const. for soft materials, and decrease somewhat in the case of cold-worked material, (2) the most consistent Brinell results are obtained when $P \cong 5D^2$, where D is the dia. of the indentation obtained with 2.5 or 5 mm. dia. balls, (3) with the exception of cold-worked 99% Al, the hardness of 99.99 and 99% Al does not vary in different directions, (4) the hardness of wrought alloys is greater when measured \parallel than \perp the direction of working, the difference (up to $\sim 10\%$ with ball indenters, and $\sim 15\%$ with knife-edge indenters) being dependent on the degree of cold work, the thickness of the material, and the depth of indentation, (5) age-hardened Al-Cu-Mg and Al-Mg alloys—with or without subsequent cold work—have hardness values which are greater \perp than \parallel the direction of original deformation, (6) the U.T.S. of the various materials have directional properties corresponding to those associated with hardness, (7) the U.T.S. (σ_z) and the hardness (H) are related by the equation: $\sigma_z = cH$, where c has the value 0.364 for max. deviations in σ_z of $\pm 7.2\%$, and (8) there appears to be no relationship between the P.S. and the hardness. 6 ref.—E. N.

Properties and Technology of the Ergal [Aluminium-Zinc-Magnesium-Copper] Alloys. — (*Alumina*, 1952, 21, (4), 403-426).—A report from the Istituto Sperimentale dei Metalli Leggeri. The Ergal series of Al-Zn-Mg-Cu alloys consists of Ergal 55 (Zn 5.8, Mg 2.5, Cu 1.6, Mn 0.2, Cr 0.15, Ti 0.08%, balance Al); Ergal 60 (Zn 6.8, Mg 2.5, Cu 1.6, Mn 0.2, Cr 0.15, Ti 0.1%, balance Al); and Ergal 65 (Zn 7.8, Mg 2.5, Cu 1.6, Mn 0.2, Cr 0.15, Ti 0.1%, balance Al). Ergalplat alloys have a cladding of Al contg. Zn 1% and Mn 1%. Phys., mech., and chem., properties are given, as well as working, machining, and welding characteristics, heat-treatment, and methods of surface treatment. 7 ref.—I. S. M.

*Mechanical Properties of Integrally Stiffened Aluminium [Alloy] Extrusions. Roberto Contini (*Product Eng.*, 1951, 22, (12), 129-133).—Results of tests on integrally stiffened 24S and 75S extrusions are given.—M. A. H.

*Age-Hardening of Aluminium-Silver Alloys. Ryoji Watanabe and Shigeyasu Koda (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 203-213).—[In Japanese, with diagrams in English]. Al alloys contg. 9.63, 24.59, and 19.83% Ag have been examined, and the results obtained show that: (1) alloys contg. 9.63 and 24.59% Ag age-harden at room-temp; (2) from time/hardness curves of 24.59% Ag alloy at 30°, 50°, 70°, and 90° C. it was found that (a) $p/(1-p) \propto t^n$, where p = degree of hardening, t = ageing time, and $n = 1$ at 50°, 70°, and 90° C., and (b) the activation energy at these temp. was $Q = 8200$ cal./mole; (3) double ageing was observed clearly between 140° and 200° C. with the 19.83% Ag alloy; (4) between 140° and 350° C. the 19.83% Ag alloy shows a linear relationship between $\log t$ and $1/T$ where T = abs. ageing temp.; $Q = 22,000$ cal./mole; (5) 9.63% and 24.59% Ag alloys showed distinct reversion (*Rückbildung*) phenomena. The ageing results after various heat-treatments are well illustrated by 20 graphs.—AUTHORS.

*Improved Aluminium-Tin [and Aluminium-Tin-Copper] Alloys as Possible Bearing Materials. H. K. Hardy, E. A. G. Liddiard, J. Y. Higgs, and J. W. Cuthbertson (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 457-482).—See *M.A.*, 19, 706.

*Thermodynamic Properties of the Liquid Ternary System Bismuth-Cadmium-Tin. Svante Mellgren (*J. Amer. Chem. Soc.*, 1952, 74, (20), 5037-5040).—Activity studies on Bi-Sn, Bi-Cd, and Cd-Sn binary systems are reviewed, and c.m.f. detn. of Cd activity in liq. Bi-Cd-Sn alloys are presented. Integral and partial molar excess free energies for all the components are tabulated.—J. R.

*The Constitution of Chromium-Manganese Alloys Below 1000° C. W. B. Pearson and W. Hume-Rothery (*J. Inst. Metals*, 1952-53, 81, (6), 311-314).—The constitution of Cr-Mn alloys between 1000° and 525° C. has been studied by microscopical and X-ray methods. The σ phase undergoes a transformation at 980°-1005° C. (according to compn.), and high-temp. X-ray photographs show that both the high-temp., σ' , and low-temp., σ , modifications have characteristic " σ " structures resembling that of the σ -Fe-Cr phase. The phase appears to be stable down to 523° C., and no signs of a eutectoid decompn. could be found. The solid solubility of Mn in Cr diminishes markedly below 1000° C., the temp. of the $\sigma \rightleftharpoons \sigma'$ transformation. In the range 1000°-800° C. normal two-phase (α -Cr + σ) alloys are formed when the solubility limit is exceeded. Between 800° and 600° C., three-phase alloys are found consisting of α -Cr, σ , and small amounts of a phase denoted α' -Mn, whose crystal structure appears to be similar to that of α -Mn; the amount of this last phase diminishes gradually on prolonged annealing, and the stable equilibrium almost certainly involves two-phase (α -Cr + σ) alloys. Below 600° C., the solubility of Mn in Cr diminishes even more markedly, and three-phase (α -Cr + α' -Mn + small amounts σ) alloys are formed. With annealing periods of the order of 1-2 months at 600°-500° C., equilibrium conditions are not obtained, but it is thought that the α' -Mn phase has a compn. in the region of Mn₂Cr. The lattice spacings of the solid soln. of Mn in α -Cr have been determined.—AUTHORS.

*Transitions in the Chromium-Manganese and Nickel-Vanadium Sigma Phases. W. B. Pearson (*Nature*, 1952, 169, (4309), 934).—Transitions occur in the Cr-Mn σ phase at 1005° C. and in the Ni-V σ phase (*ibid.*, (4289), 70; *M.A.*, 20,

256) at $<800^{\circ}\text{C}$. High-temp. photographs of these systems show that the same main X-ray reflections occur as at room temp., and quenched alloys do not show decomposed microstructures. The transitions may be of the order-disorder type.—R. S. B.

***The Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron, and Chromium.** Hakaru Masumoto and Hideo Saitō (*Sci. Rep. Research Inst. Tôhoku Univ.*, 1952, [A], 4, (3), 246-254).—[In English]. Values of the modulus of rigidity (G) and of its temp. coeff. (g) for Co-Fe-Cr alloys contg. 50-90% Co and $<20\%$ Cr have been measured at 20° - 50°C . Values of g for most of the alloys are negative. As the compn. approaches that of stainless Invar (Co 54, Fe 36.5, and Cr 9.5%), g decreases, at first slowly and then rapidly, becoming zero, then changing sign and attaining its max. positive value of $+35.9 \times 10^{-5}$ at a compn. corresponding to that of stainless Invar. Alloys in this system of alloys having a zero temp. coeff. of rigidity modulus have been called Co-Elinvar. These results resemble those already obtained for the temp. coeff. of Young's modulus (Y) of the alloys (*ibid.*, 1949, [A], 1, 17; *M.A.*, 18, 165), except that in the case of g the compn. range characterized by positive values of g and the position of the positive max. occur at concentrations of higher Co and lower Cr than in the case of Y . The value of G at 20°C . shows a max. value of $9.34 \times 10^3 \text{ kg./cm.}^2$ for the alloy contg. 50% Co and 5% Cr, and a min. value of $5.92 \times 10^3 \text{ kg./cm.}^2$ for the alloy contg. 65% Co and 8% Cr.

—J. S. G. T.

***The Thermal Expansion, Rigidity Modulus, and Its Temperature Coefficient of Alloys of Cobalt, Iron, and Vanadium and a New Alloy "Velinvar".** Hakaru Masumoto, Hideo Saitō, and Takeo Kobayashi (*Sci. Rep. Research Inst. Tôhoku Univ.*, 1952, [A], 4, (3), 255-260).—[In English]. The thermal coeff. of linear expansion (α), the rigidity modulus (G), and its temp. coeff. (g) of Co-Fe-V alloys contg. 50-80% Co and $<13\%$ V have been measured at 10° - 50°C . The least value of α is 3.94×10^{-6} for the alloy contg. 56% Co and 9% V. In the temp. range 20° - 50°C ., the values of g are, at first, negative, and as the compn. approaches that at which α is least, g decreases at first slowly then rapidly, becoming zero, and then changing sign. The alloy having the least value of α has the max. positive value of g , viz. $+31.5 \times 10^{-5}$. G has a max. value $8.46 \times 10^3 \text{ kg./cm.}^2$ corresponding to the compn. 55% Co and 13% V, and a min. value, $5.40 \times 10^3 \text{ kg./cm.}^2$ corresponding to the compn. 63% Co, 7% V. The alloys contg. $\sim 60\%$ Co and having a comparatively small value of g at 20° - 50°C ., viz. -6.7 to $+0.5 \times 10^{-5}$, have been called "Velinvar", i.e. Elinvars contg. V.—J. S. G. T.

***Study on the Materials [Stellite and 65% Ni-Cu-Cr-Si-Fe Alloys] for Valve Seatings at High Temperatures and Pressures.** —Y. Mitsuru Okano and Hideji Hotta (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 225-228).—[In Japanese, with table and graphs in English]. Results are reported and compared of wear-resistance, thermal expansion coeff., high-temp. hardness, and corrosion tests on Stellite and 65% Ni-Cu-Cr-Si-Fe alloys. Experiments and graphs show that the former is superior to the latter for valve seatings.

—AUTHORS.

New Copper Alloy Has High Stress-Corrosion Resistance. C. H. Hannon (*Iron Age*, 1952, 170, (21), 131-132).—The addn. of 0.3-1% Fe to Cu contg. Ni 3.5-5, Si 0.7-2% improves the properties of sand-cast and hot-worked parts. The best mech. properties are developed by successive soln. and ageing heat-treatment.—J. H. W.

***The Influence of Cold Work and Heat-Treatment on the Engineering Properties of Beryllium Copper Wire.** J. T. Richards, R. K. Levan, and E. M. Smith (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 771-791).—Elect. conductivity and tension tests were performed on Cu-Be alloy wire to determine the influence of cold work, soln. treating, and pptn. Grain-size, preferred orientation, straightening, overstraining in tension, and stress-relieving had a marked effect on U.T.S., Y.P., ductility, and tension modulus. Soln. treating increased the elongation, but lowered the tensile properties. Low soln.-treating temp. gave smaller grain-sizes, higher tensile properties, and decreased elongation. On cold drawing

tensile properties increased almost linearly up to $\sim 90\%$ reduction of area and then fell off with further reductions. Elect. conductivity, tension modulus, and elongation decreased with cold work. Pptn.-hardening increased the tensile properties, conductivity, and tension modulus, but decreased elongation. Tensile properties decreased on overaging, and hardening times were reduced by raising the heat-treatment temp. Preferred orientation resulting from excessive cold reductions gave higher tensile properties and tension modulus, with decreased elongation and conductivity. Machine straightening increased the tensile properties in soln.-treated material, but decreased them in wire drawn over $\sim 20\%$. The opposite was true for elongation; the tension modulus was increased slightly in all tempers. Similar trends were observed for material pptn.-hardened after straightening. Overstrain improved the tensile properties with some reduction in elongation and modulus. Tensile overstrain and cold drawing produced similar results. Stress-relieving heat-treatable or pptn.-hardened wires gave a higher Y.P., proportional limit, elongation, and modulus, but the effect on the tensile strength varied. As the elastic portion of the stress/strain relationship for Cu-Be alloy is curved throughout, an average tension modulus is believed to be of greater practical value than the initial modulus. Typical properties for Cu-Be alloy are listed. 35 ref.

—P. T. G.

***On Heat-Treatable Copper-[Low] Chromium Alloys.** Shigeyasu Koda and Eiji Isono (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 213-217).—[In Japanese, with tables and diagrams in English]. A series of tests are reported of the working, age-hardening, elect. conductivity, and mech. properties of low-Cr alloys of the Cu-Cr system. K. and I. prepared by a sintering process a 90:10 Cr-Cu alloy and added this master alloy to Cu melts to form alloys contg. $\sim 0.5\%$ Cr. Tests indicate that: (1) low-Cr alloys can be easily hot or cold worked; (2) the hardness on tempering the cast alloys at 300° - 700°C . for 1 hr. after soln. treatment by quenching from 950°C ., shows a max. at 500°C .; a temp. above 1000°C . is necessary for complete soln. and hence the greatest max. hardness of ~ 60 Rockwell; and (3) elect. conductivity and mech. properties of 0.49% Cr wire (2 mm. dia.) are:

Treatment	Conductivity, %	U.T.S., kg./mm. ²	Elongation, %
Quenched and Tempered at 500°C . for 1 hr.	91	39	18
Quenched, Cold-Drawn (97.6% Reduction), and Tempered at 500°C . for 1 hr.	90	40	9
Quenched, Cold-Drawn (81% Reduction), Tempered at 500°C . for 1 hr., and then Cold-Drawn (88% Reduction)	86	62	2

It is concluded from the results that the low-Cr Cu alloys have very good conductivity, but their strength is inferior to that of Cu-Cd or Corson (Cu-Ni-Si) alloys. K. and I. suggest that by modification of the prodn. process improvements in tensile properties may be made.—AUTHORS.

[Discussion on a Paper by E. W. Palmer and F. H. Wilson:] **Constitution and Properties of Some Iron-Bearing Cupro-Nickels.** — (*J. Metals*, 1952, 4, (11), 1216-1217).—See *M.A.*, 19, 583.

***Some Factors Affecting the Wear of Bronze.** S. G. Daniel and R. Graham (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 613-631).—The wear of 10% Sn bronze rods revolving at 2000 r.p.m. under a loaded and lubricated steel half bearing was assessed by wt. loss. The influence of the load, of the surface finish of the rod and bearing, and of grain-size was studied. The results show that wear takes place irregularly, but increases with load, surface roughness,

and grain-size, the influence of the latter factor being more marked at high loads and long times. 4 ref.—D. M. P.

[Discussion on a Paper by R. M. Evans and R. I. Jaffee:] Low-Melting Gallium Alloys. — (*J. Metals*, 1952, 4, (11), 1184).—See *M.A.*, 19, 766.

*Constitution of Germanium-Rich Germanium-Gallium Alloys. E. S. Greiner (*J. Metals*, 1952, 4, (10), 1044).—An A.I.M.M.E. Research in Progress summary. The liquidus of the Ge-Ga system decreases linearly from 936° to 860° C. between 0 and 20.4% Ga. Ga has a limited solid solubility in Ge—2 and 2.5% at 600° and 780° C., resp. The lattice const. of Ge is 5.6575 ± 0.0001 Å. at 25° C., and it increases by 0.0004 Å. for each 1% Ga addn. All compn. are in at.-%. —E. N.

[Discussion on a Paper by A. N. Holden:] Dislocation Collision and the Yield Point of Iron [Containing Carbon]. — (*J. Metals*, 1952, 4, (11), 1207-1208).—See *M.A.*, 19, 766.

*On the Wiedemann Effect of the Magnetostriction Alloy "Alfer" [Fe-12.91% Al]. Yūki Shirakawa, Tōru Ōhara, and Takeshi Abe (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (5), 239-242).—[In Japanese, with diagrams in English]. The apparatus used and the measurement of the Wiedemann effect in Alfer (Fe-12.91% Al) alloy are described. Longitudinal magnetic fields of strengths up to 820 Oe. and currents up to 8 amp. through the specimens, which were 3 mm. in dia. and 150 mm. in length, were used. The effect, i.e. the angle of twist, of Alfer increases with increasing longitudinal field and const. current, and after attaining a max., gradually decreases. With increasing current flowing through the specimen the max. value of the angle and the corresponding field both increase. In a weak field, the effect increases at first at a const. rate and reaches a saturation value with an increasing current. In strong fields the effect \propto the current. The effect in Alfer has approx. an equal numerical value to that of Ni, but is of opposite sign. Graphs are given showing the relations between angle and field, angle and current, and angle and intensity of magnetization for electrolytic Fe and Ni and Alfer.—AUTHORS.

A Comparison Between Fe-Cr-Al and Ni-Cr Alloys for High-Temperature Service. Gösta Hildebrand (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 632-636).—The properties and behaviour of the two alloys under various conditions as resistance materials are compared. The cost, life, and elect. and mech. properties of Fe-Cr-Al alloy are superior, but the corrosion- and heat-resisting properties are inferior to those of Ni-Cr.—D. M. P.

*Magnetic Measurements of Age-Hardening of Iron-Molybdenum Alloys. Tokushichi Mishima, Ryukiti R. Hasinguti, and Yasuo Kimura (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 656-667).—The ageing at various temp. of quenched Fe-Mo alloys contg. 15 and 20% Mo was studied by observing changes in hardness, lattice const., and magnetic properties. The changes can be expressed by the Austin-Rickett equation $p/(1-p) = Kt^n$, where t is the ageing time, K and n const., and p is the fractional change in (e.g.) hardness defined by $p = (H - H_0)/(H_s - H_0)$ where H is the hardness at time t , and H_0 and H_s are the initial and final hardness, resp. For the 20% alloy the values of K and n for coercive force and lattice const. changes were identical, but those for hardness changes were dissimilar. The relation between $\log K$ (the rate const.) and $1/T$ is linear, and the activation energy of the ageing process can be calculated as 75,600 cal./mole. For the 15% alloy the const. were identical for coercive force and saturation magnetization changes but dissimilar for changes in initial susceptibility. The activation energy in this case was 72,000 cal./mole. The changes are correlated with the atomic process of ageing. 17 ref.—D. M. P.

*Phase Changes Associated with Sigma Formation in 18:8:3:1 Chromium-Nickel-Molybdenum-Titanium Steel. K. W. J. Bowen and T. P. Hoar (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 695-703).—Changes in a Cr-Ni-Mo-Ti steel quenched from 1150° C. and consisting

of approx. equal parts of austenite and ferrite were followed metallographically and by magnetic and d measurements. On reheating to 850° C. σ is rapidly formed up to a max. amount of 15% by vol. within 13 min., accompanied by a marked d increase; the remaining ferrite transforms completely to austenite in ~50 hr. with a further slight increase in d . Quenched or air-cooled austenite formed at 750° or 800° C. partly transforms to ferrite at room temp.; that formed at 850° C. is stable at room temp. but partly transforms at -196° C. The observations are discussed. 13 ref. —D. M. P.

*Sigma Formation and Its Effect on the Impact Properties of Iron-Nickel-Chromium Alloys. A. M. Talbot and D. E. Furman (*Amer. Soc. Metals Preprint*, 1952, (2), 12 pp.).—Metallographic methods and hardness measurements were employed to fix the σ boundaries in Fe-rich alloys contg. Ni 20-35 and Cr 15-30%; the temp. range 650°-900° C. was investigated. Most of the work was carried out using cold-worked material exposed to the σ -forming conditions for 3000 hr. In this material the boundary was found to extend from 21% Cr at 20% Ni to 24% Cr at 35% Ni. In annealed or as-cast structures the boundary was shifted towards higher Cr contents. Increasing the Si content from <1 to ~37 moved the σ boundary to ~19% Cr with 25-~35% Ni. The boundary found in the work agrees with that of Nicholson, Samans, and Shortleeve (*Trans. Amer. Soc. Metals*, 1952, 44, 601; see *M.A.*, 19, 767) determined at lower alloy contents. The room-temp. impact properties fall rapidly with increase in the amount of σ -phase, regardless of the base compn.; 5% of σ -phase produces serious embrittlement. 4 ref.—R. W. R.

*The Magnetic Shunt Characteristics of Fe-Ni-Cr Alloys and M.S. Alloy. Hakaru Masumoto, Yūki Shirakawa, and Tōru Ōhara (*Sci. Rep. Research Inst. Tōhoku Univ.*, 1952, [A], 4, (3), 237-245).—[In English]. Owing to a decrease of the magnetic intensity of the pole pieces with rise of temp., the magnetic field between the pole pieces of a permanent magnet decreases with rise of temp. To counter this decrease, a magnetic shunt made of an alloy, the magnetic permeability (μ) of which decreases considerably with rise of temp. is placed in the pole gap. With a view to improving the characteristics of magnetic shunt alloys, the magnetic properties of Fe-Ni-Cr alloys contg. 30-60% Ni, 1-18% Cr, and having no allotropic transformations were measured at -50° to 100° C. The alloys hitherto used as magnetic shunts, viz. a Ni-Cu alloy of Monel type contg. 70-90% Ni and 30-10% Cu with some Fe or Mn, and an Fe-Ni alloy contg. ~29% with a little C, Cr, and Mn, are, resp., too expensive and not sufficiently easily reproducible. Fe-Ni-Cr alloys of the above compn. having a magnetic transformation point at ~100° C. possess excellent characteristics for use as magnetic shunts. μ in a field of intensity 400 Oe. at 0° C. is ~5-20, the temp. coeff. of μ is 0.003-0.040, and μ varies approx. linearly with temp. They have been named "M.S. Alloy".—J. S. G. T.

*A Study of Equilibrium Diagrams [of Pb-Cd, Bi-Cd, and Sn-Bi Alloys] by Specific-Heat Measurements.—I.—II. S. Nagasaki and E. Fujita (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 313-317; 317-321).—[In Japanese, with tables and diagrams in English]. [I.—] The sp. heats of Pb-Cd, Bi-Cd, and Sn-Bi alloys of various compn. were measured continuously from the solid state to the liq. state. From the results, the equilibrium diagrams, energy of fusion, energy of transformation in the solid state, and entropy of fusion, and the variation of the latter two functions with compn. were obtained. Using the theory of equilibrium diagrams proposed by Takagi and N., the results were examined. It was found that the results confirmed the theory in most cases, and some anomalies could be explained by more developed theories. Positions of the eutectic points in the Pb-Cd and Bi-Cd systems are discussed. They are situated at the compn. near to the component having the higher m.p. This conflicts with the result expected from the theory, but can be explained by considering the very different entropies of fusion of both alloy components. [II.—]. Results from [I.], together with those obtained from Sn-Bi alloys, are discussed. In the study

of the energy of soln. of Bi atoms in solid Sn the compn. contg. the mutual potential of Bi and Sn atoms was estimated, and the solubility limit of α solid soln. of Sn was investigated. The existence of anomalous liq. states of Bi, Sn, and their alloys is suggested.—AUTHORS.

***The Transmission and Spectral Response of Lead Sulphide and Lead Telluride.** M. A. Clark and R. J. Cashman (*Phys. Rev.*, 1952, [ii], 85, (6), 1043–1044).—The transmission through PbS and PbTe crystals, 0.48 and 0.11 mm. thick, has been measured as a function of wave-length, near the absorption edge, at temp. of -194° , -72° , and 23° C. The variation of the threshold energy with temp. is of the same magnitude as that for Si and Ge, but in the opposite direction. The spectral response of PbS and PbTe photocells shows a related behaviour.

—P. C. L. P.

***Magnesium-Cadmium Alloys. IV.—The Cadmium-Rich Alloys; Some Lattice Parameters and Phase Relationships Between 25° and 300° C. Structure of the $MgCd_3$ Superlattice. Schottky Defects and the Anomalous Entropy.** Donald A. Edwards, W. E. Wallace, and R. S. Craig (*J. Amer. Chem. Soc.*, 1952, 74, (21), 5256–5261).—Cf. *ibid.*, 1952, 74, 136; *M.A.*, 19, 768. The lattice parameters of Cd and three Mg-Cd alloys were determined between 25° and 300° C., and the structure of the $MgCd_3$ superlattice was established. Schottky defects to the extent of 1–2% were found, and account for the previously observed anomalously high entropy of formation of Cd-rich alloys. For 75–100% Cd at $>80^\circ$ C. only one phase exists, but at $<80^\circ$ C. the intermediate phase $MgCd_3$ (ordered) and the saturated primary solid soln. of Mg in Cd (disordered) co-exist, the heterogeneous region extending from 75 to 84% Cd at 25° C. The effects of compn., temp., and degree of order on the axial ratio are discussed in terms of the variation in lattice energy with compn., and of a postulated special short-range force acting between adjacent Cd atoms in the 001 plane.—J. R.

***On the Superlattices of the Mg-Cd System. V.—A Calorimetric Study on Fusion of the Mg-Cd Alloys.** Makoto Hirabayashi (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 295–299).—[In English]. H. has measured the sp. heat during fusion of Mg-Cd alloys and obtained the heat of fusion and the accompanying entropy changes as a function of the compn. Thus the solidus and liquidus were exactly determined, and confirmed the results of Hume-Rothery and Raynor (*Proc. Roy. Soc.*, 1940, [A], 174, 471; *M.A.*, 8, 32). In discussing the results, H. compares them with the theoretical predictions developed by Takagi and Nagasaki (*Japan Inst. Metals Section Rep. No. III, 1950*, [in Japanese]).—S. R. W.

***Order-Disorder Transformation, and the Magnetic Susceptibility of Mg-Cd Alloys.** Nahonori Miyata (*Sci. Rep. Yokohama Nat. Univ.*, 1952, [1], 1, 15–26).—[In English]. Values of the magnetic susceptibility, χ , of the complete range of Mg-Cd alloys were determined at 0° – 350° C. The alloys between pure Cd and 60% Mg are diamagnetic, and those between 60 and 100% Mg are paramagnetic. In the disordered state, values of χ are independent of temp., and vary linearly with compn. In the ordered state, the values of χ , both for the dia- and para-magnetic alloys, are increased. The difference of the Brillouin zone of the h.c.p. structure in the ordered and disordered state is discussed. More planes of energy discontinuity are present in the ordered than in the disordered state, together with more planes of AB_3 than of AB type.

—J. S. G. T.

***System Molybdenum-Boron and Some Properties of the Molybdenum Borides.** Robert Steinitz, Ira Binder, and David Moskowitz (*J. Metals*, 1952, 4, (9), 983–987).—The Mo-B system has been studied by thermal, metallographic, and X-ray methods, within the range 0–25% B, and from room temp. to the liquidus, the raw materials used being commercial powders of Mo (99+%) and B (83–85%, balance mainly O). Most of the impurities in the B evaporated at the high temp. of boride formation, the final products contg. <96 – 98% Mo + B, with C, Fe, and O as the balance. The borides were formed by compressing the powders and heating under H in an induction furnace at 1500° – 1700° C. From the results,

some of which have been reported previously (S., *ibid.*, (2), 148; *M.A.*, 19, 768), a tentative partial phase diagram has been produced. The new findings are: (1) the non-existence of borides lower than Mo_2B and higher than Mo_3B_5 ; (2) the existence of the two-phase fields (a) Mo + Mo_2B , from very small amounts of B to 5.3% B and at temp. up to 2000° C., (b) Mo_2B + MoB, between 5.3 and 9.7% B, and below 1850° C., and (c) MoB + Mo_3B_5 , (or their high-temp. modifications, depending on the temp.) between 10.7 and 19.5% B; (3) eutectics at (i) $\sim 1\%$ B and 2000° C., and (ii) $\sim 14\%$ B and 2060° C.; (4) Mo_3B forming peritectically at 2000° C. and 5.3% B, and having a Fe_2B -type tetragonal structure, with $a = 5.54$ and $c = 4.74$ Å.; (5) Mo_3B_2 forming at 7.0% B, with a stability range 1850° – 2070° C., and a Cr_2B_2 -type structure; (6) MoB, existing between 9.7 and 10.7, and from 9.7 to $\sim 10\%$ B, at room temp.– 2000° C., and room temp.– 2180° C., resp., and having a tetragonal structure with $a = 3.11$ and $c = 16.97$ Å.; (7) β - Mo_2B , existing between ~ 10.0 and 10.7% B at 2000° – 2180° C., with a CrB-type orthorhombic lattice, $a = 3.16$, $b = 8.61$, and $c = 3.08$ Å.; and (8) MoB_2 and Mo_2B_3 , existing between ~ 19.5 and 20.8% B, and temp. of 1600° – 2100° , and $<1600^\circ$ C., resp. the first having a hexagonal lattice, $a = 3.06$ and $c = 3.10$ Å., and the second a rhombohedral structure with hexagonal axes $a = 3.01$ and $c = 20.93$ Å. Some of the phys. properties— d , hardness, transverse bending strength, and thermal and elect. conductivities—are noted; none of the three room-temp. borides can be classified as oxidation-resistant; the influence of the presence of C on the Mo-B reactions is discussed. All compn. are in wt.-%. 14 ref.—E. N.

***A New Complex Eta-Carbide [in Ni-Base Alloys].** A. Taylor and K. Sachs (*Nature*, 1952, 169, (4297), 411).—A microconstituent of a complex Fe-free Ni-base alloy contg. Co, Cr, Mo, and W has been extracted, and the Debye-Scherrer pattern found to be analogous to that of a sample of η -carbide (Fe_3W_2C), though its lattice parameter was very much lower (10.951 against 11.0246 kX). Chem. analysis suggests that the structural formula of the new carbide is $(Ni_{0.58}Co_{0.30}Si_{0.12})_3(Mo_{0.19}W_{0.07}Cr_{0.44})_3(C_{0.95}N_{0.05})$, which is analogous to the complex high-speed steel η -carbide $Fe_3(W,Mo)_2C$ reported by Goldschmidt (*J. Iron Steel Inst.*, 1948, 160, 345; *M.A.*, 16, 397).—R. S. B.

***Creep-Rupture and Recrystallization of Monel from 700° to 1700° F. (370° to 925° C.).** Nicholas J. Grant and Albert G. Bucklin (*Amer. Soc. Metals Preprint*, 1952, (5), 20 pp.).—Creep-rupture tests were carried out on Monel in the annealed and 30 and 75% cold-worked conditions; the tests were carried out at temp. in the range 370° – 925° C. and using rupture times between 0.001 and 2700 hr. The recrystn. behaviour of bar specimens given various reductions between 4 and 75% was studied by means of hardness, resistivity, and X-ray measurements and metallographic examination. The long-time creep and rupture properties of Monel were shown to be governed by the incidence of intercryst. fracture, oxidation, and recrystn. The onset of intercryst. cracking cannot be accurately deduced from time-temp. relationships for recrystn. obtained from hardness measurements; evidence of recrystn. was found at much lower temp. and shorter times in creep-rupture tests than was predictable from the static recrystn. studies. The recrystn. which occurs during creep-rupture testing, lowers the creep resistance and rupture life as the result of the formation of a very fine grain structure along the grain boundaries. The creep-rupture strength at 480° C. for times up to 2000 hr. is improved by 30% cold work, but at 595° C. no such improvement was apparent. The method devised in earlier work (*Trans. Amer. Soc. Metals*, 1950, 42, 720; see *M.A.*, 17, 336), of graphically extrapolating and interpolating short-time creep-rupture data can be effectively used with Monel. The equicohesive temp. of 30% cold-worked Monel is 370° C. for a strain rate of 0.10%/hr. 6 ref.—R. W. R.

***Influence of Grain-Size on High-Temperature Properties of Monel.** Paul Shahinian and Joseph R. Lane (*Amer. Soc. Metals Preprint*, 1952, (6), 22 pp.).—Monel specimens (single-phase alloy) of various grain-sizes in the range 0.024–

0.78 mm. average grain dia., were tested in creep-rupture at temp. in the range 370°–705° C. at stresses between 7000 and 65,000 lb./in.². The different grain-sizes were produced by cold work and recrystn. At low temp. a decrease in grain-size was found to produce longer rupture times and lower creep rates; at higher temp. there is an optimum grain-size for max. rupture time. Between 480° and 595° C. there is an optimum grain-size which produces min. creep rate, but at 705° C. the min. creep rate decreases with increase in grain-size. Grain-size has little effect on elongation at temp. below the equicohesive temp., but at higher temp., elongation generally increases with decrease in grain-size and increase in temp. The reduction in area behaves similarly. Rupture life and creep rate, especially at the lower temp., were found to be significantly affected by minor variations in compn. 16 ref.—R. W. R.

A Study of Magnetically Soft Nickel-Containing Materials at Frequencies up to 24,000 Megacycles. I. Epelboin (*Rev. Nickel*, 1952, 18, (1), 11–20).—E. reviews information on the variation with frequency of the magnetic properties of Ni-contg. magnet alloys. 22 ref.—R. W. R.

***Electrical Properties of Sodium Tungsten Bronzes.** Hellmut J. Juretschke (*Phys. Rev.*, 1952, [ii], 86, (1), 124–125).—A letter. J. points out that the properties of the Na₂WO₃ bronzes where $x < 1$, are not inconsistent with those which would be given by Na itself distributed uniformly in a cubic lattice under high pressure. The resistivity min. found by Brown and Banks (*ibid.*, 1951, [ii], 84, 609) at $x = 0.70$ then corresponds to the predicted position of the resistivity/pressure min. in Na itself.—P. C. L. P.

***Electrical Properties of Antimony-Doped Tellurium Crystals.** Tadao Fukuroi, Seiichi Tanuma, and Shōtarō Tobisawa (*Sci. Rep. Research Inst. Tōhoku Univ.*, 1952, [A], 4, (3), 283–297).—[In English]. The elect. resistivity, ρ , Hall coeff., A_H , and thermoelect. power, p , of Te crystals alloyed with 0.002–5 at.-% Sb were measured at –190° to 300° C., and the results are compared with those for pure Te. Values of ρ and A_H at –15° C. range from 4.2×10^{-1} to 1.7×10^{-3} Ω -cm. and from -3.6×10^3 to $+3.25$ e.m.u., resp.; the d and mobility of holes calculated from these data range from 2.3×10^{15} to 3.3×10^{10} /cm.³ and from $>4.9 \times 10^2$ to 1.6×10^2 cm.²/V.sec., resp. Tenth or hundredth parts of added Sb atoms produce acceptor levels having little or no excitation energy. The decrease of hole mobilities produced by an increase of Sb is attributed to the predominance of acceptor-ion scattering. The variation of p with temp. shows a max. at low temp. and a min. at intermediate temp. for the pure metal, and an approx. linear increase with temp. rise with increase of Sb concentration.—J. S. G. T.

***The Martensite Transformation Temperature in Titanium Binary Alloys.** Pol Duwez (*Amer. Soc. Metals Preprint*, 1952, (35), 7 pp.).—The temp. at which the martensite transformation from β solid soln. to α' supersaturated solid soln. takes place was determined in binary alloys of Ti with Nb, Ta, W, Fe, Cr, and Mn. In the experimental method used, specimens 0.020 in. thick by $\frac{1}{16}$ in. sq. were spot-welded to Chromel and Alumel wires. The specimens were heated *in vacuo* by means of a Mo coil and quenched with a He jet. The break in the cooling curve due to the heat evolved in the transformation enabled the transformation temp. to be located to within $\pm 5^\circ$ C. Cooling rates in the range 100°–10,000° C./sec. were employed. In all cases the critical temp. decreased with increase in the amount of alloying element, Fe having the biggest effect (on the basis of at.-%) and Nb the smallest. Variation of rate of cooling had no effect. Extrapolation to room temp. of the transformation temp./% alloying element curves led to values of the critical concentration above which the β structure is retained after quenching, which were in rough accord with the results of other workers except in the case of Ti-Fe alloys. 13 ref.—R. W. R.

[Discussion on a Paper by H. R. Ogden, D. J. Maykuth, W. L. Finlay, and R. I. Jaffee:] **Constitution of Titanium-Aluminium Alloys.** — (*J. Metals*, 1952, 4, (11), 1213–1215).—See *M.A.*, 19, 526.

***Chemical Properties [and Analysis] of the Titanium-Aluminium Alloys.** Jean Cueilleuron and Claude Pascaud (*Compt. rend.*, 1952, 235, (20), 1220–1221).—The prepn. by an aluminothermal method of Ti-Al alloys contg. 15–65% Ti has already been described (*ibid.*, 1951, 233, 745; *M.A.*, 19, 356). Since then Gruhl (*Metall*, 1952, 6, 134) has published a thermal diagram which confirms the chem. properties indicated above. The analysis of these alloys is not easy: they are dissolved in HF contg. 1–2% H₂SO₄ and the Al and Ti are separated with cupferron, which precipitates Ti in cold acid soln. The chem. behaviour of the alloys varies considerably with the Ti content. The limit, 37.28%, corresponds to TiAl₃. Between this and 53% Ti all the alloys contain this compound, which can be isolated. The alloys contg. 53–65% Ti do not contain an intermetallic compound. By attacking the powdered alloy with, for example, 8% NaOH for 8 hr. powdered Ti contg. 0.2–0.3% O and 1–3% Al can be obtained. The grains are covered with the hydrated oxide, which can be removed by washing with 10% H₂SO₄ + 1% HF. The powdered Ti easily oxidizes and should be kept in an inert organic liquid.—J. H. W.

[Discussion on a Paper by C. W. Phillips and D. N. Frey:] **Isothermal Transformation Characteristics of an Iron-Chromium Alloy of Titanium.** — (*J. Metals*, 1952, 4, (11), 1205–1203).—See *M.A.*, 20, 15.

***Titanium [and Titanium Alloys] Can Be Case-Hardened by Nitriding.** Edmund J. Silk (*Iron Age*, 1952, 170, (20), 166–170).—Hardness gradients have been established by nitriding pure Ti and Ti alloys in sheet and slab form under varying conditions. With RC-55 Ti max. hardness was obtained after 16 hr. at 1600° F. (870° C.) in NH₃. The highest surface hardness, 1098 D.P.N., was obtained in L 431 alloy after 64 hr. at 1600° F. Tank N gives equal surface hardening, but requires a treating temp. of at least 1800° F. (995° C.). Depth of case runs to a max. of ~0.003 in.—J. H. W.

***Tungsten-Cobalt-Carbon System.** Pekka Rautala and John T. Norton (*J. Metals*, 1952, 4, (10), 1045–1050).—The phases and equilibria in the W-Co-C system have been studied by X-ray diffraction, and metallographic and thermal methods. The raw materials were powder W, WC, Co, and C, of the normal commercial purity used in the prodn. of cemented carbides; these were pressed, and sintered *in vacuo* either for 1 hr. at 2000° C., or 2–4 hr. at lower temp.; evaporation of Co was small at 1400° C. but severe above 1500° C. Specimens sintered at 1400° C. showed: (1) the well-known η phase, formed by the peritectic reaction $\text{liq.} + \theta + \text{W} = \eta$ at ~1600° C., having a homogeneity range C 7–20 and Co 38–48% and in equilibrium with WC, θ , W, δ , β , and liquid; and the two additional phases; (2) θ , formed by the peritectic reaction $\text{liq.} + \kappa + \text{W} = \theta$ at ~1700° C.; it corresponds to the formula Co₃W₆C₂, has a cubic structure with $a = 11.25$ Å., and is related to the η phase; its homogeneity range is narrow—only ~2%—and it is in equilibrium with WC, κ , W, and η ; it forms a two-phase field, $\eta + \theta$; and (3) κ , formed by the peritectic reaction $\text{liq.} + \text{W}_2\text{C} + \text{W} = \kappa$ at $1880 \pm 15^\circ$ C.; it has the formula Co₃W₁₀C₄, and a hexagonal structure with $a = c = 7.848$ Å.; its homogeneity range is smaller than that of θ , i.e. <1%, and it is found in equilibrium with W₂C, WC, W, and θ . Both θ and κ are found to form, readily, in the systems Fe-W-C and Ni-W-C, where they have similar compn. and lattice structures. There is a ternary eutectic reaction, $\text{liq.} = \beta + \text{WC} + \text{C}$ at 1298° C., and two ternary transitions: $\text{liq.} + \delta = \eta + \beta$, at ~1400° C., and $\text{liq.} + \eta = \beta + \text{WC}$, at 1357° C.; there is a binary eutectic reaction, $\text{liq.} = \beta + \text{C}$, at 1300°–1315° C. The reactions which occur, and the following equilibrium diagrams are discussed in detail, and the following equilibrium diagrams are presented: a 1400° C. isothermal section, a metastable and a stable equilibrium diagram, representations by basal projection (which are virtually the same above 1357° C.), a vertical section through the C corner of the metastable system, and a vertical section of Co-WC. The microstructures

of the alloy contg. W 9, Co 81, and C 10% are illustrated. All compn. are in at.-%. 7 ref.—E. N.

The Commercial Development of Three German Wrought Zinc Alloys. Jacob Schramm (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 436-456).—A description of the war-time development of three Zn-base alloys designed to economize in Cu and Al: (1) Zn-1% Al- $\frac{1}{2}$ % Fe possessing good extrusion and forging properties, (2) Zn- $\frac{1}{2}$ % Mn-1% Pb with improved machinability and produced from low-grade Zn, and (3) Zn-32% Al-3% Cu for friction bearings. The compn., prodn., mech. properties, corrosion resistance, and machinability of the alloys are given, and comparison is made with other Zn-base alloys.—D. M. P.

[Discussion on a Paper by E. E. Underwood and B. L. Averbach:] **Vapour Pressures of Zinc Over Ag-Zn Alloys.** — (*J. Metals*, 1952, 4, (11), 1220-1223).—See *M.A.*, 19, 644.

***Small Additions Raise Strength of Zirconium at Elevated Temperatures.** A. D. Schwoppe and W. Chubb (*J. Metals*, 1952, 4, (11), 1138-1140).—A study has been made of the hardness and the U.T.S., at temp. up to $\sim 800^\circ\text{C}$., of the following alloys of Zr: (1) binary—with up to Al 2.0, Pb 4.7, Mo 1.2, Ni 1.8, Nb 2.2, Ta 6.4, Ti 10.4, W 2.6, V 3.1, and Zn 0.4 wt.-%, and (2) ternary—with (a) Mo 3.1 + Nb 0.4, (b) Ti 4.6 + Al 0.8, (c) Ti 3.9 + Mo 1.9, and (d) Ti 4.0 + N 0.2 wt.-%. The alloys were prepared, from iodide Zr and high-purity alloying metals, by induction heating in non-outgassed graphite crucibles, either *in vacuo* or an A atmosphere, and cooled slowly in the crucible—which resulted in a C content of $\sim 0.3\%$. The ingots, ~ 200 g. in wt., were forged and hot rolled at 1000°C ., in air, to 0.125 in., cold rolled to 0.070 in., annealed *in vacuo* for 3 hr. at 700°C ., and the resulting sheet cleaned by machining up to 0.010 in. off each side. The results, which are given in tables and graphs, and which agree, in general, with the data available in the literature, show that Mo and Nb are most effective in strengthening Zr at temp. up to 500°C . but do not maintain their efficacy above 600°C .; Ti is most effective in the range 300°C – 700°C ., while Al, Ta, and V are effective above 600°C .; of the ternary alloys, those contg. Ti + Mo are best up to 500°C ., but in the range 500°C – 700°C . alloys with Ti and Al are the most efficient. The microstructures of the alloys are discussed. 5 ref.—E. N.

[Discussion on a Paper by E. T. Hayes, A. H. Roberson, and M. H. Davies:] **Zirconium-Chromium Phase Diagram.** — (*J. Metals*, 1952, 4, (11), 1211-1213).—See *M.A.*, 20, 16.

[Discussion on a Paper by M. Hansen, W. R. Johnson, and J. M. Parks:] **Correlation Between Electrical Conductivity and Temperature Coefficient of Resistance of Solid-Solution Alloys.** — (*J. Metals*, 1952, 4, (11), 1225-1228).—See *M.A.*, 19, 530.

High-Temperature Materials: Tests Used as Criteria of Service Behaviour. L. B. Pfeil (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (3), 88-97).—[In English]. The properties required of materials for use at elevated temp. in gas turbines are listed and methods of testing these properties are discussed. The significance of the onset of tertiary creep is emphasized, and it is shown that in Nimonic alloys tertiary creep begins at lower strains as the temp. rises and time increases. It is suggested that time of fracture is largely determined by some condition of the grain boundaries or by the balance between the properties of the grain boundaries and the grains and that optimum creep properties are obtained only by a controlled amount of over-ageing, delayed cooling from the soln. temp. or pptn. at a temp. higher than that which produces max. hardness. There is a steady decrease in room-temp. fatigue properties with strain in tertiary creep. A Gerber diagram for Nimonic 80A at 700° and 750°C . is plotted. In studying the effect of V in the fuel on the oxidation of high-temp. alloys, the amount and method of supply of the accelerating agent greatly influence the extent to which the rate of oxidation is affected. Ni-Cr alloys are much more resistant to accelerated oxidation than Fe-rich alloys, probably because NiO in the scale is not fluxed by the V_2O_5 ; however, the Fe-contg. materials are more resistant to S

which may also be present in the products of combustion, and V_2O_5 has been shown to stimulate sulphidation. A suitable balance of Fe and Ni must be found for any particular ratio of V_2O_5 to sulphate in the fuel ash. Rig tests for thermal shock are also described. 25 ref.—K. S.

***Damping, Elasticity, and Fatigue Properties of Temperature-Resistant Materials.** B. J. Lazan and L. J. Demer (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 611-646; discussion, 647-648).—Damping capacity, dynamic modulus of elasticity, and fatigue properties are of great importance in the design of parts used in appn. involving dynamic loads. Data are given from tests at room and elevated temp. designed to reveal changes in the damping and elasticity properties of various materials during const. reversed cyclic-stress tests at engineering stress levels. Newly-developed rotating-cantilever-beam fatigue-testing equipment was used. Materials tested were: (i) S816 (Co 43, Ni 21, Cr 20, W 4.5, Nb 4, Mo 3.5, Fe 2.5%) at room temp., 900° , and 1600°F . (480° and 870°C .); (ii) Mo at room temp. and 900°F .; (iii) Inconel X (Ni 73, Cr 15, Fe 7, Ti 2.5, Nb 1, Al 1%) at room temp.; (iv) N-155 (Fe 32, Cr 22, Ni 19, Co 19, Mo 3, W 2, Mn 2, Nb 1%) at 1500°F . (815°C .); (v) 98:2 Mo-W alloy at room temp. and 900°F .; (vi) Type 403 (Fe 86, Cr 13, Ni 0.5%) at room temp. and 500°F . (260°C .); and (vii) 85:15 Fe-Cu alloy at room temp. and 500°F . (Materials (i), (iii), (iv), and (vi) contained small amounts of C, Mn, Si, &c.) Usual S/N fatigue curves are given, and a series of new diagrams designed to show the effects of both stress magnitude and stress history on the damping and elasticity properties. Two methods for comparing these properties are presented, and the merits of each discussed. The first is on the basis of equal stress magnitude, and the second on the basis of the same ratio of applied stress to fatigue strength. Diagrams are given which facilitate comparison of the elasticity properties of materials tested at a given temp. For all materials and at all temp. investigated, the energy dissipated by damping increased rapidly with stress at values close to the fatigue strength of the material. During a const. reversed cyclic stress test, the damping energy may decrease, remain the same, or increase, or have a varying pattern as the number of stress cycles is increased. In general, the changes in dynamic modulus of elasticity were reciprocal to the changes in damping energy. 9 ref.—P. T. G.

***On Certain Phenomena of a Physico-Chemical and Structural Nature That Affect the Mechanical Properties of Austenitic Heat-Resistant Alloys at Elevated Temperatures.** P. Chevénard and X. Waché (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (4), 127-136).—[In French]. The phenomena responsible for the high mech. properties of austenitic heat-resistant alloys are discussed, viz. pptn. of carbides and intermetallic compounds and order-disorder transformations. The methods of studying the various transformations are reviewed, attention being drawn to the relative facility of dilatometric techniques, the ability of magnetic methods to follow the formation of micro-heterogeneities in the solid soln. during the pre-pptn. stage, and the possibility of employing thermo-elect. effects in the study of bars under stress. Ref. is made to mech. tests devised by C. and W. for very small specimens and their appn. to samples machined from creep bars after test. An analogy is drawn between very sensitive creep tests and isothermal dilatometry of stressed specimens. Numerous examples are given of the effect of varying compn. and heat-treatment on the microstructure and its correlation with the creep properties.—K. S.

***A Theoretical Study of Young's Modulus of Binary Solid Solutions.** Y. Shibuya (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (5), 235-238).—[In Japanese]. The relation between Young's modulus and the compn. of solid soln. has been investigated. Denoting the interaction energy force const. between A atoms, that between B atoms, and that between atoms of A and B by ξ_{AA} , ξ_{BB} , and ξ_{AB} , resp., the following results are reported: (1) a linear relation between Young's modulus and compn. when $\xi_{AB} = \text{mean of } \xi_{AA} \text{ and } \xi_{BB}$; (2) a non-linear relation when $\xi_{AB} \neq \text{mean value}$; (3) the theoretical curves obtained with appropriate values of force

const. agree well with those obtained by experiment; and (4) using the value of $\xi_{1,1}$ obtained from measured values of the lattice const. and the compressibility, the magnitude of Young's modulus of polycryst. Mo has been estimated and found to agree to within ~10% with the measured value. Mo-W, Ag-Pd, and Au-Pd systems have been investigated.

—AUTHORS.

Study on Age-Hardening. Yoshitsugu Mishima (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 668-681).—Age-hardening data are reviewed, and it is shown that the changes in hardness with time can be expressed by the Austin-Rickett equation $p/(1-p) = Kt^n$, where t is ageing time, K and n const., and p is the fractional change in hardness defined by $p = (H - H_0)/(H_s - H_0)$, where H is the hardness at time t , and H_0 and H_s are the initial and final hardness, resp. The equation allows the activation energy to be calculated. The data fall into 2 groups: (1) $n = 1$, corresponding to hardening by two-dimensional pseudo-pptn. and (2) $n > 1.9$, which corresponds to hardening by three-dimensional precipitates. 24 ref.—D. M. P.

***Electrical-Resistance Alloys.** Hans Thomas (*Z. Physik*, 1951, 129, (2), 219-232).—In certain primary solid soln., contg. at least one transition metal, the elect. resistance/temp. curve has an S-form, there being an anomalous rise in resistance with decreasing temp. at medium or low temp. Experimental measurements were made on alloys in the systems Ni-Cr, Fe-Al, Fe-Si, Ni-Cu-Zn, and Ni-Cu. The S-shaped curve applies to slowly cooled alloys; quenched alloys have lower resistances, which increase when the alloy is annealed in the appropriate temp. region, but decrease if the alloy is cold-worked. The results are interpreted in terms of the formation of a rather ill-defined "K-state" of the alloy, and the resistance/temp. curves are separated into a normal component and a resistance which rises steeply with falling temp., corresponding to the formation of this "K-state".—J. W. C.

Influence of Stress Concentrations on Diffusion Processes in Solid Solutions. B. Ya. Lyubov and N. S. Fastov (*Doklady Akad. Nauk S.S.S.R.*, 1952, 84, (5), 939-941).—[In Russian].

Math. Fick's second law becomes $\frac{\partial c}{\partial t} = D_{ef} \frac{\partial^2 c}{\partial x^2}$, in which

$D_{ef} = D \left[1 + \frac{12\mu K \omega^2 v c}{(K + \frac{1}{2}\mu)RT} \right]$, where μ is the shear modulus,

K the bulk modulus, ω a const., and v the at. vol. For the diffusion of C in Fe at 720° C., $\omega = 0.2$ and $D_{ef} = D(1 + 20c)$.

—G. V. E. T.

***The Kirkendall Effect in Alloy Systems.** Herbert N. Hersh (*J. Appl. Physics*, 1952, 23, (9), 1055-1056).—A note. The "Kirkendall" effect in diffusion is the displacement of the diffusion interface due to unequal diffusion rates of the constituents, accompanied by the rejection of excess vacancies by the lattice (forming pores), where the unequal rates of diffusion have concentrated vacancies. This underlying mechanism has been directly demonstrated by heating α -brass wire specimens so as to evaporate some of the Zn. The dia. decreased progressively (\propto (time)^{1/2}, as for the Kirkendall effect). It was shown that the contraction was a vol. effect, not unidirectional. The effect must be due to the rejection of vacancies at the surface (and the pores); the vacancies have been left at the lattice sites whence Zn atoms have evaporated.—R. W. C.

Ultrathin Magnetic Alloy Tapes with Rectangular Hysteresis Loops. M. F. Littmann (*Elect. Eng.*, 1952, 71, (9), 792-795).—Hysteresis and other properties of four magnetic alloys (Ni 79, Mo 5; Ni 79, Mo 4; Ni 48; and Si 3%, balance Fe in each case), cold-rolled into strips $\frac{1}{8}$ -1 mil thick for subsequent slitting and winding into toroidal cores, are considered.—J. R.

[Discussion on a Paper by C. M. Hsiao and A. W. Schlechten:] **Volatility and Stability of Metallic Sulphides.** — (*J. Metals*, 1952, 4, (11), 1179).—See *M.A.*, 19, 592.

Alloys Containing Sulphur in Mining, Metallurgy, and Cosmic Physics. Rudolf Vogel (*Z. Metallkunde*, 1951, 42, (7), 202-206).—Ternary systems of Fe and S with Cu, Ag, Ca, Zn, Hg, B, Al, Tl, Ce, C, Si, Ti, Zr, Pb, Sn, P, V, Nb, Sb, Bi, O, Cr, Mo, Mn, Ni, and Co are discussed. 6 ref.—E. N.

Metallurgical Equilibrium Diagrams. (Hume-Rothery, Christian, and Pearson). See col. 540.

3 — STRUCTURE

(Metallography; Macrography; Crystal Structure.)

[For all abstracts on the constitution of alloy systems, including X-ray studies, see 2—Properties of Alloys.]

***Some Factors Affecting the Grain-Size of Annealed Aluminium Sheet of Commercial Purity.** Eiichi Hata (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 355-358).—[In Japanese, with tables and graphs in English]. Al ingot slabs of commercial purity were hot rolled from 120 to 6 mm., cold rolled from 6 to 0.6 mm., and then annealed. The finest grain-size was obtained when ingots were hot rolled above 500° C. Addn. of Fe and Si refined the grains of annealed sheet, Fe being the more effective, whereas Mn increased the grain-size. Extremely coarse grain-size was obtained when sheet was annealed at a slow heating rate. In order to fabricate fine-grained sheet, H. states that Mn content should be carefully controlled.

—AUTHOR.

***Crystal Fragmentation in Aluminium During Creep.** D. McLean (*J. Inst. Metals*, 1952-53, 81, (6), 287-292).—Seven specimens of super-pure Al having grain-sizes of 1-9½ grains/mm., were made to creep at 200° C. under loads varying from $\frac{1}{4}$ to $\frac{3}{4}$ ton/in.²; the extensions produced ranged up to 50%. Observations and measurements were made relating to the sub-crystals formed. These are consistent with a polygonization model for secondary creep and permit a quant. check of this model to be made. Certain of the observations appear to be inconsistent with the theory of sub-crystal formation advanced by Wilms and Wood (*ibid.*, 1948-49, 75, 693; 1951, 79, 159; *M.A.*, 17, 790; 18, 660).—AUTHOR.

***Grain-Boundary Slip During Creep of Aluminium.** D. McLean (*J. Inst. Metals*, 1952-53, 81, (6), 293-300).—Grain-

boundary displacements during creep at 200° C. have been measured in seven super-pure Al specimens. The tests covered a range of grain-sizes from 1 to 9½ grains/mm. and of stress from $\frac{1}{4}$ to $\frac{3}{4}$ ton/in.². The curves of grain-boundary displacement plotted against time resemble the corresponding extension/time curves. The fraction of the total extension due to the grain-boundary displacements was calculated. At a const. load of $\frac{1}{4}$ ton/in.² this increased with decrease in grain-size from about one-fiftieth for 1 grain/mm. to about one-sixth for a grain-size of 9½ grains/mm. At const. grain-size (4½ grains/mm.) it increased with decrease in load, from about one-fiftieth for a load of 1 ton/in.² to about one-fifth for a load of $\frac{1}{4}$ ton/in.². A plot of grain-boundary displacement against extension due to crystal deformation is linear for all specimens, suggesting a linear interaction between these two quantities. A model for this interaction is proposed, and calculation shows it to agree with experiment within 2:1.—AUTHOR.

***On the Deformation and Polygonization of Single Crystals of Aluminium.** Honoré Lambot and Lawrence Vassamillet (*Compt. rend.*, 1952, 235, (20), 1232-1234).—L. and V. applied the method of accurately measuring small angular disorientations by transmitted X-rays (*ibid.*, (19), 1136) to the study of the lattice distortions occurring in metal subjected to different mech. and thermal treatments, using single crystals of Al prepared by the Elam-Carpenter method and elongated to 10%. The deformation occurring within this range is described. Polymerization was shown to occur at much lower temp. than the 450° C. found by Guinier and Tennevin

("Progress in Metal Physics", Vol. II, p. 177. London: 1950 (Butterworths Scientific Publications)), being 200° C. after 12 hr. for 99.99% Al elongated to 4%. For 99.95% Al it occurs after 12 hr. at 550° C., showing the large effect of a small amount of impurity.—J. H. W.

***Laue Asterism and Deformation Bands [in Aluminium].** E. A. Calnan (*Acta Cryst.*, 1952, 5, (5), 557-563).—[In English.] Correlation of detailed Laue and microscopic data on six stretched crystals of super-pure Al has confirmed earlier observations on "kink bands" and "bands of secondary slip". The latter kind are almost but not quite || the primary slip plane, and within the bands this slip plane operates scantily or not at all. The rumpling on the surface within these bands is attributed to small (secondary) kink bands \perp one, or two, of the other possible glide directions of the crystal; this hypothesis accounts for the shapes of Laue asterisms. When the secondary slip planes associated with these localized secondary kink bands make sufficiently large angles with the free surface, the slip traces can be distinguished. The dependence of the secondary slip plane(s) observed on the orientation of the crystal is rationalized by a variant of C. and Clews' (*Phil. Mag.*, 1950, [viii], 4, 1085; *M.A.*, 19, 191) theory of deformation textures.—R. W. C.

[Discussion on a Paper by I. R. Kramer and R. Maddin:] **Delay Time for the Initiation of Slip in Metal Single Crystals [Pure Aluminium and α - and β -Brass].** — (*J. Metals*, 1952, 4, (11), 1200-1201).—See *M.A.*, 19, 772.

***Extinction Effects in Neutron Transmission of Polycrystalline Media [Aluminium].** R. J. Weiss (*Phys. Rev.*, 1952, [ii], 86, (3), 271-275).—It is pointed out that in addn. to primary extinction effects, secondary extinction can also disturb the proportionality of the neutron-scattering cross-section of a sample to the cross-section/nucleus. The grain-size is the main factor affecting extinction effects, though the mosaic-block size and angular spread have an influence. Experimental work on polycryst. Al of different grain-sizes supports the theory. A method of measuring the mosaic-block size and angular spread is proposed, but it requires a somewhat better resolu. than available at present.

—P. C. L. P.

***Holes in [Single] Crystals [of AlB_2].** F. H. Horn, E. F. Fullam, and J. S. Kasper (*Nature*, 1952, 169, (4309), 927-928).—Single crystals of AlB_2 , originally firmly embedded in a matrix of Al which was removed by soln. in HCl, were found almost invariably to have a small round hole (1-20 μ in dia.) near the centre. Crystals without visible holes resulted when the Al was removed with milder etchants. These crystals, after a slight etch, showed spiral terraces (step-heights \sim 200 Å.). The observations can be understood if each crystal contains at least one screw dislocation, which made growth possible. The dislocation thus would be normal to the close-packed planes, and centrally located. It is suggested that selective etching techniques may be an additional help to a study of the occurrence and the properties of screw dislocations.—R. S. B.

***Electron-Diffraction Study of Aluminium-Copper Alloys Obtained by Thermal Evaporation in Vacuo.** Jean Jacques Trillat and Noboru Tokahashi (*Compt. rend.*, 1952, 235, (21), 1306-1308).—By evaporating two metals *in vacuo* and condensing their vapours on rock-salt substrates held at different temp., it is possible by electron diffraction to control the structure of the metallic films thus formed and to follow the appearance of solid soln. and of alloys of definite compn. This method was applied to Al and Cu. By vaporizing the two metals and condensing the vapours on rock-salt at 20° C., a mixture of the metals in various proportions is always obtained. If, however, the rock-salt is at 300° C., solid soln. and compounds are formed. With known mixtures of the two metals only diffuse patterns are obtained on rock-salt at 20° C., indicating the formation of solid soln. with strongly deformed and out-of-equilibrium lattices. Using a particular alloy, say $CuAl_2$, the same results are obtained as with a mixture of this compn.—J. H. W.

***Electron-Diffraction Study of the Changes in Thin Films of Antimony, Arsenic, and Bismuth, Produced by Thermal**

Vaporization in the Body of the Diffractor Itself. Pierre Conjeaud (*Compt. rend.*, 1952, 235, (20), 1213-1215).—Vaporization effected in the body of the diffractor itself (a suitably modified J. J. Trillat apparatus) avoids the alteration that occurs during the transfer of the specimen and enables the changes in the specimen to be followed immediately after evaporation. Thin films of Sb, originally amorphous, develop, slowly at room temp. and rapidly under the influence of a beam of electrons, an oriented cryst. structure. As films remain amorphous, and those of Bi assume a cryst. structure immediately.—J. H. W.

***Fundamental Research on Primary Crystallization. I.—Preliminary Reports on a Research into the Primary Crystallization of the [90:10] Bi-Sn Alloy.** T. Yanagihara and K. Itoh (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (5), 272-274).—[In Japanese, with diagrams in English]. A 90:10 Bi-Sn alloy was heated to 300° C. and cooled at 3.5° C./min. to a temp. in the solidification range, where it was held for various times, before being allowed to fall through a hole in the bottom of the crucible into a receiver in which it was weighed. Almost all the primary crystals were formed in about the first 10 min. at the holding temp., followed by the growth of these crystals, equilibrium being reached after \sim 30 min. at the temp. The influence of the cooling rate was also investigated. Cooling rates $>0.5^\circ$ C./min. seemed to allow the amount of primary crystals in the primary state to crystallize.—AUTHORS.

***Effect of Surface Films on the Twinning of Metal [Cadmium] Crystals.** Ronald King (*Nature*, 1952, 169, (4300), 543-544).—Long single crystals of Cd were cut into several lengths which were given different surface treatments. Stress/strain curves were obtained and the onset of twinning detected. The results are in accord with those of Gilman (*ibid.*, (4291), 149; *M.A.*, 20, 256). Increasing times of surface oxidation increased the twin stress by up to 30%. Electrolytically deposited hydroxide layers increased the twin stress by up to 50%. Evidence has been obtained that the criterion for the onset of twinning is that the resolved shear stress on the twin plane in the twinning direction must attain a critical value.—R. S. B.

***Twin Formation in Cadmium.** N. Thompson and D. J. Millard (*Phil. Mag.*, 1952, [vii], 43, (339), 422-440).—The use of equipment embodying a piezo-elect. pick-up has shown that the process of twinning in 99.98%-purity Cd single-cryst. wires under tension takes place discontinuously in $>10^{-4}$ sec. The evidence obtained favours a critical resolved shear-stress law for twinning, with a critical stress of 138 and 295 g./mm.² at room temp. and at 90° K., resp. Creep by twinning was found at room temp., but not at 90° K. A detailed discussion is given of a dislocation mechanism of twinning in h.c.p. lattices. The mechanism satisfies the twinning conditions proposed by Cottrell and Bilby (*ibid.*, 1951, [vii], 42, 573; *M.A.*, 19, 837).—P. C. L. P.

***Oxide Films on Electrolytically Polished Copper Surfaces.** J. A. Allen (*Trans. Faraday Soc.*, 1952, 48, (3), 273-279).—Surfaces of polycryst. Cu sheet polished electrolytically have been examined, by electron diffraction, and by an electro-metric method of measuring the thickness of oxide films, based upon the apparatus designed by Campbell and Thomas (*Trans. Electrochem. Soc.*, 1939, 76, 303; see *M.A.*, 6, 414), with a view to obtaining quant. evidence of the presence of oxide films on the polished sheets. The end-point of the cathodic reduction of the oxide is determined by following the changes of potential as the reduction proceeds. The Cu surfaces used were shown to be initially free from oxide films when removed from the electrolytic polishing bath. Subsequent growth of oxide films on the metal in air at room temp. depends on the washing procedure employed. Surfaces freed from phosphate contamination oxidize rapidly, producing films 15 Å. thick in $\frac{1}{2}$ hr., and \sim 20 Å. thick in 17 hr. Surfaces contaminated by phosphate are partially protected from oxidation, but their behaviour is variable.—J. S. G. T.

***Contribution to the Explanation of the Optical Anisotropy of Cubic Cuprous Oxide [Films on Copper].** Eduard Eiseltauer (*Z. Metallkunde*, 1951, 42, (7), 210-212).—A report of a

microscopic study of the colour and anisotropy of thermally produced coatings of Cu_2O on Cu. The results show that the red Cu_2O , of cubic habit, is covered by a superficial blue film, the thickness of which determines the apparent colour of the coating, and the polarization effects observed between crossed nicols. Cathodic reduction causes the film to lose its blue coloration, and to become brick red—the normal colour of Cu_2O —while the polarization effects almost or entirely vanish. The nature of the superficial film is discussed. The effect of cathodic reduction confirms the hypothesis that it is Cu_2O enriched in O, but does not demonstrate the presence of CuO—although Cu_2O is known to oxidize slowly to CuO when exposed to the atmosphere at normal temp. 6 ref.

—E. N.

***Recrystallization and Grain Growth in Alpha Brass.** S. L. Channon and H. L. Walker (*Amer. Soc. Metals Preprint*, 1952, (8), 20 pp.).—Cold-rolled 70:30 brass specimens of commercial purity and of various grain-sizes were annealed isothermally for various times and at different temp., and the recrystn. grain-size measured. Confirming earlier work by W. (*Univ. Illinois Eng. Exper. Sta. Bull.*, 1945, (359); *M.A.*, 13, 293), the recrystallized grain-size was found to be independent of annealing temp. but related to the degree of deformation, d , by the equation: $\log r = nd^{1/2} + \log m$, where $n = \text{const.}$ and m is a function of initial grain-size. The initial grain-size, i , was related to the recrystallized grain-size by: $r = bi^a$, where $a = \text{const.}$ and b is a function of the degree of deformation. The heat of activation for recrystn. decreases with increasing deformation and decreasing initial grain-size, reaching a lower limit of 41 kg.cal./mole. After long annealing the grain-size is essentially independent of the amount of prior deformation and initial grain-size. The rate of grain-growth at 600° C. appears to decrease and at longer times to increase again; this may be due to the agglomeration or dissoln. of impurities. The rate of growth tends to be slower at lower temp. After annealing for 10⁷ sec., the grain-size was still increasing but appeared to be approaching an equilibrium size. For practical purposes, grain-growth of brass is a continuous process at annealing temp. below 700° C. and times shorter than 128 days. The heat of activation for grain-growth is 61 kg.cal./mole and is independent of the initial grain-size or the degree of prior deformation. 20 ref.

—R. W. R.

[Discussion on a Paper by A. H. Geisler, J. H. Mallory, and F. E. Steigert:] On the Mechanism of Precipitation in Copper-Beryllium Alloys. — (*J. Metals*, 1952, 4, (11), 1196).—See *M.A.*, 20, 19.

***The Epitaxial Growth of Germanium on Rock-Salt.** L. E. Collins and O. S. Heavens (*Proc. Phys. Soc.*, 1952, [B], 65, (10), 825–826).—A letter. Ge films, which were amorphous < 480° C., are shown to take up the orientation of the rock-salt above this temp., increasing in order as the temp. is raised up to 530° C. Beyond this, the rate of evaporation of the rock-salt is too high to allow film formation.—E. O. H.

***Growth Spirals Originating from Screw Dislocations on Gold Crystals.** S. Amelinckx (*Phil. Mag.*, 1952, [vii], 43, (340), 562–567).—An illustrated account is given of the growth spirals which have been observed on the (111) faces of Au crystals obtained by reaction and pptn. from an aq. soln. Details of the spiral shapes are explained by the crystallographic variation of the radial growth velocity. Interacting spirals of opposite signs were not seen, though craters were visible at the centres of many spirals. The spiral step-height often exceeded 100 Å., corresponding to a large Burgers dislocation vector. The behaviour is probably affected by the pptn. of NaCl also, allowing the growth of Au to make use of screw dislocations present in the NaCl. The large lattice misfit may be significant.—P. C. L. P.

***Some Observations on Slip Lines in Iron.** H. W. Paxton, M. A. Adams, and T. B. Massalski (*Phil. Mag.*, 1952, [vii], 43, (337), 257–258).—A letter. The appearance of the slip lines on mild steel contg. 0.003% C varies with the surface prepn. The slip lines caused by 0.5% extension were more obvious and more widely separated on the surface of an electropolished specimen which had been lightly rubbed

with fine polishing alumina, than on one tested in the as-polished condition.—P. C. L. P.

***Several Experiments Relating to the Production of Iron Single Crystals by the Recrystallization Method.** Mikio Yamamoto and Ryōfu Miyasawa (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 300–304).—[In Japanese, with tables and graphs in English]. Results of experiments to obtain further information on the prodn. of Fe single crystals by the recrystn. method are reported. Rods 3–5 mm. in dia. were prepared from 5 materials contg. 0.06–0.13% C (commercially pure Fe and soft steels) and heated in a moist H stream to 1000° C., at which temp. they were held for different times. It was found that the greater part of the C had already been removed during heating, indicating that the diffusion of C in α -Fe is faster than in γ -Fe. The degree of grain growth during heating-up to 1000° C., however, is much smaller than that during heating at that temp. The decarburization velocity is shown to be inversely proportional to the dia. of the specimen. Specimens with 40–90 grains/mm.² prepared by the decarburization treatment at 1000° C. for 2 days were elongated to various degrees and then annealed at 880° C. for 2 or 3 days. Max. grain growth was obtained with specimens elongated to ~4%. The grain growth was found to be independent of the heating velocity in the recrystn. heat-treatment and was completed for specimens of 4 mm. in dia. by heating for 2 days. It was noticed that the higher the purity, the more pronounced was the grain growth, although it is known that the especially pure material shows rather less marked grain growth.—AUTHORS.

***Production of Single Crystals of Iron-Aluminium Alloys by the Strain-Anneal Method.** Mikio Yamamoto and Ryōfu Miyasawa (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 305–309).—[In Japanese, with tables and diagrams in English]. The prodn., by the recrystn. method, of circular-rod single crystals, 3 mm. in dia., from Fe-Al alloys contg. < 6% Al was studied, and the optimum conditions for the decarburization treatment in a moist H stream, the degree of elongation, the annealing for recrystn., and macro-etching were determined. With increasing Al content, the optimum temp. of the decarburization treatment (1 day duration) and the optimum degree of elongation decreased, resp., from 970° C. and 4% for electrolytic Fe to 900° C. and 2% for an alloy contg. 6% Al, while the annealing temp. for recrystn. (2 days duration) increased from 880° C. for electrolytic Fe to 1000° C. for a 6% Al alloy. The greatest grain growth (max. length 16 cm.) was obtained in the 0.53% Al alloy and the least (6 cm. long) was obtained with the 2.47% Al alloy. Conc. HNO_3 + a little boiling H_2O was suitable for etching both pure Fe and the alloys, while conc. HCl was used for alloys contg. > 2.5% Al. Dil. HNO_3 may be used for cutting crystals by etching regardless of the Al content. It was confirmed that a polycryst. layer consisting of one layer of minute grains which existed before recrystn. remained on the surface of the Fe-Al single crystals prepared by the recrystn. method.—AUTHORS.

***Crystal Orientation in Cold-Rolled Silicon Iron Sheet.** I. Gokyu and H. Abe (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 580–590).—A study was made of cold-rolled Fe-Si alloy sheet by X-ray, magnetic, and etch-pit methods. The cold-rolling texture consists of four sets of orientations: (001)[110], (112)[110], (111)[112], and (111)[110]. The recrystn. texture is related to the above by rotations around [100] and [110] axes. The coarsening texture is related to the recrystn. texture by rotation around the [110], [112], and [100] axes. 4 ref.—D. M. P.

***Domain Patterns on Fe-Si Crystals.** C. F. Ying, S. Levy, and R. Truell (*Phys. Rev.*, 1952, [ii], 86, (1), 133–134).—A letter. Interesting sub-domain patterns observed on a single crystal of Fe-Si alloy contg. 3.8% Si, are reproduced and interpreted. The bending of a domain boundary around an inclusion is also shown.—P. C. L. P.

[Discussion on a Paper by E. C. Burke and W. R. Hibbard, Jr.]: Plastic Deformation of Magnesium Single Crystals. — (*J. Metals*, 1952, 4, (11), 1200).—See *M.A.*, 20, 21.

*Studies on the Recrystallization of Magnesium and Its Alloys. III.—Recrystallized Grains Annealed at Higher Temperatures After Severe Deformation. Riehl Ichikawa and Chūyō Hisatsune (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 189–191).—[In Japanese, with diagrams in English]. The orientation and grain-size of pure Mg crystals, which were deformed 20–60% and annealed at 640° C. for 1–4 hr., have been examined metallographically and by X-ray analysis. It is reported that: (1) recrystallized grains of crystals deformed 45–55% grew abnormally; (2) the inclination of the hexagonal axis [0001] to the direction of working was from 0° to ~30° after pressing or forging; (3) for samples annealed at 640° C., the inclination of [0001] to the direction of working was from 0° to ~50° and for samples whose grains grew abnormally it was 15°–70°; and (4) the inclination increased a few min. after heating at 640° C. and after 1–4 hr. heating at this temp. it was 15°–70°.—AUTHORS.

[Discussion on a Paper by R. S. Busk:] Effect of Temperature on the Lattice Parameters of Magnesium Alloys. — (*J. Metals*, 1952, 4, (11), 1223–1225).—See *M.A.*, 19, 775.

*Growth Spirals on Magnesium Crystals. A. J. Forty (*Phil. Mag.*, 1952, [vii], 43, (339), 481–483).—A letter. By exposure to air and Plasticene and examination under phase-contrast illumination, growth spirals have been revealed on the (0001) surfaces of Mg crystals grown from the vapour. The step-height corresponds to either 1 or 2 interatomic spacings.—P. C. L. P.

[Discussion on a Paper by N. K. Chen and R. Maddin:] Plasticity of Molybdenum Single Crystals. — (*J. Metals*, 1951, 4, (11), 1198–1200).—See *M.A.*, 19, 535.

[Discussion on a Paper by M. Semchysen and G. A. Timmons:] Preferred Orientation of Arc-Cast [and Rolled] Molybdenum Sheet. — (*J. Metals*, 1952, 4, (11), 1197).—See *M.A.*, 20, 22.

*Crystal-Chemical Studies of the 5f-Series of Elements. XVII.—The Crystal Structure of Neptunium Metal. XVIII.—Crystal Structure Studies of Neptunium Metal at Elevated Temperatures. W. H. Zachariasen (*Acta Cryst.*, 1952, 5, (5), 660–664; 664–667).—[In English]. Cf. *ibid.*, (1), 19; *M.A.*, 20, 22. [XVII.—] At room temp. Np is found to be orthorhombic, with $a_1 = 4.723 \pm 0.001$, $a_2 = 4.887 \pm 0.002$, $a_3 = 6.663 \pm 0.003$ Å., with 8 atoms/cell. The structure can be regarded as a heavily distorted b.c.c. structure; it is similar to the α -U structure. There are 4 nearest neighbours and 4 rather farther apart; the former are so close that they must be covalent, with a strength between that of a single and double bond. From the effective atomic radius it is concluded that Np has either one or no 5f electron. [XVIII.—] The orthorhombic α -form of Np is stable up to ~278° C. Expansion coeff. are listed. Above 278° C., β -Np is tetragonal, with $a_1 = 4.897 \pm 0.002$, $a_3 = 3.388 \pm 0.002$ Å. (at 313° C.), with 4 atoms/cell. There are 4 closest neighbours, thought to be covalently bound. There is some evidence for the existence of a b.c.c. γ -Np above ~550° C.—R. W. C.

*Creep-Rupture and Recrystallization of Monel from 700° to 1700° F. (370° to 925° C.). (Grant and Bucklin). See col. 468.

[Discussion on a Paper by W. C. Leslie, K. G. Carroll, and R. M. Fisher:] Diffraction Patterns and Crystal Structure of Si_3N_4 and Ge_3N_4 . — (*J. Metals*, 1952, 4, (11), 1201).—See *M.A.*, 19, 776.

[Discussion on a Paper by F. D. Rosi, B. H. Alexander, and C. A. Dube:] Kinetics and Orientation Relationships of Secondary Recrystallization in Silver. — (*J. Metals*, 1952, 4, (11), 1206).—See *M.A.*, 19, 776.

*Interatomic Distances and Atomic Valences in NaZn_{13} . David P. Shoemaker, Richard E. Marsh, Fred J. Ewing, and Linus Pauling (*Acta Cryst.*, 1952, 5, (5), 637–644).—[In English]. A precision re-detn. has been made of the cell parameter a and the atomic position parameters, y , z , of NaZn_{13} . Least-squares methods were used for all 3 quantities. For a , this was combined with Nelson and Riley's (*Proc. Phys. Soc.*, 1945, 57, 160; *M.A.*, 12, 282) extrapolation function; this seems to be a new procedure. Precision was ~1 in 40,000 for a , and 1 in 500 and 2000 for y and z . The structure is described. Bond distances are calculated, and

various possible valences are considered as the basis of Pauling's relation between load strength and interatomic distance. The results are consistent with valences of 4 and 5 for the 2 kinds of Zn atom. For Na the valence then proves to be 1.27; if this is significant it implies some electron transfer. With Zn = 4 and 5, and putting Na = 1, there are 432 electrons/cell. A Brillouin zone bounded by {800}, {444}, and {640} is almost spherical and can contain 428.5 electrons; these forms give strong X-ray spectra.—R. W. C.

*Plastic Deformation [of Single Crystals] of Silicon and Germanium. R. G. Treuting (*J. Metals*, 1952, 4, (10), 1044).—An A.I.M.M.E. Research in Progress summary. On bending single crystals of Ge and Si (which have a diamond structure) at temp. of 900° and 1170° C., resp., traces of a (111) slip plane and gliding are observed. X-ray analysis of deformed Ge crystals suggests that polygonization and flow mechanisms other than slip also occur—phenomena which do not appear to take place in Si at less extensive deformation. Experiments to strain Ge in uniaxial tension are in progress, and it is hoped to report on the slip direction. 2 ref.—E. N.

*Twinning in Single Crystals of Titanium. T. S. Liu and M. A. Steinberg (*J. Metals*, 1952, 4, (10), 1043).—An A.I.M.M.E. Research in Progress summary. When Ti is produced by fused-salt electrolysis, the flakes formed have a single-crystal nature, and the flat surfaces correspond to (0001) basal planes; these flakes show profuse twinning when handled. Two sets of mutually \perp twin traces can be distinguished on the basal plane, which make perfect 60° angles with each other. The planes responsible for twinning have been identified by two methods, and found to be the (10 $\bar{1}$ 2), (11 $\bar{2}$ 1), (11 $\bar{2}$ 2), (11 $\bar{2}$ 3), and (1124) planes.—E. N.

*Growth Spirals Originating from Screw Dislocations on Electrolytically Produced Titanium Crystals. M. A. Steinberg (*J. Metals*, 1952, 4, (10), 1041–1042).—An A.I.M.M.E. Research in Progress summary. In the prodn. of Ti by fused-salt electrolysis, large hexagonal flakes have been obtained, which X-ray and metallographic examination have shown to be single crystals with flat (0001) plane surfaces exhibiting growth spirals originating from screw dislocations, and having an average step height of 240 ± 100 Å. The last-mentioned is evidence that these spirals cannot be caused by dislocations of unit strength, but are generated by groups of dislocations all having the same sign and having a resultant Burgers vector with a component \perp (0001) of approx. 100 Å. However, in some cases, steps of <100 Å. have been found. Besides multiple spirals originating at the same dislocation centres, spirals of opposite sign, interacting so as to form closed loops have been observed in accordance with theory.—E. N.

*Observations on the Lattice Parameters of the Alpha and TiO Phases in the Titanium-Oxygen System. W. Rostoker (*J. Metals*, 1952, 4, (9), 981–982).—An X-ray study of the Ti-O system shows that α -Ti can tolerate the unusually high-saturation solubility of ~34 at.-% O. The O occupies interstitial positions in the h.c.p. α lattice, and causes a pronounced distortion in its c parameter, which increases to 4.82 Å. ($c_0 \cong 4.68$ Å.), while the a parameter ($a_0 = 2.945$ Å.) increases only to 2.955 Å. at 10 at.-% O, and thereafter remains const. The NaCl-type cubic structure of the TiO phase is confirmed; its parameter decreases from 4.181 Å. at 47 at.-% O to 4.162 Å. at 54 at.-% O. The nature of the bonding within this phase is discussed. Resistivity measurements, which suggest a full Brillouin-zone condition and exclude the possibility of either covalent or ionic bonding (as postulated by Ehrlich), favour the hypothesis of a metallic bonding with O as a donor rather than an acceptor of electrons. Within the miscibility range the phase has a const. concentration of ~23.85 electrons/unit cell, if the O^{3+} ion is assumed to be present. An O^+ ion would yield the same trend; O^{2+} and O^{4+} ions are obviated for various reasons. 7 ref.—E. N.

*Quantitative [X-Ray] Determination of Preferred Orientation [in Uranium]. J. H. Bach and J. B. Burnham, Jr. (*J. Metals*, 1952, 4, (10), 1043).—An A.I.M.M.E. Research in Progress summary. It is shown that if there exists, in a randomly oriented sample of known structure and symmetry,

a family of planes whose total diffracting power remains const., no matter what the orientation of the sample, the intensity ratio of all other sets of planes to that of such a standard plane can be calculated and the quotient of the measured ratio with calculated ratio can be taken as a measure of orientation. Such a standard plane has been observed in samples of U and found to have the (111) habit. Experiments are in progress to determine whether such const. intensity planes can be found in other metals.—E. N.

***The Plastic Deformation of Zinc Bicrystals.** Tomoyoshi Kawada (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 591-602).—*Cf. M.A.*, 19, 719. Zn bicrystal specimens were prepared with a longitudinal grain boundary and with the orientations of the crystals relative to the boundary differing by selected amounts. Stress/elongation curves were taken, and the cross-sectional shapes and twist of the specimens after deformation studied. It is shown that the results can be satisfactorily explained by the interaction of the component crystals without considering the mech. properties of the boundary, and that the tensile properties of the bicrystals can be related to those of single crystals. 5 ref.

—D. M. P.

***Energy Absorption During Twin Formation in Zinc Single Crystals.** E. I. Salkovitz (*Phys. Rev.*, 1952, [ii], 85, (6), 1046-1047).—Two single crystals of 99.999%-purity Zn of different orientation were grown, and the energy absorbed on twinning by impact measured, using a ballistic pendulum. Results on one crystal tested at -180° , 20° , and 200° C. indicate that the energy absorbed decreases with increasing temp. At room temp. the data obtained on two crystals suggests that the energy absorbed is less the closer the basal plane approaches normality to the specimen axis.

—P. C. L. P.

***Electrolytic Polishing of Zirconium, Titanium, and Beryllium.** P. A. Jacquet (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 732-751).—Zr can be electrolytically polished in an electrolyte contg. 350 c.c. ethyl alcohol (95%), 100 c.c. aq. HClO_4 ($d = 1.20$), and 100 c.c. butyl cellulose in the automatic Disa-Electropol apparatus (Knuth-Winterfeldt, *Rev. Aluminium*, 1951, (175), 84; *Trans. Instruments and Measurements Conf., Stockholm*, 1949, 223; *M.A.*, 19, 374) with a voltage of 30 V. Standard acetic-perchloric acid baths do not give good results unless the Zr is pure. Ti is best polished in an electrolyte contg. 191 c.c. acetic anhydride, 46 c.c. HClO_4 ($d = 1.59$), and 12 c.c. distilled H_2O at 60 V. and a c.d. of 20-25 amp./dm.². Agitation and frequent cooling of the cell are essential. A method of colouring the Ti grains is described. The Zr electrolyte can be used for polishing Be in the Disa-Electropol or a simple cell at 40 V. The methods were applied to Zr and Ti and Ti alloys of various compn. and in various conditions. The microstructures were found to be very sensitive to surface abrasion. 20 ref.—D. M. P.

***The Use of the Three-Stage Electron Microscope in Crystal-Structure Analysis: [Dimensions of Unit Cell of σ -Phase from Cr-Ni-Mo Steel].** J. F. Brown and D. Clark (*Acta Cryst.*, 1952, 5, (5), 615-619).—[In English]. The principles involved in using a (commercial) electron microscope to give single-crystal electron-diffraction patterns from a selected crystallite, are explained. The method is applicable to crystals 100-1000 Å. thick and a few sq. μ in area. If the crystal is tabular, the orientation is likely to be symmetrical. The use of such patterns is in the detn. of the shape and size of unit cells, allowing intractable X-ray powder patterns of the corresponding substance to be indexed. In this way, σ -phase extracted from Cr-Ni-Mo steel was found to have a tetragonal unit cell with $a = 8.809 \pm 0.004$, $c = 4.585 \pm 0.002$ Å. An extract of Cr_{23}C_6 was found to be tabular || {111} planes of its f.c.c. lattice. In this way the identity of a constituent recognizable on electron-microscope replicas has been confirmed.—R. W. C.

***Microconstituents in High-Temperature Alloys.** H. J. Beattie, Jr., and F. L. VerSnyder (*Amer. Soc. Metals Preprint*, 1952, (1), 27 pp.).—The microconstituents present in a number of high-temp. alloys were electrolytically separated from the matrix of the alloy and examined microscopically

and by X-rays. Alloys of five compn. groups were studied: (a) C 0.15, Si 1, Mn 1, Cr 19, Co 10, Mo 10, Ti 2, Al 0.3-1, Fe 0.5-4.0%, balance Ni; (b) C 0.1, Si 0.3-0.8, Mn 1.6, Cr 16, Mo 6, Ni 26%, balance Fe; (c) C 0.1, Si 0.75, Mn 1.7, Cr 18, Mo 2.5, Ti 1.4, Al 1.4, Ni 24, W 1%, balance Fe; (d) C 0.2, Si 0.5, Mn 1, Cr 19, Co 48, Fe 3, Ni 15, Nb 1, W 12%; (e) C 0.2, Si 0.2, Mn 0.5, Cr 19, Co 49, Fe 1.3, Ni 17, Nb + Ta 1, W 11.5%. The carbonitrides of Ti and Nb were found in most of the alloys. Formation of the N-rich Ti(C,N) depends on N contamination of the melt—this constituent is mech. included in the alloy. Diffusion of C into the N-rich Ti(C,N) may ultimately result in formation of C-rich crystals of Ti(C,N). The N-rich carbonitride in alloys of group (a) is little affected by heat-treatment below the solidus temp., but the C-rich Ti(C,N) is changed in size and shape. A Laves compound M_2Ti isomorphous with MgZn_2 , is formed when the Ti content of alloys of group (a) is increased, or the (low-C) alloy is given extended heat-treatment. An unstable Laves compound Fe_2Al , may appear in the as-cast structure of alloys of group (c). An ordered h.c.p. Hägg-type double nitride CrMoN_2 is found in alloys of group (b). The complex carbide M_6C is found in alloys contg. $>5\%$ Mo or W. Much crystallographic information is given on the carbides and nitrides present in these alloys. The structure factors of the M_6C and M_{23}C_6 carbides, indicate that the second Brillouin zones in these structures contain ~ 7 electrons/metal atom. 13 ref.—R. W. R.

***Interferometric Studies of Hardness-Test Indentations: Investigations on Tungsten Carbide, Steel, Duralumin, and Tin.** S. Tolansky and D. G. Nickols (*Phil. Mag.*, 1952, [vii], 43, (339), 410-421).—The surface of specimens after hardness tests has been studied by multiple-beam interference methods. Indentations much greater than the grain-size were made in sintered WC, martensitic steel, and Duralumin with a Vickers pyramidal diamond indenter, and in the steel with a conical indenter also; these reveal that the association between "concavity and sinking-in" and "convexity and piling-up" is not as simple as previously supposed. The observation that in WC, indentation concavity occurs together with piling-up, is attributed to the effect of elastic recovery. The unsymmetrical surface topography around indentations on individual crystals of a flat surface of 99.992% purity Sn is related to the anisotropy and crystal orientation. In certain directions appreciable distortion extended beyond four times the diagonal length, so that, in hardness tests on individual grains, it is recommended that the indentations be separated by at least eight times the diagonal length.

—P. C. L. P.

[Discussion on a Paper by R. B. Pond and S. W. Kessler:] **Model for Dendrite Growth Form in Metals and Alloys.** (*J. Metals*, 1952, 4, (11), 1186-1189).—*See M.A.*, 19, 651.

***Origin of Spiral Eutectic Structures.** R. L. Fullman and D. L. Wood (*J. Metals*, 1952, 4, (10), 1041).—An A.I.M.M.E. Research in Progress summary. It is proposed that eutectic structures in which two phases appear spiralled about each other in cross-section, are produced when one phase grows faster in all directions lying in the plane of the spiral, and the other phase is the faster growing one in the direction \perp the plane of the spiral. Observations of the three-dimensional shape of the spirals in an alloy of Zn with 3% Mg are in agreement with predictions based on this hypothesis.—E. N.

Nucleation from Solids: Theory of Nucleation in Solids. Roman Smoluchowski (*Indust. and Eng. Chem.*, 1952, 44, (6), 1321-1323).—Presented at an American Chemical Society Symposium on Nucleation Phenomena. The basic problem of a theory of nucleation in solids is outlined and the complications caused by a departure from the conditions for applicability of Volmer's theory are described. The various theories and their comparison with experimental data are summarized and a discussion given of the nucleation theory of recrystn. and its successful interpretation of observations. The qual. agreement with experiment confirms general ideas about nucleation, but the absence of quant. agreement does not permit a critical appraisal of the sp. assumptions.—D. P. M.

Precipitation from Solid Solution. J. C. Fisher, J. H. Hollomon, and J. G. Leschen (*Indust. and Eng. Chem.*, 1952, 44, (6), 1324-1327).—Presented at an American Chemical Society Symposium on Nucleation Phenomena. Pptn. in solids differs from that in liquids and vapours largely by the possibility of coherency relationships between the parent and precipitating phases. The free energy/unit area of coherent interfaces is very small, and coherent precipitates form whenever the free-energy change of the transformation is sufficient to provide the elastic coherency strain. Many observations of the types of precipitates that form in various temp. ranges and of the mech.-property changes that accompany pptn. can be understood in terms of coherent and non-coherent pptn.—D. P. M.

Nucleation and Growth of Flow and Fracture Markings. Waller George (*Indust. and Eng. Chem.*, 1952, 44, (6), 1328-1331).—Presented at an American Chemical Society Symposium on Nucleation Phenomena. Macroscopic observations of the temporal and spatial development of localized plastic flow and fracturing in polymeric solids and metals are used to suggest "models" of the phys. character of the microscopic processes of plastic flow. The nature of delayed yielding in metals and polyamides is reviewed. Special emphasis is placed upon the advance nucleation of macroscopic flow and fracture elements in the region of stress concentration in advance of the primary flow or fracture event. This effect is illustrated in the growth of fatigue fractures, creep fracture, horizontal flow markings, or craze cracks. Fracture pairs and showers are illustrated, and it is suggested that these phenomena similarly involve advance nucleation within the contracted stress fields associated with rapidly advancing primary flow or fracture elements. 33 ref.—D. P. M.

***The Order-Disorder Transformation Viewed as a Classical Phase Change.** F. N. Rhines and J. B. Newkirk (*Amer. Soc. Metals Preprint*, 1952, (12), 18 pp.).—To determine whether order-disorder changes are normal Gibbsian phase changes or are second-order transformations as is commonly held, R. and N. have reviewed published information on these transformations. In addn. resistivity and X-ray-diffraction measurements were made on Cu-Au and Cu-Zn alloys to obtain further evidence. This experimental work showed: (a) that ordered and disordered phases can exist in equilibrium within the temp. interval of transformation in Cu-Au alloys near the compn. Cu_3Au ; and (b) that resistivity changes in Cu-Au and Cu-Zn alloys are not inconsistent with the view that the ordering changes are classical phase changes. In the case of the Cu-Au alloys, the temp. interval of transformation nears zero as the compn. Cu_3Au is approached. Measurements were also made of the rate of the ordering transformation in Cu-Au alloys. The rates found are consistent with a nucleation and growth mechanism, and thus support the idea of a classical phase change. Consideration of all the evidence leads to the view that order-disorder changes are normal phase changes. 41 ref.—R. W. R.

***Some Generalized Order-Disorder Transformations.** R. B. Potts (*Proc. Cambridge Phil. Soc.*, 1952, 48, (1), 103-109).—The problem posed is to consider the inversion transformations for a square lattice in which each unit is capable of r configurations. The analysis follows the lines of the matrix method used by Kramers and Wannier in deducing an invariant transformation of the no-field Ising lattice, under which the partition function of the lattice is invariant when the temp. is transformed from a low to a high, "inverted" value (*Phys. Rev.*, 1941, [ii], 60, 252, 263; *M.A.*, 9, 6). Inversion transformations can be found for $r = 2, 3$, and 4 only. The case of 3 configurations has been shown to be a particular case of a more general problem of r kinds of units in equal abundance, and the inversion transformation and transition point have been found.—J. S. G. T.

[Discussion on a Paper by W. Rostoker:] **Analytical Representation of Certain Phase Boundaries.** — (*J. Metals*, 1952, 4, (11), 1209-1211).—See *M.A.*, 19, 539.

***The Separation of Stacking-Fault Broadening in Cold-Worked Metals.** B. E. Warren and B. L. Averbach (*J.*

Appl. Physics, 1952, 23, (9), 1059).—A note. The line shapes of 5 orders of the (111) reflection, and of 4 orders of (200) from a cold-worked (rolled) Cu-2% Si crystal were measured. (333) and (511), and (600) and (442) could be separated since the worked specimen retained a preferred orientation. The line shapes were analysed by W. and A.'s Fourier method (*ibid.*, (4), 497; *M.A.*, 20, 172) and the coeff. A_L plotted against $(h^2 + k^2 + l^2)$. If the broadening is partly due to stacking faults, different reflections are differently affected, (333) and (600) having no broadening due to faults. This would result in the values of A_L for these reflections being displaced from the smooth curves passing through the other orders of the (111) or (200) series. No such displacements were found. It is thought that experiments with the 5% Si alloy might give positive results.—R. W. C.

***The Non-Hookean Interaction of a Dislocation with a Lattice Inhomogeneity.** M. A. Jaswon and A. J. E. Foreman (*Phil. Mag.*, 1952, [vii], 43, (337), 201-220).—Calculations are made of the interaction between an edge dislocation and discontinuities where the interatomic force law changes across the slip plane. Such changes can arise from a micro-crack in the slip plane, a change in lattice spacing, or at a grain boundary. It is necessary to assume that the elastic const. of the material show no discontinuity. The external shear stress required to hold a dislocation at various distances from different barriers is evaluated, and the results extended to an array of similar dislocations piled up against the barrier.—P. C. L. P.

Influence of Texture on the Deformation of Metals. J. Hérenghuel (*Métaux, Corrosion-Ind.*, 1952, 27, (317), 1-13).—H. reviews briefly the causes and effects, and methods of correcting orientation textures, and textures due to inhomogeneity of solid soln. and to the presence of insoluble phases.—M. A. H.

***The Interpretation of Diffuse X-Ray Reflections from Single Crystals.** J. Hoerni and W. A. Wooster (*Acta Cryst.*, 1952, 5, (5), 626-630).—[In English]. The construction is described of a set of 4 charts for identifying the particular point in reciprocal lattice space corresponding to each point of the diffuse pattern near a Bragg or Laue spot on a single-crystal photograph (diffuse scattering being due to temp. vibrations, age-hardening, stacking faults, &c.). So that the same chart can be used for the surrounds of all reciprocal lattice points, the photometric readings from the (cylindrical) film need to be replotted with different vertical and horizontal scales. The charts are calibrated in terms of co-ordinates referred to special Cartesian axes, of which one is the vector joining the reciprocal lattice point itself to the origin. A specimen chart is reproduced.—R. W. C.

***Statistical Mechanics and the Partition of Numbers. II.—The Form of Crystal Surfaces.** H. N. V. Temperley (*Proc. Cambridge Phil. Soc.*, 1952, 48, (4), 683-697).—In continuation of previous work (*Proc. Roy. Soc.*, 1949, [A], 199, 361) the classical theory of the partition of numbers is used to discuss the equilibrium profile of a simple cubic crystal. Two problems are discussed, viz. (1) the equilibrium shape to be expected if a cubic crystal is grown in the space bounded by two or three walls at right angles, and (2) the explanation of the "saw-tooth" pattern, characteristic of real crystals. It is considered that it may be "thermodynamically profitable" for the crystal surface to be saw-toothed rather than plane, the extra entropy, ϕ , associated with such a configuration compensating for the additional surface energy. For a simple cubic lattice, ϕ associated with the formation of a tooth contg. N atoms has the estimated value $3.3 kN^{2/3}$, where k is Boltzmann's const. The variation of the "equilibrium roughness" of a crystal with temp. can be estimated if the surface energy of the crystal is known.—J. S. G. T.

***An Aid for Making Stereographic Plots when Working with Cubic Crystals.** Colman Goldberg (*J. Metals*, 1952, 4, (11), 1160-1161).—Latitude and longitude tables are given, which make it possible to plot any plane (hkl) of a cubic crystal on a standard (001) projection, if the abs. values of the individual h , k , and l are nine or less, which is almost always the case. The tables enable: (1) a standard

projection to be made, which will be of exactly the proper size for the available stereographic net, and (2) planes to be easily plotted that do not appear on the previously published standard projections. 2 ref.—E. N.

***The Stability of Hexagonal [Crystal] Lattices with a Simple Law of Force.** F. R. N. Nabarro and J. H. O. Varley (*Proc. Cambridge Phil. Soc.*, 1952, 48, (2), 316–328).—An hexagonal crystal lattice, bound by central forces between nearest-neighbour atoms is always close-packed, and for ideal close-packing, the axial ratio, $c/a = 1.63299$. In metals, observed values of c/a range from 1.47 for Be to 1.89 for Cd. An h.c.p. equilibrium structure is still possible, if there is present energy which, like the Fermi energy of free electrons, depends only on the vol., but there may be another hexagonal structure of lower energy. The combination of a vol. energy with a central potential showing two sharp min. is shown to lead to a stable hexagonal structure which is not close-packed. A numerical example in which values of the lattice spacing, binding energy, and elastic const. are comparable with those of Zn, and in which the law of force shows no obvious peculiarities is worked out. The Cauchy elastic const. relations are not satisfied.—J. S. G. T.

Markings Found in the Oxide Replicas for Electron Microscopy. Shigeto Yamaguchi (*J. Appl. Physics*, 1952, 23, (9), 935–936).—Oxide replicas of faceted cryst. surfaces are sometimes particularly transparent at the facet edges, sometimes opaque. On the evidence of his own and other work, Y. concludes that transparent edges occur when the facets are related to the crystal structure. There is oriented growth of the oxide \perp the facets, causing a gap in the film at the edges. Where the facets are “ghosts” of a former cryst. structure, there is no oriented growth and the film is thicker at the edges. In the first case the width of the transparent image of an edge is always 300–800 Å.—R. W. C.

***On the Metallic Shadow-Casting Using a Nozzle System.** Tadatosi Hibi (*J. Appl. Physics*, 1952, 23, (9), 957–963).—Shadows formed by streams of metal atoms evaporated at an angle to a replica surface improve contrast in an electron microscope, but the quality and definition of the shadows is often poor. This has been remedied by interposing a glass nozzle between the evaporation coil and the replica, and also a shutter so that the coil can be outgassed without affecting the replica. The nozzle slows down the metal atoms, and so reduces their surface mobility on the replica, and stray impacts are prevented. Results are good for a large number of shadowing metals. There is a discussion of the relative excellence of different metals; the metals with the highest heat of sublimation give the best shadows.—R. W. C.

***Electronic Bound States at the Surface of a Metal.** G. R. Baldock (*Proc. Cambridge Phil. Soc.*, 1952, 48, (3), 457–469).—Conditions under which bound states associated with atoms in the surface of a metal may exist are investigated math., using the tight-binding approximation. These states arise as the result of modifications in the wave parameters of atoms.

It is shown that most of the simpler crystal structures do not exhibit surface states (which have been invoked to explain various phenomena, e.g. frictional electricity, rectification characteristics of a metal/semi-conductor contact, and the contact potentials of Si surfaces) without such modifications; in the graphite and diamond lattices surface states occur due solely to the lattice geometry.—J. S. G. T.

***Some Investigations in the Field of the Theory of Solids. I.—Linear Chain of Similar Atoms. II.—Linear Chain of Different Atoms. Binary Systems.** (I) T. A. Hoffmann and A. Kónya. (II) T. A. Hoffmann (*Acta Phys. Acad. Sci. Hungar.*, 1951, 1, (1), 5–35; (2), 175–195).—[In English]. [I.—] A math. analysis of the properties of long chains of similar solid atoms, including metals, based upon the molecular-orbital method of quantum mechanics is developed. An expression is derived for the wave function, and, therefrom, values of certain end effects, viz. the work-function and dipole moment, are deduced. [II.—] The analysis developed in [I] is extended to include long chains of different atoms, more especially to cases in which atoms of different kinds are present in approx. the same numbers. Formulae are derived for the average energy per electron, the binding energy, band widths, &c., for ordered linear binary alloys, with particular ref. to binary alloys of the types A-B-A-B, A-A-B, A-A-B-B, A-A-A-B.—J. S. G. T.

***(I.) An Extension of the Statistical Formulation of the Prohibited Occupation of Fully-Occupied Electronic States in Atoms. (II.) Theory of the Noble and Alkali Metals.** P. Gombás (*Acta Phys. Acad. Sci. Hungar.*, 1951, 1, (3), 285–294; 301–316).—[In German]. (I.) The math. atomic theory developed by G. in previous work (*Z. Physik*, 1941, 118, 164), is improved by grouping the electrons of statistically-treated atomic residues according to their second quantum number. The resulting formulae facilitate the calculation of the energy levels both of the noble and alkali metals as well as the metals Cu, Ag, Au, Zn, Cd, and Hg; moreover, new bases are provided for a theory of the structures of the noble and alkali metals and Zn, Cd, and Hg. (II.) The theory developed in (I) is used to develop a theory of electronic states in the noble metals. Theoretical and observed values of atomic dimensions, lattice energy, and energy of sublimation are in good agreement for Cu and K.—J. S. G. T.

***The Exchange Integral in the 3d Shell.** Harvey Kaplan (*Phys. Rev.*, 1952, [ii], 85, (6), 1038).—A letter. Calculation of the exchange integral J , between two atoms each with one 3d electron has given a positive result. The corresponding internuclear sepn. is only ~ 0.75 Å., and although J probably remains positive at considerably larger sepn., it remains unproven that J is positive in the transitional metal crystals.—P. C. L. P.

***Motion of an Electron in a Perturbed Periodic Potential.** Edward N. Adams, II (*Phys. Rev.*, 1952, [ii], 86, (3), 427–428).—A letter. A. simplifies the mathematics of his paper (*ibid.*, 1952, [ii], 85, 41; *M.A.*, 20, 413), generalizes certain parts of the treatment, but arrives at a similar conclusion.—P. C. L. P.

X-Ray Crystallographic Technology. (Guinier). See col. 541.

5 — POWDER METALLURGY

***Effect of Cycle-Sintering in the Powder Metallurgy Process [of Iron].** H. H. Hausner (*J. Metals*, 1952, 4, (10), 1039–1040).—An A.I.M.M.E. Research in Progress summary. High-purity, fine-grained Fe powder has been formed into small compacts at pressures of 10–40 tons/in.² and sintered at various temp. for 2 hr., (a) at const. temp., and (b) by cycling every 5 min. from 15° above to 15° C. below the desired temp. In general, no difference could be observed between the properties of the two types of compacts. When cycle-sintering was carried out through the $\alpha \rightarrow \gamma$ transformation temp., however, the compacts, as compared with the regularly sintered compacts (1) had a linear shrinkage which was less in the compacting direction but considerably greater \perp this direction, (2) were of substantially larger grain-size, and (3) contained fewer, but larger, voids. It is considered that

cycle-sintering is a valuable method for the analysis of the sintering process.—E. N.

***Experimental Production of Magnetic (Sendust) Powder Cores.** E. G. Thurlby (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 490–501).—The properties of Fe-Si-Al powder magnetic cores are outlined from early Japanese work. The initial permeability reaches a peak of 35,000 Oe. at 9.6% Si and 5.4% Al, and the max. permeability (reported as 160,000 Oe.) occurs at 9.7% Si and 6.2% Al. The compn. are critical, and an insulating film has to be formed on the particles to reduce losses. T. reports the results of a preliminary survey of the problems of producing satisfactory cores. Melting can be carried out under H; crushing and milling present no difficulties; annealing the powder to restore permeability and produce an insulating oxide film is thought

to be best carried out for 2 hr. at 600° C. *in vacuo* (0.1 mm. Hg); the powder can be bound with Na silicate and boric acid and pressed at pressures up to 130 tons/in.²; final baking is best carried out at 500°–700° C. and greatly affects the properties of the cores. Many problems remain, but cores made under correct conditions should prove a substitute for Permalloy. 5 ref.—D. M. P.

***On the Development and Properties of Heat- and Scale-Resistant Hard Alloys Based on Titanium Carbide with Nickel-Cobalt-Chromium Binders.** R. Kieffer and F. Kölbl (*Planseeber. Pulvermet.*, 1952, 1, (1), 17–35).—The results of the most important researches on Ti-rich sintered carbides, with and without binders, are tabulated. While the oxidation of most sintered carbides is linear, that of TiC is parabolic and if a scale-resistant matrix is used oxidation is remarkably slow (~0.54% increase in weight in 48 hr. at 900° C., as against 14.8% for metallic W; ~0.03% in 48 hr. at 700° C., as against 0.63% for metallic W, 2.0% for W₂C and 3.0% for WC). TiC, WC, TiC–Mo₂C, and TiC–WC powders were pressed and the compacts allowed to absorb molten alloys of the following compn.: 80:20 Ni–Cr; 80:20 Co–Cr; 66:28:6 Co–Cr–Mo; 65:28:6:1 Co–Cr–Mo–C; 72.7:17.3:10 Co–Cr–TiC. Hardnesses of ~90 Rockwell A and bending strengths of ~100 kg./mm.² were obtained. The scaling behaviour of all samples was similar up to 1100° C., except for alloys with >10% Mo₂C which were somewhat less resistant; at 1200° and 1300° C. alloys with 3–5% Mo₂C were noticeably worse than Mo-free samples. Co–Cr and Ni–Co–Cr binders gave better resistance to scaling than Ni–Cr. On the basis of these and of unpublished results, the WZ range of alloys was put into prodn.; the binders were added in the form of powder. In this range, WZ 12b (TiC 60, Ni 24, Co 8, Cr 8%) has the highest resistance to oxidation (0.230% increase in wt. in 50 hr. at 900° C., 0.305% in 50 hr. at 1000° C., 0.384% in 30 hr. at 1100° C.). The U.T.S. at room temp. of WZ 12c (TiC 50, Ni 30, Co 10, Cr 10%) is 75–85 kg./mm.². Alloy WZ 1b (TiC 60, Ni 32, Cr 8%) will sustain ~32 kg./mm.² for 100 hr. at 800° C., ~19 kg./mm.² at 900° C., ~10 kg./mm.² at 980° C., ~19 kg./mm.² for 1000 hr. at 800° C., ~13 kg./mm.² at 900° C., ~6 kg./mm.² at 980° C. A turbine rotor of WZ 12 has given satisfactory service at 30,000–35,000 r.p.m. with a blade temp. of 1020° C. WZ alloys are produced in England under the designation "Elmet-H.R.", and high resistance to temp. fluctuation is claimed (3500–4000 cycles at 800° C., as against 2000 for Nimonic 80A).—K. S.

***Sintered Electrical-Contact Materials. III.—Infiltration of Tungsten Bodies with Copper and Silver.** W. Rutkowski and S. Stolarz (*Prace Inst. Met.*, 1952, 4, (1), 67–81).—[In Polish]. Cf. *ibid.*, 1951, 3, 297; *M.A.*, 20, 27. Powdered W with a grain-size of up to 3 μ was compacted into 15 mm. long cylinders of 7½ mm. dia. at 2–20 tons/cm.², sintered for 3 hr. at 800°–1200° C. in a H atmosphere, and infiltrated in a Tamman furnace for 20 min. with Cu at 1100°–1400° C. or with Ag at 1100° C. In some cases already sintered W specimens with grain-sizes of <65, 65–125, and 126–150 μ were compressed at 5 or 10 tons/cm.² and used for infiltration. The effects of compn., grain-size, sintering temp. and pressure, and temp. and time of infiltration on *d*, hardness, elect. conductivity, and arcing resistance were investigated, and the results are tabulated and plotted. As compared with sintered (not infiltrated) contacts, the infiltrated contacts have a higher *d* and hardness and their arcing resistance is five times greater; their prodn. is cheaper and takes less time, but requires a special furnace, and machining is more difficult.—A. G.

***Reactions During Sintering of a Zirconium Carbide-Niobium Cermet.** W. G. Lidman and H. J. Hamjian (*J. Amer. Ceram. Soc.*, 1952, 35, (9), 236–240).—A study was made of the effect of sintering time and temp. on the structure and mech. properties of a ZrC–Nb Cermet contg. 12.5% Nb; the specimens were prepared by sintering under pressure. Lattice-parameter measurements showed that the following reaction occurred during sintering: Nb + ZrC → NbC + Zr, and that the NbC thus produced formed a homogeneous solid soln. with the remaining ZrC. Metallographic examination showed that at 3900° F. (2140° C.) the Zr metal was found in the grain

corners of the carbide structure. Fine dispersion of the Zr results in high strength and modulus of rupture. Since long sintering times result in coalescence of the Zr particles, there is an optimum sintering time.—R. W. R.

***Effect of Grain-Size and Density on Mechanical Properties of Sintered Carbides.** W. G. Lidman and H. J. Hamjian (*J. Metals*, 1952, 4, (10), 1040–1041).—An A.I.M.M.E. Research in Progress summary. The effects of varying sintering temp. and time on the phys. properties of powder compacts are being studied. The results show that: (1) increasing grain-size and *d* improves the room-temp. strength and hardness, (2) max. phys. properties are obtained with specimens below max. *d*, and (3) a coarse grain-size may not be detrimental to strength at elevated temp.—E. N.

Metal-Ceramic Composites.—I.—II. J. H. Westbrook (*Amer. Ceram. Soc. Bull.*, 1952, 31, (6), 205–208; (7), 248–250).—[I.—] W. briefly discusses composite materials in general and describes the principal properties of metal-ceramic bodies. The manufacture and appn. of these bodies are considered. 63 ref. [II.—] W. discusses the mechanism of bonding in metal-ceramic compacts; information on the mech. and phys. properties of these materials is briefly reviewed. The need for further work is emphasized. 44 ref.—R. W. R.

***The Initial Phase of Sintering.** H. H. Hausner and J. L. Zambrow (*J. Metals*, 1952, 4, (10), 1040).—An A.I.M.M.E. Research in Progress summary. Detn. have been made of the elect. resistivity of carbonyl Ni powder compacts heated to 100° C. in A and H. Heating in A to 100° C. resulted in an extremely slight decrease in resistivity, probably as a result of strain-relief. Considerable decrease in resistivity (up to ~40%) was observed when heating occurred in H at temp. as low as 50° C., and the decrease was the greater the smaller the grain-size of the powder. It is considered that, although it is improbable that reduction of the slightly oxidized powder-particle surfaces could have taken place at this low temp., a certain state of readiness, or an induction period, for reduction must have occurred, involving lattice disturbances and imperfections. These imperfections appear to be the cause of the migration and exchange of atoms resulting in a low degree of bonding between powder particles and, therefore, a lowering of the elect. resistivity.—E. N.

***Two Powder-Metallurgical Methods to Prepare Alloy Specimens on a Laboratory Scale.** Jacob Schramm (*Proc. First World Met. Congress (Amer. Soc. Metals*, 1951, 682–694).—Details are given of methods evolved for the prodn. of alloys from components of widely differing m.p., e.g. Fe and Zn. (1) Powder mixtures were packed in a refractory tube, sealed in a welded Fe crucible, and sintered. The sintered compact was sealed in a thin-walled Fe container and hot forged, resulting in *d* approaching the theoretical value and uniform compn. (2) When powders contg. O were used, they were cold compacted and heated in H to reduce the oxides in a special assembly contg. molten Zn into which the compact is dipped for impregnation. The impregnated compact was then homogenized.—D. M. P.

Forming Processes for Metals [The Powder Metallurgy Process]. W. M. Halliday (*Mass Prod.*, 1952, 28, (3), 81–87; (4), 62–69).—H. describes the technique of making powder-met. components and discusses the advantages and appn. of the process. H. discusses the characteristics and prepn. of the powdered metals and the design of the components and dies.—R. W. R.

On the Present State of German Hard-Metal Technique. W. F. Bladergroen (*Polytechn. Tijdschr.*, 1952, 7, (9/10), 149a–156a; (11/12), 183a–188a; (13/14), 220a–225a).—A detailed review of the development and present extent of the technique of producing sintered hard metal bodies in Germany. Appn. are shown with tables giving cutting speeds for a number of materials, including cast Fe, steel, bronze, brass, light-metal casting alloys, Sn alloys, and synthetic resins. Working data are given with special ref. to appn. in the elect. industry; and methods are compared showing the most economical. 21 ref.—I. S. M.

A History of the Development of Metallwerk Plansee and Its Significance to Powder Metallurgy. F. Benesovsky (*Planseeber. Pulvermet.*, 1952, 1, (1), 3-16).—A close connection is claimed between the history of the Plansee works and the development of powder metallurgy on the Continent. The plant was founded in 1921 for the prodn. of Mo and W wire and sheet by powder-met. methods. The prodn. of carbonyl Fe and Ni powders and of sintered carbides was initiated in the years 1930-35. Creep- and oxidation-re-

sistant sintered carbides in a Ni-Cr or Stellite matrix were developed in 1950; similar materials, using silicides, especially Mo silicide, are showing some promise at present.—K. S.

Powder Metallurgy: An Estimate of Its Industrial Scope in India. A. A. Krishnan (*Indian Engineering*, 1951, 129, (1), 27-30).—After a short survey of metal resources in India, K. discusses the powder prodn. and scope for powder products, giving examples of the range of these products. 13 ref.—S. R. W.

6—CORROSION AND RELATED PHENOMENA

***Atmospheric Corrosion and Stress-Corrosion of Aluminium-Copper-Magnesium and Aluminium-Magnesium-Silicon Alloys in the Fully Heat-Treated Condition.** G. J. Metcalfe (*J. Inst. Metals*, 1952-53, 81, (6), 269-278).—The corrosion behaviour of the Al alloys H10-WP and H15-WP in the extruded form has been determined in the stressed and unstressed condition by exposure to sea-water, river water, and various natural atmospheres. The corrosion attack was assessed by visual and microscopical examination and by tensile tests on the corroded material. The most severe attack of both alloys resulted from exposure to the indust. atmosphere of Sheffield, where the average loss of strength after 2 years' exposure was approx. 11%, which is equivalent to a loss of thickness of 0.012 in. There was no indication of stress-corrosion failure of either of the alloys at any of the exposure sites. The high stress-corrosion resistance of the H15-WP alloy is somewhat surprising, since in sheet form the alloy is known to be very susceptible to stress-corrosion failure. The absence of such failure is attributed to preferential attack ("foliation") occurring along grain boundaries and bands || the direction of extrusion which redistributes the concentration of stress at corrosion pits. The rate of loss of strength of both alloys exposed at Sheffield, and of H15-WP alloy exposed to a marine atmosphere, was found to decrease with time, apparently exponentially. Scatter of the results from the remaining sites was appreciable, but it was clear that in general there was a decrease in the rate of corrosion with time.—AUTHOR.

***Observations on the Behaviour of Light Alloys and Heterogeneous Assemblies in Marine Atmospheres.** A. Guilhaudis (*Rev. Mét.*, 1952, 49, (11), 791-799; discussion, 799-800).—G. describes the results of practical corrosion tests of light alloys in sea-air at various stations on the Mediterranean and Atlantic coasts of France. Corrosion appeared on the specimens during the first few months of exposure, and they then became stable. Light alloys could be used without protection, but their tarnishing is unpleasing, and they are better protected by anodic oxidation. However, local corrosion can occur in spite of this protection if Al alloys are in contact with other metals, in particular steel, and such junctions should be protected by metal spraying with Al or Zn, or by painting with Zn chromate.—J. H. W.

***Solution-Body Phenomenon [Lösungskörper] and Anisotropy of Corrosion in Bismuth Single Crystals.** Mikio Yamamoto and Jirô Watanabé (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 234).—[In English]. A letter. Y. and W. have studied the soln.-bodies of trigonal Bi crystals obtained by etching spherical single crystals of Bi, which were prepared by a method described elsewhere (*Sci. Rep. Research Inst. Tôhoku Univ.*, 1951, [A], 3, (6), 655; *M.A.*, 20, 367), with 31.6% HNO₃ for 1½ hr. This soln.-body (Lösungskörper) phenomenon is caused by different rates of corrosion along different crystallographic directions. Y. and W. report that the rates of corrosion along the <111>, <211>, and <101> directions were in the ratio 1.0 : 1.2 : 1.4. A cross-section || the (111) plane was hexagonal, whereas those || the (101) and (211) planes were nearly perfect ellipses. 10 ref.—S. R. W.

***The Corrosion of Cadmium and Zinc Coatings.** G. Schikorr (*Metalloberfläche*, 1951, [A], 5, (12), 177-185).—A study has been made of the corrosion (at 20°-25° C.) of Zn

and Cd coatings, 0.01 ± 0.001 mm. thick, electrodeposited from cyanide soln. on to 1-mm.-thick steel sheet, the amount of corrosion being measured by the loss in wt. of the specimens after the corrosion products had been removed. The results show that: (1) Cd is appreciably more resistant than is Zn, to distilled water, moist gypsum, and salt spray (3% NaCl); in synthetic sea-water, however, Cd loses almost all its superiority; (2) moist air contg. traces of phenols or ammonia has very little effect on either coating; (3) Cd corrodes rapidly, at a much faster rate than Zn, in air contg. large amounts of CH₃COOH; when only traces of this chemical are present, however, Cd is the more resistant, although, at best, both metals are rapidly attacked, and must not be used in surroundings likely to contain the vapour of this or other low-C fatty acids; (4) the fact that Cd corrodes more rapidly than Zn in S-contg. atmospheres is the result of its higher equivalent wt.; (5) Cd coatings must be < 6-8 μ thick if they are to give adequate protection against perspiration arising from const. handling; and (6) for the cathodic protection of buried steelwork, Zn is a better anode material than is Cd. 22 ref.—E. N.

***Atmospheric Exposure of Copper-Nickel-Chromium Deposits on High-Carbon Steel.** — (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 204-213).—This report of Sub-Committee II of A.S.T.M. Committee B-8 on Electrodeposited Metallic Coatings is a continuation of a first report (*ibid.*, 1949, 49, 226; *M.A.*, 18, 716). Various types of Ni and Cu + Ni coatings on steel, all with Cr finishes, were exposed at five sites, two indust., one marine, and two rural. Results are summarized for exposure periods between ~1½ and 3½ years, and the following conclusions are drawn from the results to date: (1) The type of atmosphere had a very marked effect on the rate of deterioration of the deposits as protective and decorative coatings. (2) The thickness of the Ni plate, whether direct on to the steel or part of a composite coating, was the principal factor determining the behaviour of a coating. (3) Cu undercoatings added little protective value, their effect being shown only in the early stages of deterioration or in the mildest atmospheres. (4) Buffing of a Cu undercoat had a slight beneficial effect in a similar way. (5) Applying a Ni coating in two stages with the first layer buffed was highly beneficial in a marine atmosphere, but of no benefit in indust. atmospheres. (6) The type of Ni plate (dull, semi-light, or bright) was unimportant. (7) Similar coatings behaved similarly on a high-C steel base and on a low-alloy steel base.—P. T. G.

***Oxide Films on Electrolytically Polished Copper Surfaces.** (Allen). See col. 476.

[Discussion on a Paper by W. D. Robertson:] **Metallurgical Mechanism for Mercury Stress-Cracking of Copper Alloys.** — (*J. Metals*, 1952, 4, (11), 1196).—See *M.A.*, 19, 659.

***Season-Cracking of Manganese Brass Propellers.** Yoshio Kaneda (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 637-644).—Stressed Mn brass specimens of various compn. in the as-cast and annealed conditions were immersed in NH₄OH and the times to fracture noted. The fractures were transcryst. in all cases. The results, which indicated that the test was sensitive to residual stresses, but not to microstructure, were confirmed by further tests on welded specimens. As service fractures are invariably intercryst., a chromic acid reagent (0.6 g. CrO₃, 5 c.c. H₂SO₄, 95 c.c.

H₂O) was developed which produces this type of fracture when corrosion and microstructure are the major factors and which is also sensitive to residual stresses. A summary of service failures is given and discussed.—D. M. P.

*Effect of Corrosion and Growth on the Life of Positive Grids in the Lead-Acid Cell. J. J. Lander (*J. Electrochem. Soc.*, 1952, 99, (11), 467-473).—The corrosion and growth of several binary and ternary Pb alloys were measured under various conditions. It is shown that addn. of Sn have a definite effect in slowing down corrosion. Small amounts of a third element may be added to Pb-Sn alloys to increase their tensile strength without increasing the corrosion rates. An empirical relationship between growth and tensile strength is illustrated. Positive-plate grid growth is correlated with capacity-life data for a cell having grids of 8% antimonial Pb.—G. T. C.

*Metallic Corrosion [of Magnesium] Influenced by Ultrasonic Waves. Shigeto Yamaguchi (*J. Appl. Physics*, 1952, 23, (9), 1057-1058).—A note. Two Mg specimens were subjected to attack by 3% NaCl soln. for 5 hr. at room temp. In one case the soln. was still; in the other it was agitated ultrasonically at 1 Mc./s. and an amplitude of 2.5 W./cm.². The second specimen was barely attacked, unlike the first. It is thought that this passivity is due to prevention of the normal coagulation of MgO and Mg(OH)₂; these corrosion products form thixotropic aq. suspensions, which are known to coagulate more slowly if ultrasonically agitated. The fine product particles act protectively. At double the amplitude corrosion-erosion of the corrosion products led to increased attack.—R. W. C.

Corrosion-Resisting Nickel Alloys and Chemical Progress. W. Z. Friend and F. L. LaQue (*Indust. and Eng. Chem.*, 1952, 44, (5), 965-971).—Presented at an American Chemical Society Symposium on Nickel. The importance of Ni and its alloys in the development of the chem. and process industries is emphasized. A summary of the corrosion-resisting characteristics of the principal Ni-contg. alloys is given, together with examples of sp. appn. of these alloys in the manufacture of a number of chem. products, such as those involving halogens and HF, synthetic textiles, dyestuff manufacture, and textile dyeing and finishing, synthetic plastics, antibiotics, and fatty acid and corn products. 84 ref.—D. P. M.

[Corrosion-Resistance of] Hastelloy Alloy D. Edward D. Weisert (*Chem. Eng.*, 1952, 59, (8), 258, 260, 262, 264, 266, 267).—The corrosion-resistance of Hastelloy D (Si 8.5-10.0, Cu 3.85-4.25%, balance Ni) to 69 corrosive agents is indicated by a series of charts. Data on the mech. properties and uses are also provided.—S. R. W.

*Reaction of Tantalum with Hydrogen Chloride, Hydrogen Bromide, and Tantalum Pentachloride; Action of Hydrogen on Tantalum Pentachloride. Ralph C. Young and Carl H. Brubaker, Jr. (*J. Amer. Chem. Soc.*, 1952, 74, (19), 4967).—A note. On passage of gaseous HCl over Ta metal, at $\geq 410^\circ\text{C}$., white TaCl₅ is formed, this, or some lower chloride being reduced or decomposed when the temp. is raised to 600°-750° C., a thin film of metal contg. dissolved H being then deposited on the tube walls; this reaction diminishes after a few hours, and an olive-coloured powder, probably TaCl₂, forms on the surface of the unreacted metal, which, after the H had been evolved on fusion of the metal with Na₂CO₃, was found to be $\geq 99.9\%$ Ta. With HBr, at 375° C. TaBr₃ is formed, and on maintaining the temp. at $\geq 550^\circ\text{C}$. some TaBr₃ mixed with a lower bromide or the metal is obtained; at higher temp. (up to 800° C.) Ta metal is deposited, this reaction being slowed on formation of green TaBr₃ powder on the metal. It was confirmed that TaCl₅ is not reduced by the metal at 350°-400° C. in an evacuated tube, but at 475°-500° C. a small amount of green chloride was formed. TaCl₅ is unaffected by H at up to 400° C., but some reduction occurs at 500° C., Ta contg. H being deposited on the tube walls.—J. R.

[Discussion of a Paper by J. R. Cobb and H. H. Uhlig:] Resistance of Titanium to Sulphuric and Hydrochloric Acids

Inhibited by Ferric and Cupric Ions. — (*J. Electrochem. Soc.*, 1952, 99, (12), 554).—See *M.A.*, 19, 782.—G. T. C.

*Oxidation Products Which Contribute to the Oxidation-Resistance of TiC-Base Cermets. Harold M. Greenhouse (*J. Amer. Ceram. Soc.*, 1952, 35, (10), 271-274).—A microscopical and X-ray-diffraction study was made of the oxide layers produced on the surfaces of two Cermets of high oxidation-resistance during heating in air at 2000° F. (1100° C.). One Cermet had the compn. TiC 55.4, TiB₂ 17.9, Si 10, Co 16.7%, and the other consisted of carbides of Ti, Ta, and Nb bonded with 20% Co. The oxide layers formed on another Cermet of lower oxidation-resistance (TiC + 20% Co) was also examined. The high oxidation-resistance of the first-mentioned Cermet was found to result from the formation of a surface layer of borosilicate glass; that of the second Cermet is attributed to the formation of two oxide layers, the inner one of which, being of a stoichiometric character, hinders the inward diffusion of O²⁻ ions. The theory of the oxidation of Cermets is discussed in some detail. 4 ref.

—R. W. R.

*Inter-crystalline Corrosion in Cast Zinc-Aluminium Alloys. C. W. Roberts (*J. Inst. Metals*, 1952-53, 81, (6), 301-309).—To determine the susceptibility of Zn-Al alloys to intercryst. corrosion in an air/water-vapour atmosphere at 95° C. and to examine the effect of the presence of other elements on the incidence of this form of corrosion, alloys of various compn. within the range Al 0-22, Cu 0-1.5, Mg 0-0.09, Pb, Sn, and Cd 0-0.030, Bi 0-0.016, and Mn 0-0.050% were prepared and tested in the as-cast condition. The main conclusions drawn from the work are that: (1) intercryst. corrosion is confined to the α (Zn-rich) phase, although attack is more severe when the β (Al-rich) phase is also present, as a result of the larger surface area of the α grains in the two-phase alloys; (2) the severity of attack is greatly increased by the presence of small % of Pb, Sn, Cd, and Bi; (3) the addn. of a small amount of Mg greatly reduces the severity of the corrosion, whether impurities are present or not, provided conditions are such that intermetallic compounds of Mg with the impurity elements are not formed; and (4) the presence of Cu increases the resistance of two-phase alloys to intercryst. attack. The results of the present investigation and those published by other investigators are discussed, and tentative theories are put forward to explain certain aspects of the phenomenon.

—AUTHOR.

*The Scaling of Zirconium in Air. C. A. Phalnikar and W. M. Baldwin, Jr. (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 1038-1059; discussion, 1059-1080).—Zr forms a double-layered scale after heating in air for sufficient time. An outer, white or buff scale of monoclinic ZrO₂ predominates at temp. below 1050° C., and an inner, black scale consisting of monoclinic and tetragonal ZrO₂, cubic ZrN, and possibly N occupies the greater thickness at temp. above 1050° C. The outer white layer requires a definite time before it begins to form—from 100 hr. at 400° C. to < 5 min. at 1300° C. The appearance of the white scale increases the scaling rate enormously at low temp., but not at high temp. A parabolic relationship between gain in weight and time is approx. followed before the white scale appears. The Zr strip used was found to undergo extraordinary dimensional changes during scaling. In some cases increases in dimensions in the rolling plane trebled the original area of the specimen. This phenomenon did not set in immediately on heating, but also required a definite time to begin. The time was in general much greater than that required to nucleate the outer white scale except in the temp. range 850°-1050° C., where the two times coincided. 12 ref.—P. T. G.

*The Influence of Chemical Factors on the Corrosion of Metals. W. Feitknecht (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (11), 368-379).—[In German]. Those properties of solid corrosion products which determine the course of corrosion are discussed in detail: compn., crystal lattice, morphology, thermodynamic stability, and reactivity. The direct formation of stable compounds occurs mostly at cathodic points, the pptn. of metastable, active products predominantly in anodic regions. The rate of soln. is also of great importance,

because a soluble substance may dissolve so slowly that it effectively protects the underlying metal. A number of examples, mostly taken from F.'s study of the corrosion of Zn, Cd, and Cu in NaCl, are given of the operation of these effects; local differences in the compn. of the products of corrosion may set up galvanic couples and cause severe pitting; the protective effect of a layer of corrosion product may depend on its origin and morphology and, of course, on its chem. nature. The corrosion of Zn, Cd, and Cu under equivalent conditions is plotted against the concentration of NaCl; there is no great difference at high concentrations, but dilution leads first to an increase in the rate of corrosion of Zn, then to a flat max., and finally to a decrease; with Cd the curve passes through two max.; the corrosion of Cu slows down steadily as the NaCl concentration falls; these differences are explained by the nature of the corrosion products formed.

—K. S.

***On the Corrosion of Various Metals in Liquid Sulphur Dioxide.** J. Bollinger (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (10), 321-342).—[In German]. Liq. SO₂ is used in refrigeration and oil refining, and has to be transported in large quantities in suitable pressure vessels. The solubility of water in liq. SO₂ was determined between -28° and +33° C. and corrosion tests were carried out on Fe, Al, Cu, and their alloys with liq. SO₂ with and without varying addn. of water and O. The weight loss of small metal plates was determined after a fixed time at a given temp. in a sealed ampoule contg. the corrosive agent, and the consumption of the substances added to the SO₂ was determined by micro-analysis of the corrosion products and the gaseous phase, using a special gas-analysis apparatus developed for the purpose. The specimens were partly immersed in the liquid, but the extent of corrosion by the vapour phase was negligible. Little difference was found in the attack on Al and two commercial Al alloys (Avional and Anticorodal) in 14 days at 20° C. with 1% H₂O in SO₂. Dry O-free SO₂ did not attack Fe, Al, or Cu in 14 days at 20° C., and saturation with O (0.51%) had no effect, but the presence of moisture initiated corrosion on Fe and Al, a sulphite being formed in the absence of O, a sulphate when O was present. An 18:8 austenitic stainless steel was not attacked in 2 months at 20° C. in SO₂ contg. 50% water and 0.28% O. With Al alloys, corrosion increased linearly with moisture content above 0.4% H₂O, being insignificant below that level; with up to 5% H₂O pitting occurred and corrosion products precipitated from the aq. phase were deposited near the pits and at the bottom of the ampoule; above 5% H₂O corrosion was more uniform. Corrosion slowed down with time, but had not ceased entirely after 21 days. A protective oxide layer is present, and its porosity is largely responsible for the pitting observed. The reactions are summarized: $2Al + 3SO_2 + 3O_2 + 18H_2O \rightarrow Al_2(SO_4)_3 \cdot 18H_2O$. The presence of the hydrated sulphates was confirmed by X-ray examination of the corrosion products in the case of Fe and Al. Al taken from the weld in a pressure vessel was found to corrode twice as severely as that from the walls; anodized Al corroded at half the rate of the unprotected metal. Cu and brass were slightly discoloured (reddish, with brown patches), though corrosion was very slow; the aq. phase had a weak blue-green tint, but corrosion products were not precipitated. Cu sulphate and oxide are formed; at low water contents the latter protects the surface (there is no corrosion below 1% H₂O), but it dissolves if sufficient free water is present. The corrosion of other metals in 14 days at 20° C. in liq. SO₂ contg. 1% H₂O and 0.21% O was also studied: Pb, Cr, Ni, Zn corroded uniformly; Sn and Cd were pitted; in the case of the Mg-Si alloy the evolution of H was so rapid that there was a danger that the ampoule might explode. The efficiency of a number of inhibitors was studied on Fe and Al and compared with the inhibiting effect in 5% HCl; it varied between 16.5 and 93%, and the same inhibitor

had widely different effects in the two media and on the two metals. 32 ref.—K. S.

***Polyphosphate Detergents in Mechanical Dish-Washing. I.—Solubilizing Action of Polyphosphates on Certain Metals. II.—Metallic Staining of Silverware.** Leslie R. Bacon and Eugene G. Nutting, Jr. (*Indust. and Eng. Chem.*, 1952, 44, (1), 146-150; 150-155).—[I.—]. It is shown that Cu, brass, and Zn are readily dissolved by polyphosphate soln. generally and by several commercial and experimental dish-washing detergents. The tests were made in distilled water soln. at 80° C., a temp. which exceeds those of commercial dish-washing practice (55°-70° C.). The corrosion rates found were insufficient to account for the failures of impellers, valves, &c., observed within short periods in the field, which were more acute in regions where the water supply approaches zero hardness. It is considered that elect. leakage from the power supply, the compn. and condition of the exposed metals and alloys, and dynamic as opposed to static exposure, have an important influence. The inclusion of Na metasilicate retards the corrosive action of polyphosphated dish-washing detergents on dish-washing machine parts, pyrophosphate being the most difficult to inhibit. A brassy tarnishing of silverware is attributed to Cu dissolved from machine parts in poorly inhibited detergents and deposited on the silverware by electrolytic action. [II.—] The latter effect occurs when silverware is in elect. contact with a more electronegative metal, such as Al or Zn. Fe and Monel metal have a negligible effect. Polyphosphate activity can be determined by formulating with an excess of silicates, a 50% excess of Na metasilicate pentahydrate giving a practicable measure of control.

—D. P. M.

Corrosion of [Oil-] Refinery Equipment by Sulphuric Acid Sludges. R. J. Hafsten and V. J. Groth (*Proc. Amer. Petroleum Inst.*, 1952, 32M, (III), 84-107; discussion, 107-110).—A detailed survey is presented of the various corrosion troubles encountered in oil refineries as a result of handling H₂SO₄ sludges. Pb is mentioned as the principal material used for resisting weak H₂SO₄ and H₂SO₄ sludges. It is used as a liner for welded or riveted steel tanks, and for pipes and heating coils. When used for heating coils, Pb often fails by rupturing owing to pressure or steam hammer. Brass heating coils are also used, but usually fail by corrosion. Red brass is used as a pipe material for handling weak acid and weak acid sludge. Brass is used as a pump material for weak acid and weak sludge. Brief information is given on the performance of other non-ferrous metals, including Monel. 8 ref.—G. T. C.

Experience with Corrosion in Girbotol Plants [in Oil Refineries]. H. M. Wilten (*Proc. Amer. Petroleum Inst.*, 1952, 32M, (III), 111-119; discussion, 119-120).—Although ferrous materials are normally used in these plants, brief information is included on the performance of a number of non-ferrous metals and alloys.—G. T. C.

***Alternate-Immersion Corrosion-Test Equipment: Improvements in Design.** Chuk-Ching Ma (*Indust. and Eng. Chem.*, 1952, 44, (3), 583-585).—Modifications of an alternate-immersion corrosion-test equipment, constructed in compliance with the tentative method specified by A.S.T.M. Designation B 192-44T, are described. The characteristic features are: (1) the hanging of the test samples in positions which ensure equal durations of immersion of all parts of the samples in the corrosive media, (2) the continuous up-and-down movement of the samples to distribute the corrosive conditions uniformly and to prevent any tendency to strongly localized attack due to the presence of concentration cells, and (3) structural simplicity and convenience. Experimental data given for tests on anodized and unanodized Ti show that results are reproducible to 1-7%, and to ~5% for Al and stainless steel. Specimens are hung with glass sewing thread.—D. P. M.

7 — PROTECTION

(Other than by Electrodeposition)

***Anodizing Aluminium with Sulphuric Acid: Comparison of Sulphuric, Oxalic, and Sulphamic Acid Processes.** Sakae Tajima, Yasuyuki Kimura, and Toshiro Fukushima (*Metal Finishing*, 1952, 50, (10), 67-71; (11), 65-69, 74).—The anodizing of 99% Al sheet with sulphamic acid was studied. Full details are presented of the experimental conditions. The use of D.C. at a c.d. of 1 amp./dm.² gave satisfactory films in acid above 7.5% concentration at 25°C. 1 amp./dm.² at 25°C. and 7.5% concentration was the optimum c.d. for good abrasion- and corrosion-resistance in the film. Films formed by A.C. are rough if formed at 25°C. at any concentration. Better A.C. films may be produced at temp. above 35°C., but they are still inferior to D.C. films. Bath temp. may vary between 25° and 35°C. Steam-sealing of the film produced at 35°C. is very effective. The D.C. film is nearly colourless with higher bath temp. and concentration. The A.C. film was greenish at higher temp. Superimposition of A.C. on D.C. was unfavourable to the abrasion-resistance and appearance of the film. Comparison with H₂SO₄ and oxalic acid films formed at 25°C. and a c.d. of 1 amp./dm.² shows that the thickness of films anodized for 30 min. was about the same in all cases, but after 45 min. those from sulphamic acid were thickest. Abrasion-resistance was highest in sulphamic acid films, and so was the corrosion-resistance and affinity for dyes. 10 ref.—G. T. C.

Hard Aluminium Finishes Resist Wear and Abrasion. R. V. Vanden Berg (*Iron Age*, 1952, 170, (18), 81-83).—Harder, thicker, and denser anodic surface coatings on Al give considerably better resistance to wear and abrasion, and on Al alloys may well replace heavier metals for many aircraft appn. Other metals, such as Cr, Sn, brass, and Pb, coated on Al also give good results.—J. H. W.

***Effect of Carbon Content and Heating Time on Aluminium Diffusion into Steel.** Etsujiro Yajima (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (6), 333-337).—[In Japanese, with tables and diagrams in English]. When one metal diffuses into another, its diffusion const. is invariable at a const. temp. and its value is independent of the diffusing time. However, generally in experiments of metal diffusion the const. decreases with increasing heating time owing to the concentration of the diffusion metal. When Al diffuses into steel the C content of the steel increases gradually, causing a decrease in the diffusion const. Y. reports his investigation of the effect of C content and heating time on the diffusion of Al into steels.—AUTHOR.

***On the Formation and the Properties of the Antimony Coating by a Special Cementation Method.** Hirokichi Kanayama (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (2), 100-104).—[In Japanese]. Powder contg. 30% Sb, 30% ZnO, 30% C, and 10% Na₂CO₃ is packed around the Fe specimen and heated to 550°-650°C. for 30-60 min. K. postulates that the coating is formed by solid diffusion and gaseous penetration of Sb. He studied the effects of Sb contents of the powder (10-90%), heating temp. (400°-800°C.), and heating time (0.5-4 hr.) on the nature of the coating. Experiments showed that: (1) the coating had 2 layers; an outer layer, which is the thicker, consisting of Sb contg. a little Fe, and the inner layer consisting of Fe-Sb metallic compounds; the latter was not formed when the heating temp. was below 630°C.; (2) the total thickness of the coating was 0.02 mm. after heating at 600°C. for 30 min.; and (3) the cohesion depended on the thickness of the inner layer and was best when the heating temp. was 650°C. and the inner layer thickness was very small. Results are also reported of the corrosion of the coating in 10% HCl, 10% H₂SO₄, 10% HNO₃, and 2% NaCl aq. soln. and in air. The merits of the cementation method are: (i) the apparatus and technique are simple, (ii) the coating produced has a beautiful silver lustre, and (iii) the cohesion of the coating is superior to that obtained by electroplating. However, the coating is relatively brittle.—AUTHOR.

Chromium and Glass High-Temperature Coatings for Molybdenum. — (*Metal Finishing*, 1952, 50, (10), 61).—A brief description is presented of a technique for coating Mo with a deposit of Cr and glass, thus greatly increasing its useful life at high temp.—G. T. C.

Bright Chromizing by the French Onera Process. Bernard Jousset (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 603-605).—See *M.A.*, 19, 728.

Chromizing Steel Provides Corrosion-, Wear-Resistance. — (*Western Metals*, 1952, 10, (9), 54-56).—A brief description of the process and its usefulness in industry is given.—T. G.

***(I) Surface Impregnation of Steel with Vanadium from a Gaseous Medium. (II) Surface Impregnation of Steel with Tungsten from a Gaseous Medium. (III) Surface Impregnation of Steel with Molybdenum from a Gaseous Medium. (IV) Surface Impregnation of Steel with Manganese from a Gaseous Medium.** G. N. Dubinin (*Doklady Akad. Nauk S.S.S.R.*, 1952, 84, (2), 269-272; (4), 693-696; (5), 935-938; (6), 1155-1158).—[In Russian]. Fe (0.03% C) and steels (0.1-1.2% C) were coated with V, W, Mo, and Mn by the gaseous-diffusion process, using gaseous media contg. a chloride of the coating metal, HCl, and H. The compn. of the surface zones were determined by spectrochem. analysis, X-ray diffraction, electron microscopy, and microhardness measurements, and are discussed in relation to the constitutional diagrams of the resp. systems. Photomicrographs are given. (I) Coating temp. was 800°-1300°C. The phases formed and kinetics of the process were similar to those for chromizing, but large columnar crystals were obtained in specimens vanadized for 6 hr. at 1100°C. 2% HNO₃ is recommended for etching. In Fe vanadized for 6 hr. at 1000°C., the V content varied from 43% at the surface to ~1.5% at a depth of 135 μ; with 1.18% C steel (6 hr. at 1100°C.) from 82% at the surface to 2% at a depth of 40 μ. The shape of the compn./depth curves indicated a difference in the nature of the diffusion zones obtained in Fe and steel. With Fe, a relatively thick (0.09-mm.) layer of α solid soln. is produced; with the steels, a layer of VC 0.004-0.012 mm. thick. Microhardness of the surface zones was 1850-1920 D.P.N. for the steels and 298 for the Fe. Wear-resistance was improved, but heat-resistance was little affected. Vanadizing increased the corrosion-resistance of Fe and 0.47% C steel to 50% HNO₃, 85% acetic acid, and 26% H₂O₂; that of Fe to 10% NaCl, and that of steel to 98% H₂SO₄. Resistance to 37% HCl was low. (II) Coating temp. used was 900°-1300°C. Tungstenized Fe (6 hr. at 1300°C.) had a surface layer (7 μ) of Fe₇W₆ (~500 D.P.N.), and beneath this a two-phase layer (45 μ) of α solid soln. + Fe₇W₆ (165 D.P.N.) and a layer (348 μ) of α solid soln. (141 D.P.N.). With tungstenized 1.03% C steel (6 hr. at 1300°C.), the coating (270 μ) consisted of α solid soln. + Fe₂W₂C + Fe₇W₆ (229 D.P.N.). Tungstenized Fe and steel show little change in heat-resistance, but resistance to corrosion by 26% H₂O₂, 37% HCl, and 50% HNO₃ is improved. (III) Coating temp. used was 900°-1300°C. Two-phase layers were formed; in the case of Fe (6 hr. at 1200°C.) they were 600-650 μ thick, and consisted of α solid soln. + Fe₇Mo₆ (179 D.P.N.); with 0.47% C steel (6 hr. at 1200°C.), they were 50 μ thick and consisted of α solid soln. + Fe₂Mo₂C (218 D.P.N.). Molybdenizing improved the corrosion-resistance of Fe and steel to 50% HNO₃, 85% acetic acid, and 26% H₂O₂, and that of Fe (not steel) to 37% HCl; there was no improvement in the resistance to 98% H₂SO₄ or to 10% NaCl. (IV) Coating temp. 800°-1200°C. Manganized Fe (3 hr. at 1100°C.) had an outer coating (0.03 mm.) of γ-Mn or solid soln. of Fe in γ-Mn (1124 D.P.N.), and beneath this 0.14 mm. of a solid soln. of Mn in γ-Fe (176 D.P.N.); with steel (6 hr. at 800°C.), a layer 0.016 mm. thick of (Mn,Fe)₂C and solid soln. of Fe in γ-Mn (1145 D.P.N.) was formed. Manganizing improved corrosion-resistance to 26% H₂O₂ and 10% NaCl, but resistance to 50% HNO₃, 37% HCl, 96% H₂SO₄, and 85% acetic acid was low.—G. V. E. T.

***Anti-Corrosive Treatments for Magnesium.** Tukasa Kawamura (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 645-650).—The coating of anti-corrosive Se and lacquer produced on Mg by the Bengough process may blister or peel off when exposed to saline soln. K. has evolved two improvements for use with and without the lacquer coating. (1) *Without Lacquer Coating.*—Soluble material in the Se film is removed by boiling in slightly alkaline water, and the film is compacted by heating for 30 min. at 230° C. (2) *With Lacquer Coating.*—In this case the Se film is protected from the corrosive medium by a further coating formed by immersing in boiling aq. 3% Na₂SO₄ soln. and 3% K₂Cr₂O₇ soln. (Sutton process), followed by lacquering.—D. M. P.

The Theory and Practice of Hot-Dip Tinning. W. E. Hoare (*Wire Ind.*, 1951, 18, (214), 867-870, 873-875; discussion, (215), 969-971).—H. describes the chem. reactions that occur when Sn is applied to Fe and Cu, quoting the sequence of operations, times, and alternative methods. The problem of the wipe-removal of surplus Sn from wire is considered at length.—C. P. F.

New Process [Flame-Plating] Permits Many Metals to Be Tungsten-Carbide Coated. — (*J. Metals*, 1952, 4, (10), 1036-1037).—The "Flame-Plating" process, developed by the Linde Air Products Co., is described. The specifications and properties of the coatings are: (1) compn.—WC 92, Co 8%; (2) D.P.N. hardness (300-g. load)—1200-1500; Rockwell A hardness 89.3; (3) thickness—0.005-0.020 in.; (4) base materials—all steels, cast Fe, Al, Cu, brass, bronze, Ti, Mg; (5) process—appn. temp. < 200° C.; (6) part size—flats, or rounds up to 6 in. ext. dia. and 40 in. long; (7) part shape—almost any; (8) appn.—core rods, plug gauges, shafts, burnishers, drawing dies, mill hammers, &c.; (9) modulus of elasticity—15,000,000 lb./in.²; (10) corrosion-resistance—attacked by most acids and strong alkalis; resistant to mild alkalis, detergents in lubricating oils, atmospheres free from acid fumes; (11) thermal resistance to shock—good below 2000° F. (1100° C.); and (12) resistance to mech. shock—can absorb a moderate amount of deformation.—E. N.

Coating Metal Used in Hot-Dip Galvanizing. Wallace G. Imhoff (*Wire and Wire Products*, 1952, 27, (4), 356-360, 420-421; (5), 469-472; (6), 575-578, 630-632; (7), 686-689, 691-692).—I. lists the chem. compn. of 5 grades of Zn and discusses the influence of each impurity found in Zn slab, viz. Fe, Pb, and Cd. Cd is beneficial, since it tends to promote fluidity and to produce on sheet ware a spangle finish. Reference is also made to the addn. of Al, Sn, Sb, and Cd to the galvanizing bath in various proportions, according to the product. The respective effects of these addn. are detailed. I. considers that the addn. of Pb to the bath is beneficial, since any excess assists the removal of dross. Finally, the effects of various impurities in the coating metal on the coating itself and how they affect galvanizing operations are described.—C. P. F.

The Evolution of the Modern Hot-Dip Galvanizing Pot. Wallace G. Imhoff (*Wire and Wire Products*, 1952, 27, (8), 769-774, 828-832).—Describes various types of pot designs used, showing progressive changes down to the present time. A graph shows the attack of Zn on a Fe pot; this is negligible up to 900° F. (480° C.) after which the curve indicates that at higher temp. the pot-wall will be dissolved. A thin-lined vitreous refractory coating now overcomes this attack and

increases the life of the pot indefinitely. A chronological summary and a lengthy bibliography completes the survey.—C. P. F.

An Up-to-Date Hot-Dip-Galvanized Wire Plant. — (*Wire Ind.*, 1951, 18, (215), 966-967, 974).—An illustrated description of new plant at the Manchester Works of Richard Johnson and Nephew, Ltd. Prodn. is of the order of 1500 long tons/week, largely for cabling, fencing, and barbed wire. High-tensile wire for overhead transmission lines is also produced. Wire sizes range from 0-028 to 0-324 in. dia.—C. P. F.

South American Wire-Galvanizing Plant. — (*Wire Ind.*, 1952, 19, (218), 135-138).—Describes a hot-dip galvanizing plant and the methods used for treating Fe and steel wire mainly for cables.—C. P. F.

Zinc Dust as a Protective Pigment. A. Pass (*Paint Manuf.*, 1952, 22, (8), 299-301).—The various uses for paints contg. Zn dust as pigment are described, and the advantages and disadvantages of this type of pigment discussed.—G. T. C.

A Practical Evaluation of Metallic Coatings as Affecting Sensitivity to Stress-Corrosion Failure. C. H. Hannon (*Metal Finishing*, 1952, 50, (10), 65-66, 71).—Experiments are described to evaluate the effect of metallic coatings on Cu-base alloy bushing terminal bolts used in elect. power distribution. It was found that a Sn coating reduced susceptibility to stress-corrosion as measured by the HgNO₃ test. Diffusion of Sn at 700° C. did not provide protection. Ni and Cr coatings were likewise ineffective. On the other hand, when tested in the presence of NH₃, Sn was found to be ineffective in the electrodeposited form, but was effective as a flowed coating.—G. T. C.

Economics of Metals and Coatings to Combat Corrosion of Refinery Tank Roofs. H. F. McConomy and J. J. Hur (*Proc. Amer. Petroleum Inst.*, 1952, 32M, (III), 67-71; discussion, 71; and *Petroleum Eng.*, 1952, 24, (8), C28-C30).—Cf. *Petroleum Refiner*, 1952, 31, (5), 124-126; *M.A.*, 20, 111.—G. T. C.

Internal and External Protection of Storage Tanks [in Oil Refineries]. J. S. Cook (*Proc. Amer. Petroleum Inst.*, 1952, 32M, (III), 72-81; discussion, 81-83).—Brief mention is made of the use of galvanized coatings for both internal and external protection. The use of cathodic protection of tank bottoms is also described very briefly.—G. T. C.

Cathodic Protection Licks Corrosion. L. C. Werkin (*Petroleum Refiner*, 1952, 31, (10), 122-124).—The use of cathodic protection in the oil industry is briefly reviewed. 9 ref.—G. T. C.

Pretreatment Primers for Metal Work. E. E. Halls (*Indust. Chemist*, 1952, 28, (333), 441-445).—The use is described of "pretreatment primers" for preparing metal surfaces for painting; these primers consist of a soln. contg. a film-forming resin in alcoholic solvent with a corrosion-resisting pigment and a second soln. of H₃PO₄ in a similar solvent. The resistance to corrosion of metals treated with this primer is compared with that of similar specimens given other common pretreatment; among the metals studied were Al, brass, Mg, Zn, and Cd.—R. W. R.

Dip Painting and Spray Coating. M. Reeves (*Metal Ind.*, 1952, 81, (21), 404-405).—R. describes several methods of applying paint to metal surfaces, especially by spraying with equipment ranging in size from small units to very large and multi-gun installations.—J. H. W.

8 — ELECTRODEPOSITION

[Discussion on a Paper by D. E. Couch and A. Brenner:] **A Hydride Bath for the Electrodeposition of Aluminium.** — (*J. Electrochem. Soc.*, 1952, 99, (12), 558).—See *M.A.*, 20, 181.—G. T. C.

[Discussion on a Paper by N. Hackerman and T. Jensen:] **The Effect of Indium Sulphate in Chromium-Plating Baths.** — (*J. Electrochem. Soc.*, 1952, 99, (12), 554-555).—See *M.A.*, 19, 785.—G. T. C.

[Discussion on a Paper by R. F. McElwee and M. L. Holt:] **The Electrodeposition of Cobalt-Tungsten-Molybdenum Alloys**

from Aqueous Citrate Solutions. — (*J. Electrochem. Soc.*, 1952, 99, (12), 554).—See *M.A.*, 19, 785.—G. T. C.

***Atmospheric Exposure of Copper-Nickel-Chromium Deposits on High-Carbon Steel.** (—). See col. 490.

***The Reflectivity of Copper Electrodeposits.** (Gauvin and Winkler). See col. 450.

***Cathodic Polarization Potential During the Electrodeposition of Copper.** III.—Effect of Cathode Base Upon the Cathode Polarization Potential and the Crystal Structure of the Deposit. L. L. Shreir and J. W. Smith (*J. Electrochem.*

Soc., 1952, 99, (11), 450-456).—Cf. *ibid.*, (2), 64; *M.A.*, 19, 786. The variation in cathode potential with time during electrolysis at various c.d. and with cathode bases of different structures was studied. The effects of cold-rolled and annealed foil cathodes, showing preferred orientation and random orientation, resp., were compared, and measurements were also made using electrodeposited "const.-state polarization" bases produced under standard conditions, and electrodeposited coarse and fine structures. X-ray examinations of some of the deposits formed were made. The results suggest that the cathode polarization is related to crystal size and a change from a coarse to a fine structure is accompanied by an increase in polarization potential. 12 ref.—G. T. C.

Electrodeposition of Brass. O. Krämer (*Metalloberfläche*, 1951, [B], 3, (12), 181-183).—Recommended compn., brighteners, and operating details for still and barrel brass-plating baths are given.—E. N.

***Notes on the Electrodeposition of Thick Gold Deposits.** Charles L. Bauer (*Plating*, 1952, 39, (12), 1335-1336, 1338).—The prodn. of smooth Au deposits up to a thickness of ~0.01 in. is described. Efforts to do this in a conventional Au-plating bath were unsuccessful, and a special bath was developed with the following compn.: Au 18, KCN 120, KOH 4, K₂SO₃ 4, vanillin 0.3 g./l. The temp. of operation was 80° C. and c.d. was 5-18 amp./ft.². Pure Au anodes and vigorous agitation were used. A cathode current efficiency of nearly 100% was obtained. The effects of changes in concentration of bath constituents were studied and are described. A brief account is included of the analysis of Au plating soln.—G. T. C.

***Effect of Impurities and Purification of Electroplating Solutions. I.—Nickel Solutions.** (6). The Effect and Removal of Iron. D. T. Ewing, A. A. Brouwer, and J. K. Werner (*Plating*, 1952, 39, (12), 1343-1349).—Cf. *ibid.*, (9), 1033; *M.A.*, 20, 356. A report of work carried out under Research Project No. 5 of the American Electroplaters' Society. The effect of Fe as an impurity in four types of Ni-plating soln. was investigated. A whitening effect on grey Ni deposits was noted with an Fe concentration in the soln. of 10-200 p.p.m. Deposits from a bright Ni soln. exhibited no change in appearance within a range 0-200 p.p.m. Fe, and there was no detectable change in adherence in this range. There was a slight decrease in ductility in deposits from the Watts and the organic soln. as the Fe content increased up to 200 p.p.m. There was no noticeable influence on the ductility over this range in the case of Ni-Co deposits. There was no change in the salt-spray resistance of coatings produced from baths contg. up to 200 p.p.m. Fe except in the case of Co-Ni baths, when there was a 10-20% increase in corrosion-resistance between 25 and 100 p.p.m. Fe. The presence of Fe up to 200 p.p.m. had no significant effect on the throwing power of the soln. Ni deposited from soln. contg. 2.5-200 p.p.m. Fe generally exhibited an increase in hardness. In the case of a Watts bath (pH 5.2) the Fe produced a precipitate which was thought to be a cause of roughness. Brief details are included on methods of removing Fe from Ni soln. 5 ref.—G. T. C.

[Nickel] Plating as an Aid in the Brazing of Stainless Steel. A. Korbelak and E. C. Okress (*Plating*, 1952, 39, (11), 1220-

1222, 1228).—A detailed description is presented of a method of using Ni electrodeposits to facilitate the manufacture of large-sized intricate designs in stainless steel. The thickness of Ni necessary for different brazing temp. is given.—G. T. C.

Study on the Analysis of Nickel-Plating Baths. M. Jean (*Rev. Nickel*, 1952, 18, (3), 55-70).—Spectrophotometric methods are described for the detn. in Ni-plating baths of Ni, chloride, H₃BO₃, and N. 32 ref.—R. W. R.

Nomogram for Analysis of Watts-Type Nickel-Plating Solutions. I. Goldman (*Metal Finishing*, 1952, 50, (11), 76-77).—A nomogram, together with a description of its use, is presented.—G. T. C.

The New Tin-Nickel Alloy Electroplate. — (*Wire Ind.*, 1951, 18, (213), 794, 797; and *Indian Engineering*, 1951, 129, (9), 399).—Cf. *M.A.*, 19, 850.—S. R. W.

Electro-Tinning Copper Wire: A New Process. I.—The Process. Frederick A. Lowenheim (*Wire and Wire Products*, 1952, 27, (5), 464-467, 500-507).—After describing hot-dipping and electroplating, L. emphasizes that the speed of the latter process depends on the cathode c.d. and the current efficiency at that c.d., adding that above ~50 amp./ft.² the Na stannate bath produces unsatisfactory deposits. He prefers an alkaline stannate type of soln. to an acid bath, despite power economy, and lists reasons based on practical experience. The K stannate bath is described in detail, with calculations.—C. P. F.

Electro-Tinning Copper Wire: A New Process. II.—The Machine. C. O. Bruestle (*Wire and Wire Products*, 1952, 27, (6), 565-568, 632-633).—Cf. preceding abstract. Presents a detailed account of the phys. elements of the K stannate process for the continuous deposition of Sn upon Cu wire. Operating speeds of 600 ft./min. are attained.—C. P. F.

Electrodeposition of Zinc on Uranium Metal. Louis Silverman (*Metal Finishing*, 1952, 50, (11), 75).—It is shown that Zn may be electrodeposited on U metal. Details of soln. compn. and of operating characteristics are presented.

—G. T. C.

Report of [A.S.T.M.] Committee B-8 on Electrodeposited Metallic Coatings. — (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 200-201).—T. G.

***Disposal of Plating-Room Wastes. IV.—Batch Volatilization of Hydrogen Cyanide from Aqueous Solutions of Cyanides.** Barnett F. Dodge and Walter Zabban (*Plating*, 1952, 39, (10), 1133-1139; (11), 1235-1244).—Cf. *ibid.*, (4), 385; *M.A.*, 20, 114. A report on work carried out under Research Project No. 10 of the American Electroplaters' Society. Some results are presented of small-scale laboratory experiments on the batch volatilization of HCN gas, dealing mainly with the most important rate-controlling variables. 7 ref.

—G. T. C.

The Increasing Importance of pH Papers in Electroplating. Wilhelm Zarneke (*Metalloberfläche*, 1951, [B], 3, (12), 186-187).—pH-indicator papers are being increasingly used as a rapid, satisfactory, and cheap means of determining the pH of modern plating baths, the close control of which is so essential for their successful operation.—E. N.

Surface-Treatment Costing. Willh. Schmolz (*Metall-oberfläche*, 1951, [B], 3, (12), 183-185).—The costing of plating and lacquering is discussed, and some examples are given.

—E. N.

9 — ELECTROMETALLURGY AND ELECTROCHEMISTRY

(Other than Electrodeposition.)

Industrial Electrolysis: A Half-Century of Aluminium Developments. Junius D. Edwards (*J. Electrochem. Soc.*, 1952, 99, (11), 298C-300C).—A brief review of progress made in the past fifty years.—G. T. C.

***The Electrochemical Behaviour of Aluminium. III.—In Buffered and Alkaline Solutions of Potassium Ferricyanide and in Sodium Hydroxide.** J. V. Petrocelli (*J. Electrochem. Soc.*, 1952, 99, (12), 513-519).—Cf. *ibid.*, 1951, 98, 183; *M.A.*, 19,

139. A study is described of the reactivity and polarization characteristics of pure Al in buffered and alkaline soln. of K₃Fe(CN)₆ and in NaOH. Electrode potentials, weight-loss data, and polarization curves are presented. It is shown that the reaction of Al with these electrolytes may be interpreted from an electrochem. point of view. The analysis of the polarization behaviour is based on the theory of "mixed potentials". 8 ref.—G. T. C.

*A Polarographic Method for the Indirect Determination of Polarization Curves for Oxygen Reduction on Various Metals. III.—Chromium, Molybdenum, Tantalum, Titanium, Tungsten, and Zirconium. Paul Delahay and Lee J. Stagg (*J. Electrochem. Soc.*, 1952, 99, (12), 546-548).—*Cf. ibid.*, 1950, 97, 205; *M.A.*, 18, 199. Polarization curves were determined for these metals for the electrolytic reduction of O. The contributions of the two- and four-electron processes, viz. reduction of O to H₂O₂ and to H₂O, resp., were determined. The electrolytic reduction of O on Cr, Ta, Ti, and W may yield appreciable quantities of H₂O₂. Very little H₂O₂ is formed on Zr and Mo. 5 ref.—G. T. C.

*The Mechanism of Hydrogen Evolution at Copper Cathodes in Aqueous Solutions. J. O'M. Bockris and N. Pentland (*Trans. Faraday Soc.*, 1952, 48, (9), 833-839).—The kinetics of H evolution at Cu cathodes were studied in aq. soln. of 0.001-0.1N-HCl and 0.005-0.15N-NaOH at 10²-40² C. for c.d. 10⁻⁸-10⁻² amp./cm.². Tafel lines, heat of activation at the reversible potential, and the stoichiometric number, μ , in alkaline soln. are calculated and discussed. Values of μ indicate that proton discharge from H₂O is rate-determining. The desorption step is a catalytic combination of H atoms at low c.d.; at higher c.d. electrochem. desorption may become important. 23 ref.—J. S. G. T.

*Investigations of Anodic Passivation of Lead. I.—Effect of Cl⁻ and Co⁺⁺ Ions on the Passivation of Lead in Zinc Sulphate Solution. M. Smiałowski and E. Przybyła (*Prace Głównego Inst. Met.*, 1951, 3, (6), 501-505).—[In Polish]. The change of the Pb anode potential with time was studied experimentally at c.d. up to 0.53 m.amp./cm.², using a Curie electrometer and recording the results photographically. Tests were carried out: (1) with a "pure" bath contg. 105 g. Zn as sulphate and 140 g. H₂SO₄/l., (2) with a Pb-1% Ag anode, (3) with addn. of Cl⁻ ions, and (4) with addn. of Co⁺⁺ ions to the bath. Typical potential/time curves are plotted. For the "pure" bath $t_p/g_i = -4.7g_i + 4.2$, where t_p is the passivation time and g_i is the anode c.d. Addn. of only 2 g. Cl⁻/l. prolonged the passivation time considerably and moved the passivation charge/c.d. curve above the curve for (1); (4) acted in the opposite direction, probably owing to the fact that the redox potential of the Co³⁺/Co²⁺ system is even higher than that of Pb⁴⁺/Pb²⁺. Potential/time curves for (2) could be divided into periods in which Pb²⁺ ions passed into soln., when Ag dissolved and when the anode became passive. 5 ref.—A. G.

*Effect of Corrosion and Growth on the Life of Positive Grids in the Lead-Acid Cell. (Lander). See col. 491.

[Discussion on a Paper by J. O'M. Bockris and E. C. Potter:] The Mechanism of the Cathodic Hydrogen Evolution Reaction [on Mercury, Silver, Nickel, and Platinum]. — (*J. Electrochem. Soc.*, 1952, 99, (12), 556-557).—See *M.A.*, 20, 36.

—G. T. C.

*Influence of Impurities in the Electrolyte in Chlorine/Caustic Electrolysis by the Mercury Cell Process. I.—Investigation of the Influence of Metallic Impurities upon the Decomposition Rate of Sodium Amalgam. Gösta Angel and Tage Lundén (*J. Electrochem. Soc.*, 1952, 99, (11), 435-441).—The decompn. rate of 0-14% Na amalgam shaken with NaCl soln. buffered with NaC₂H₃O₂ and C₂H₄O₂, and to which various metal salts had been added, was studied. The reaction rate was determined by measuring the amount of H evolved/unit of time. Fe, Ni, Cd, Ba, Mg, W, and Mn had no influence on the rate of decompn., but U, Mo, and Cr greatly increased it. If two different metals are present at the same time, then in certain cases, their influence was greatly intensified, e.g. V + Fe have an effect many times greater than the same concentration of V on its own. Similarly, Fe + Mg increase the decompn., although they have no effect individually. 9 ref.—G. T. C.

*Influence of Impurities in the Electrolyte in Chlorine/Caustic Electrolysis by the Mercury Cell Process. II.—Further Investigation of the Influence of Metallic Impurities upon the Decomposition Rate of Sodium Amalgam. Gösta Angel and Rolf Brännland (*J. Electrochem. Soc.*, 1952, 99, (11), 442-446).—*Cf. ibid.*, p. 435; preceding abstract. In the absence of

other impurities, Cu, Zn, Al, and As in a concentration of 5 mg./l. have practically no influence on the decompn. rate of Na amalgam, but Al and As in a concentration of 25 mg./l. increase it slightly. In the presence of V, both Cu and As act as promoters and greatly intensify the influence of V. Ta is found to belong to the same highly reacting group as V and Mo, but Ti occupies a place between the harmless and the harmful impurities. 5 ref.—G. T. C.

*Oxidation Potentials of the Neptunium (III)-(IV) and the Neptunium (V)-(VI) Couples in Perchloric Acid. Donald Cohen and J. C. Hindman (*J. Amer. Chem. Soc.*, 1952, 74, (18), 4679-4682).—Measurements of the oxidation potentials of the Np couples in 1M-HClO₄ acid as a function of temp. are presented and discussed, and equations for the cell reactions are formulated.—J. R.

*The Neptunium (IV)-(V) Couple in Perchloric Acid: The Partial Molal Heats and Free Energies of Formation of Neptunium Ions. Donald Cohen and J. C. Hindman (*J. Amer. Chem. Soc.*, 1952, 74, (18), 4682-4685).—A formal potential scheme for Np ions in 1M-HClO₄ acid, based on measurements for the (IV)-(V) and other Np couples (cf. preceding abstract), is advanced. Partial molal heats and free energies of formation of the various Np ions are calculated, and their entropies are compared with those of U and Pu.—J. R.

The Electrochemistry of Nickel. W. A. Wesley (*Indust. and Eng. Chem.*, 1952, 44, (5), 957-965).—Presented at an American Chemical Society Symposium on Nickel. The present knowledge, both sci. and practical, of the electrochem. reactions of Ni which are applied in industry, is reviewed. Most indust. electrolytes for the electrodeposition of Ni are based on a Ni sulphate + Ni chloride + boric acid soln., which is modified to produce Ni deposits of different mech. properties, metallographic structure, or surface brightness. Evidence is cited to show that it is possible to electrodeposit sound Ni metal at speeds much higher than have yet been employed commercially. The electrodeposition of Ni-Co, Ni-Zn, Ni-Fe, and bright Ni-Sn alloys is also considered. Indust. processes discussed include electrorefining, electroforming, electroplating, resizing of mismatched parts, and electropolishing. 20 ref.—D. P. M.

*Thermogalvanic Potentials. II.—Nickel in Neutral Sulphate Solution. Dodd S. Carr and Charles F. Bonilla (*J. Electrochem. Soc.*, 1952, 99, (12), 475-482).—*Cf. ibid.*, 1951, 98, 388; *M.A.*, 19, 463. An apparatus was constructed for measuring the thermogalvanic potential developed by carefully purified Ni powder in several concentrations of neutral NiSO₄ soln. under temp. differentials up to 100² C. Reproducible values of the thermodynamic potential were obtained, and were found to vary more or less linearly with temp. difference and exponentially with Ni concentration. The hotter Ni surface was always negative with respect to the colder surface, thus having a tendency to corrode anodically. Under average conditions, the thermogalvanic potential developed was ~0.89 mV./²C. The standard potential of the Ni electrode was computed from isothermal measurements against a calomel electrode and found to be ~0.232 V. on the normal H scale. 56 ref.—G. T. C.

*On the Existence of a Discontinuity in the Cathodic Polarization of Platinum in the Electrolysis of Dilute Acid Solutions. Luc Henry Collet and (Mlle) Marie Christine Pommier (*Compt. rend.*, 1952, 235, (18), 1033-1035).—The results of experiments with electrolysis are generally not reproducible. The best methods are those which use spontaneous depolarization and the construction of $e = f(t)$ curves with the cathode oscillograph or the electrometer. The second method was used to study the depolarization of Pt in HCl soln. The e.m.f. curve has first a level part, after which the e.m.f. diminishes very rapidly to a second level part, longer but less sharp, with a slight rise before the final fall. This first level portion is not peculiar to HCl soln., but does not appear with other metals such as Ag or Cu. An equilibrium would seem to occur with Fe. The second level portion is due to the slow and continuous depolarization of the anode. Experiments with very dil. (10⁻⁴N) soln.

showed that the electrolytic equilibrium that exists between Pt polarized by H and the acid soln. suddenly becomes impossible when the concentration of the latter reaches a value of $\frac{1}{2000} N$.—J. H. W.

***Hydrogen Overvoltage on Bright Platinum.** Sigmund Schuldiner (*J. Electrochem. Soc.*, 1952, 99, (12), 488–494).—A technique is described which allowed the confirmation of surface cleanliness of bright Pt electrodes during overvoltage measurements. As the c.d. was increased, three consecutive relationships between η and i were observed. The mechanism of H overvoltage on Pt is discussed in the light of the results obtained. The true area of the Pt electrode was determined from double-layer capacity measurements. 18 ref.

—G. T. C.

[Discussion on a Paper by S. T. Ross and J. L. Bray:] **Relationships Between Germanium and Cadmium in the Electrolysis of Zinc Sulphate Solution.** — (*J. Metals*, 1952, 4, (11), 1178).—See *M.A.*, 19, 208.

***Effect of Stress on Metal Electrode Potentials.** Robert E. Fryxell and Norman H. Nachtrieb (*J. Electrochem. Soc.*, 1952, 99, (12), 495–503).—The effect of stress on the electrode potentials of Ag and Au was measured. Tension renders these metals cathodic in aq. soln. of their salts. Compression produced changes in the opposite direction. These changes are proportional to the applied load. Quinhydrone and ferrous-ferric electrodes are not affected by stress. The observations cannot be accounted for on the basis of thermodynamic changes produced within the metal. A surface phenomenon is responsible. The condition of the metal surface is shown to be an important variable, although studies of certain variables with the electrolyte have failed to reveal the nature of polarization. 11 ref.—G. T. C.

***The Kinetics of Hydrogen Evolution Reaction at High Current Densities.** J. O'M. Bockris and A. M. Azzam (*Trans. Faraday Soc.*, 1952, 48, (2), 145–160).—The dependence upon c.d. of overvoltage on Hg, W, Ag, Ni, Pt, and Pd electrodes in 5*N*-HCl soln. at c.d. 10^{-2} –100 amp/cm.² was studied. The relation between potential and electrode distance was found to be linear to within ~0.05 cm. of the electrode surface and to increase much more slowly at greater distances. The Tafel equation applies over the c.d. range specified for Hg, W, and Ag, and breaks down at higher c.d. for Ni, Pt, and Pd. A large proportion of the p.d. between the Luggin capillaries used and the cathode occurs within 0.05 cm. of the electrode surface, and is entirely ohmic in origin. The atomic-H combination reaction cannot be a rate-determining process at c.d. $> \sim 10$ amp/cm.² on any metal. On Hg electrodes, the process is one of slow discharge followed by rapid electrochem. desorption. On Ni, the process is probably a slow process of discharge followed by atomic combination desorption. The latter reaction is rate-determining on Pt and Pd up to medium c.d. in sufficiently pure soln. The free energy of activation for the atomic H recombination on Pt is zero. 36 ref.—J. S. G. T.

***Adsorption and the Hydrogen Overpotential.** P. J. Hillson (*Trans. Faraday Soc.*, 1952, 48, (5), 462–473).—The H overpotential and the capacity of the working electrode were studied on electrodes of Hg, Ni, W, Ta, Au, and Ag, in the presence of capillary-active substances, viz. *n*-hexyl alcohol, *n*-caproic acid, *n*-hexylamine hydrochloride, and *p*-toluene sulphonic acid. The different effects these substances have on the electrodes are correlated with the energies of adsorption of H and O on the various metals. The null-points of Ni and Au were estimated to be –0.50 and –0.15 V., resp., with respect to the normal calomel electrode. Experimental values of the H overpotential for the metals Hg, Ni, Ag, and Au agree well with values calculated from the heats of adsorption of H and O. Satisfactory agreement is also found between experimental and calculated overpotentials relating to Fe and Rh. 17 ref.—J. S. G. T.

A Brief Summary of Hydrogen Electrode Kinetics. J. O'M. Bockris (*J. Electrochem. Soc.*, 1952, 99, (12), 366C–369C).—It is pointed out that the reaction at a H electrode is not widely understood, and a summary is presented of our present knowledge of the kinetics of this reaction. 43 ref.—G. T. C.

***The Differential Capacity of the Electrical Double Layer: The Role of the Anion.** D. C. Grahame, M. A. Poth, and J. I. Cummings (*J. Amer. Chem. Soc.*, 1952, 74, (17), 4422–4425).—A systematic study of the influence of the anion upon the differential capacity of the elect. double layer at the Hg|soln. interface of 0.1*N*-K mercurous salts showed strong correlation between the shape of the capacity curves and the solubility of the corresponding salts. Surface-charge d values calculated from the results are tabulated.—J. R.

***Electrochemical Phenomena at a Rotating Mercury Electrode. I.—Reduction of Metal Ions.** T. S. Lee (*J. Amer. Chem. Soc.*, 1952, 74, (20), 5001–5003).—A rotating-Hg electrode which combines the advantages of dropping-Hg and rotating-Pt electrodes in analytical work and physico-chem. studies is described and illustrated. With the apparatus, the diffusion current of metal ions was found to be strictly proportional to concentration in the range 10^{-4} – $10^{-7} M$, and the half-wave potential of a given metal ion (Cd) was independent of concentration over the same range. Derived equations for other relationships are presented and discussed. The apparatus is useful for the analysis of electro-reducible substances at very low concentrations in aq. soln.—J. R.

***Influence of the Geometrical Parameters of an Electrolytic Bath on the Distribution of Electrical Energy Within It.** V. P. Mashovets, N. V. Pototskaya, N. L. Komarov, and U. F. Turomshina (*Zhur. Priklad. Khim.*, 1951, 24, (2), 154–166).—[In Russian]. A study of the effect of cell and anode dimensions on the distribution of the elect. field inside cells for Al extraction, using two-dimensional models (Cu electrodes in $CuSO_4/H_2SO_4$).—G. V. E. T.

Resistance of the Electrolyte in a Bath with Several Cylindrical Electrodes. A. D. Ershov and V. S. Afoshin (*Zhur. Priklad. Khim.*, 1951, 24, (11), 1210–1212).—[In Russian]. E. and A. derive a complicated formula for the resistance of the electrolyte in a bath having a system of cylindrical cathodes symmetrically distributed around a cylindrical anode; a simplified version is also given.—G. V. E. T.

***Primary-Current Distribution Around Capillary Tips Used in the Measurements of Electrolytic Polarization.** Sidney Barnartt (*J. Electrochem. Soc.*, 1952, 99, (12), 549–553).—Equipotentials are mapped out around the electrode and the tip of the capillary for the following arrangements: (a) capillary in front of electrode, (b) capillary behind a finite electrode, having an insulated back, (c) capillary through back of the electrode and having its tip at the front surface. Arrangement (a) can be used for accurate measurements if the distance between the electrode and the capillary tip of radius r is $4r$ or more and any appreciable IR drop subtracted. Arrangement (b) is unsatisfactory because the c.d. varies over the surface of the electrode. With arrangement (c), the c.d. is increased at the area nearest the capillary, hence the polarization measurement tends to be too high. 11 ref.—G. T. C.

***Polarographic Studies in Acetonitrile. I.—Behaviour of Inorganic Salts.** Stanley Wawzonek and Mervin E. Runner (*J. Electrochem. Soc.*, 1952, 99, (11), 457–459).—The behaviour of Li, Rb, K, Cs, Na, Ca, Mg, Pb, Cd, and Zn ions was studied at a dropping Hg cathode in anhydrous acetonitrile contg. 0.1*M*-tetrabutylammonium iodide. Values were also determined for Li, K, Cd, Zn, Pb, and Cu ions in a 0.1*M*-tetrabutylammonium perchlorate soln. The results obtained for Zn, Pb, Cu, and Cd were only approx., since the system was not completely anhydrous. The half-wave potentials were in fairly good agreement, in every case except Cu, with the standard electrode potentials reported for these metals in acetonitrile. 9 ref.—G. T. C.

Mathematical Theory of the Faradaic Admittance. (Pseudocapacity and Polarization Resistance). David C. Grahame (*J. Electrochem. Soc.*, 1952, 99, (12), 370C–381C).—The questions of pseudocapacity and polarization resistance are reviewed in detail. 22 ref.—G. T. C.

Fifty Years of Electrochemical Theory. Walter J. Hamer (*J. Electrochem. Soc.*, 1952, 99, (12), 331C–343C).—A review of the development of electrochem. theory over the past fifty years is presented. 168 ref.—G. T. C.

10 — REFINING

Comments on Catalytic Aluminium Distillation. P. Gross. W. J. Kroll (*Vacuum*, 1952, 2, (1), 56-57).—G. replies to 2 points of criticism advanced by K. in an article on vacuum metallurgy dealing with catalytic Al distillation (*ibid.*, 1951, 1, 163; *M.A.*, 20, 362). K. agrees.—J. S. G. T.

***Elimination of Aluminium Present in Bronzes.** Georges Blanc and Pierre Julien Le Thomas (*Fonderie*, 1952, (80), 3091-3106).—The use of Al bronze scrap in bronze castings is liable to result in unsoundness and poor mech. properties. Spot tests will distinguish between cupro-aluminium and brasses and bronzes, but not between Al brass and ordinary brass. A number of experiments were carried out in the foundry to eliminate 0.4-1.5% Al from bronze (5% Sn, 1-10% Zn) at 1200° C. The factors examined were: (a) nature of the oxidizers, (b) temp. of treatment, (c) period of action, (d) initial Zn content, and (e) initial P content. It was found that: (1) the oxidizers do not act by simple contact but by vigorous and prolonged mixing throughout the mass; (2) the temp. of treatment must be carefully controlled at ~1200° C.; (3) the oxidizer must not be too active and may have to be diluted (e.g. with sand); (4) for charges of ~70 kg., KNO₃ can be used, for 100-150 kg., MnO₂; (5) with KNO₃ treatment sound castings with good mech. properties are obtained directly; (6) MnO₂ treatment is easier to apply, but must be followed by remelting; (7) the tools used for stirring and skimming must be carefully protected to prevent the introduction of Fe into the melt; (8) a composite flux may be used, if care is exercised; and (9) this technique must, of course, not be considered as a general method of refining Cu alloys.—J. H. W.

Applied Vacuum Metallurgy: The Production of Magnesium, Calcium, Tantalum, and Zirconium. G. L. Miller (*Vacuum*, 1952, 2, (1), 19-32).—The vacuum technique for the indust. prodn. of Mg, Ca, Ta, and Zr is described. Contamination of the metals with gases is avoided. Small quantities of oxides in Zr make the metal brittle. The vacuum method for the removal of MgCl₂ and Mg from reduced Zr is preferable to the leaching process used in earlier work.—J. S. G. T.

***Anion Exchange of Niobium in 7.0-Molar Hydrochloric Acid.** E. H. Huffman and G. M. Iddings (*J. Amer. Chem. Soc.*, 1952, 74, (18), 4714-4715).—A note. Elution of Nb with HCl from an anion-exchange resin, under conditions precluding isotope sepn., showed a behaviour similar to that reported by Brown and Rieman (*ibid.*, (5), 1278; *M.A.*, 20, 38) for Ti

elution, and tentatively attributed by them to partial sepn. of natural and radioactive isotopes. H. and I. consider the departure from the expected type of elution curve to be probably due to slow establishment of equilibrium among various ionic species present. Elution with 6.0M-HCl gives the usual symmetrical curve.—J. R.

Production of Metallic Sodium. Harvey N. Gilbert (*J. Electrochem. Soc.*, 1952, 99, (11), 305C-306C).—A brief review, mainly devoted to the Castner process.—G. T. C.

Electrolytic Zinc Plant at Monsanto, Illinois. T. I. Moore and L. A. Painter (*J. Metals*, 1952, 4, (11), 1149-1159).—A detailed account of the plant and the processes employed to produce slab Zn assaying: Zn (by diff.) 99.9941, Cd 0.0024, Pb 0.0032, and Fe 0.0003%.—E. N.

[Discussion on a Paper by W. C. Lilliendahl, E. D. Gregory, and D. M. Wroughton:] **Removal of Embrittling Gases from Zirconium.** — (*J. Electrochem. Soc.*, 1952, 99, (12), 557).—See *M.A.*, 20, 38.—G. T. C.

***Production of Pure Rare-Earth Metals.** Frank H. Spedding *et al.* (*Indust. and Eng. Chem.*, 1952, 44, (3), 553-556).—The first of a series of papers on the prepn. and properties of the rare-earth metals. It is established that Ce, La, Nd, and Pr can be produced in a very pure state with high yields by the reduction of the rare-earth chloride with Ca, using I as an auxiliary oxidant. Full details of the methods employed are given. Ingots of Ce, weighing 150-175 g. with an average yield of 93.5%, were prepared, the ingots contg. 1-5% Ca and 0.1-1% Mg. Similar results were obtained with La and Nd and will also be obtained with Pr when larger charges are employed. The ingots may be purified by distillation of the Ca and Mg from the rare-earth metal, leaving <200 p.p.m. of these metals in the product. Typical analyses of the purified metals are given. The yields and quality of Sm and Y obtained by similar methods were poor, but further experimental work is in progress. 25 ref.—D. P. M.

[Discussion on a Paper by C. Wagner:] **Mechanism of the Reduction of Oxides and Sulphides to Metals.** — (*J. Metals*, 1952, 4, (11), 1179-1180).—See *M.A.*, 20, 40.

Industrial Electrolysis: Fifty Years' Progress in Electro-winning and Electrorefining. A. C. Loonam (*J. Electrochem. Soc.*, 1952, 99, (11), 295C-298C).—Progress in electro-winning and electrorefining in the past fifty years is briefly reviewed. 27 ref.—G. T. C.

11 — ANALYSIS

***A Note on the Comparison of Some Simple Condensed-Spark Circuits in the Spectrographic Analysis of Aluminium and Magnesium Alloys and Pure Magnesium.** E. C. Mills and S. E. Hermon (*Metallurgia*, 1952, 46, (276), 213-215).—It is concluded, from the results of an investigation of the relative performance of simple condensed spark circuits in the analysis of Al and Mg alloys and pure Mg, that although it is possible to grade the results on the basis of reproducibilities, the type of source unit does not affect greatly the precision which can be attained.—F. M. L.

***Studies on the Determination of Arsenic.** Yachiyo Kakita and Michiko Namiki (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 18, (7), 391-393).—[In Japanese, with tables in English]. The reduction of As to the metallic state by chromous, titanous, and Mo soln. was studied. It was found that the metallic state was obtained with chromous soln. + HCl or chromous soln. + HCl + H₂SO₄ and not by titanous and Mo soln. The metallic As obtained was estimated by iodometric and grav. analysis. The accurate and rapid detn. of As in Fe by appn. of this method is given.—AUTHORS.

***Ultra-Violet Absorptiometric Determination of Arsenic as 12-Molybdoarsenic Acid.** Coe Wadelin and M. G. Mellon (*Analyst*, 1952, 77, (920), 708-715; discussion, 716-717).—Paper presented to the First International Congress on

Analytical Chemistry, Oxford, September 1952. Following extraction of 12-molybdoarsenic acid from water into butan-1-ol, it is possible to determine <1 mg. of As absorptiometrically. The effects of 48 diverse ions are reported, together with methods for preventing interference by soluble SiO₂, Fe, and small amounts of orthophosphates.—F. M. L.

***Determination of Chromium by Oxidation in the Presence of Silver Nitrate.** Scott Lynn and David M. Mason (*Analyt. Chem.*, 1952, 24, (11), 1855).—A note. A more quant. oxidation of small amounts (<10 mg.) of Cr in HClO₄ and H₂SO₄ at 200°-220° C. is obtained by adding a small amount of AgNO₃.—F. M. L.

***1:10-Phenanthroline and Mono-, Di-, Tri-, and Tetra-Methyl-1:10-Phenanthroline as Chelated Copper Complex Cations.** W. H. McCurdy and G. Frederick Smith (*Analyst*, 1952, 77, (921), 846-857; discussion, 858).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A study has been made of the Cu⁺ complex cations formed from 28 mono-, di-, tri-, and tetra-methyl 1:10-phenanthrolines. The results are discussed theoretically and practically.—F. M. L.

***The Gravimetric Determination of Lead, Silver, and Mercurous Mercury on the Microgramme Scale.** Hamed M. El-Badry and Cecil L. Wilson (*Analyst*, 1952, 77, (920), 596-600; discussion, 600-601).—Paper presented to the

First International Congress on Analytical Chemistry, Oxford, September 1952. Using specialized techniques and a special micro-balance 10 γ of Pb, Ag, and Hg¹ may be determined grav. as PbSO₄, AgCl, and Hg₂Cl₂.

—F. M. L.

***On the Analysis of Pig Lead by a Polarographic Method. I.—Determination of Antimony, Bismuth, Copper, Iron, and Zinc.** Shigeru Yokosuka and Masao Tanaka (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (5), 291–294).—[In Japanese, with tables in English]. Sb, Bi, Cu, Fe, and Zn are separated from the pig Pb by removal of the Pb as PbSO₄. Cu is precipitated by oxine soln. and filtered off. H₂SO₄ and a small quantity of gelatin soln. are added to the filtrate to make the supporting electrolyte 1N-H₂SO₄. A polarogram is recorded at 0 to –0.5 V. Fe is precipitated as Fe₂(OH)₆ and the filtrate made the supporting electrolyte of 1M-Na citrate. The polarogram is recorded at –0.2 to –0.9 V. Cu and Zn are determined by pptn. with NH₄OH from the initial soln. and after adding a little gelatin soln. the supernatant liquor is filtered and the polarogram of the filtrate is recorded at 0 to –0.6 V. and –1.0 to –1.5 V.

—AUTHOR.

***Determination of Trace Impurities in Magnesium by Activation Analysis.** G. J. Atchison and W. H. Beamer (*Analyt. Chem.*, 1952, 24, (11), 1812–1815).—By irradiating pure Mg at a flux d of $\sim 5 \times 10^{11}$ neutrons/cm.²/sec. for 4 weeks, it has been possible to determine, with an accuracy of $\pm 10\%$, 1×10^{-9} g. As, 3×10^{-9} g. P, 3×10^{-8} g. Cu, 1×10^{-7} g. K, 1×10^{-7} g. Na, 2×10^{-6} g. Sr, 2×10^{-6} g. Ca, 5×10^{-6} g. Cr, and 1×10^{-5} g. S. By irradiation for 4 weeks at a higher flux d of 7×10^{12} neutrons/cm.²/sec., 5×10^{-8} g. Fe could be determined with similar accuracy. The various chem. sepn. involved after irradiation of the Mg are described.

—F. M. L.

Metallurgical Nickel Analysis. W. D. Mogergerman (*Indust. and Eng. Chem.*, 1952, 44, (5), 971–973).—Presented at an American Chemical Society Symposium on Nickel. An historical review is given of analytical difficulties that delayed general recognition of Cronstedt's discovery of Ni. The Ni methods most widely used in met. laboratories for determining Ni in both small and large quantities are discussed, and some practical hints are given for eliminating certain sources of error in grav. work.—D. P. M.

***The Polarographic Determination of Nickel in Aluminium Alloys.** E. C. Mills and S. E. Hermon (*Metallurgia*, 1952, 46, (277), 259–262, 266).—After initial dissoln. of the sample and, if necessary, removal of Cu and Si, Ni is separated from Al by NaOH pptn. and converted to chloride. A polarogram is then recorded in pyridine-pyridinium chloride-base electrolyte, using gelatin as max. suppressor.—F. M. L.

***Fire Assay for Osmium.** W. J. Allan and F. E. Beamish (*Analyt. Chem.*, 1952, 24, (10), 1569–1572).—By "salting" various flux mixtures with NH₄ bromo-osmate, the losses incurred in the detn. of Os by dry assaying have been investigated. In most cases losses to the flux were considerable, although by re-running slags a reasonable recovery was obtained. As would be expected, cupellation, either partial or complete, gives rise to large losses, particularly by volatilization of OsO₄, and wet treatment for the detn. of Os in the Pb button is essential.—F. M. L.

***Micro-Determination of Osmium.** W. J. Allan and F. E. Beamish (*Analyt. Chem.*, 1952, 24, (10), 1608–1612).—Various methods of determining small amounts of Os have been investigated. A suitable grav. method involves pptn. of Os with thionalide and ignition of the precipitate in H to metal. Thiourea is a most suitable reagent for colorimetric detn.—F. M. L.

***Determination of Oxygen in Metals and Metal Oxides by the Isotopic Method.** A. D. Kirshenbaum and A. V. Grosse (*Amer. Soc. Metals Preprint*, 1952, (30), 11 pp.).—A 100–500-mg. sample of the metal or metal oxide whose O content is to be determined is placed on a graphite boat in a Mo or Pt tube, which is itself connected to a Pyrex glass vacuum system. The detn. of O in Cu is made as follows: A known

weight (100–200 mg.) of a master alloy contg. a known proportion of O¹⁸ is also placed on the boat. The system is evacuated to 10⁻⁴ mm. Hg, and the Pt tube closed off from the vacuum system. The Pt tube is then heated to 1000°–1100° C. by induction-heating for 1 hr. The CO and CO₂ thus liberated are subsequently separated and their O¹⁸:O¹⁶ ratios determined by means of an isotopic mass spectrometer. The quantity of O in the unknown sample is then readily calculated. The detn. of O in Fe is similar, the Pt tube being replaced by a Mo tube, and the sample being heated to 1500°–1600° C. Full experimental details of the method are given, and the results of a number of sample analyses are presented. It is claimed that the method is quicker and more accurate than existing methods in which the O in the sample is completely removed and recovered. The method can be applied to the detn. of O in other metals, particularly in Ti and Zr. 27 ref.

—R. W. R.

***Microgravimetric Methods for Platinum: A Comparative Study.** A. P. Blackmore, M. A. Marks, R. R. Barefoot, and F. E. Beamish (*Analyt. Chem.*, 1952, 24, (11), 1815–1819).—The detn. of up to 10 mg. Pt by pptn. with formic acid or as (NH₄)₂PtCl₆ is proved unsatisfactory. A method based on pptn. with controlled amounts of Zn dust is described.

—F. M. L.

***Catalytic Determination of Sub-Microgramme Quantities of Silver.** A. L. Underwood, A. M. Burrill and L. B. Rogers (*Analyt. Chem.*, 1952, 24, (10), 1597–1601).—The catalytic action of Ag on the persulphate oxidation of Mn^{II} to permanganate is used as a basis for the detn. of my amounts of Ag.

—F. M. L.

***Gravimetric Determination of Thorium and Rare-Earth Elements in Magnesium Alloy.** G. B. Wengert, R. C. Walker, M. F. Loucks, and V. A. Stenger (*Analyt. Chem.*, 1952, 24, (10), 1636–1638).—The sample is dissolved in HCl, the soln. neutralized until just acid, Ce^{IV} reduced to Ce^{III} with Na₂SO₃, and then Th is precipitated, with Zr, by means of benzoic acid and the precipitate is filtered off. The filtrate is neutralized to pH 7.5–8.5 (8.5–9.5 if Zn is present), and rare earths are then precipitated with NH₄ sebacate. Both precipitates are dissolved in HCl, and Th on the one hand and rare earths on the other are precipitated as oxalates, which are filtered off and ignited to oxides for weighing.—F. M. L.

***The Complexes Formed by Thorium and Uranyl Ions with Complexones.** M. J. Cabell (*Analyt.*, 1952, 77, (921), 859–865; discussion, 865–866).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. The complexes of Th and UO₂ ions with nitrilotriacetic acid and ethylenediaminetetraacetic acid have been studied by the Bjerrum-Calvin method. Th forms definite ionic species which are stable, whereas the UO₂ complexes are very much less stable, hydrolyse readily, and the U is easily precipitated. The results are discussed in relation to the stability of uni-, bi-, and ter-valent cations.

—F. M. L.

***A Semi-Quantitative Spot Test for Tin in Magnesium and Aluminium Alloys.** J. Clark and W. Stross (*Metallurgia*, 1952, 46, (276), 215–216, 212).—A semi-quant. spot test, suitable for sorting scrap, for the estn. of Sn in Al or Mg alloys is based on the decolorization of the starch-iodine reagent of Charlot and Bézier (*Anal. Chim. Acta*, 1947, 1, 113; *M.A.*, 15, 18) by stannous ions.—F. M. L.

***Determination of Titanium in Titanium Metal.** J. M. Thompson (*Analyt. Chem.*, 1952, 24, (10), 1632–1634).—Ti metal (0.2 g.) is dissolved in fused KHSO₄ and the melt dissolved in 1:1 HCl. A preliminary reduction of Ti is carried out with amalgamated Zn; the soln. is poured through a Jones reductor and Ti then titrated with standard ferric alum soln. If it is suspected that Cr, Mo, W, and/or V are present, FeCl₃ is added to the original soln., which is then poured into NaOH soln. contg. H₂O₂ and boiled. Ti which is co-precipitated with the Fe is filtered off, and the paper and precipitate are decomposed with HNO₃ and H₂SO₄. The soln. is finally fumed with H₂SO₄ and the detn. then continued as described.—F. M. L.

*Chemical Properties [and Analysis] of the Titanium-Aluminum Alloys. (Cueilleron and Pascaud). See col. 470.

*Spectrophotometric Determination of Uranium by Thiocyanate Method in Acetone Medium. Carl E. Crouthamel and Carl E. Johnson (*Analyt. Chem.*, 1952, 24, (11), 1780-1783).—The large number of anionic interferences to which the aq. thiocyanate method for detn. of U is subject are eliminated by using a saturated soln. of NH_4CNS in acetone to develop the colour.—F. M. L.

*On the Volumetric Estimation of Zinc. Takao Honjo (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (4), 231-233).—[In Japanese, with tables in English]. As the $\text{K}_4\text{Fe}(\text{CN})_6$ method, using FeSO_4 or diphenylamine as an internal indicator, requires much skill by an operator to determine the exact end-point, H. proposes the following method. Zn is precipitated as ZnS with H_2S using monochloroacetic acid and Na monochloroacetate as a buffer soln. at $\text{pH} \sim 2.4$. The ZnS is filtered and, after washing well with H_2O , is dissolved in a definite amount of 0.35N-HCl. The soln. is boiled for 5 min. to expel H_2S , cooled, diluted to ~ 200 c.c. and the excess acid is titrated with standard NaOH ($\sim 0.35\text{N}$), using methyl orange as an indicator. The NaOH soln. is standardized against pure ZnO dissolved in HCl. Phenolphthalein cannot be used because $\text{Zn}(\text{OH})_2$ begins to precipitate at $\text{pH} \sim 6$. The method has proved to be useful in analysing alloys contg. Zn, e.g. brass, Zn Duralumin.—AUTHOR.

Vacuum-Fusion Analysis: Apparatus for Determination of Gas Content in Metals. — (*Metal Ind.*, 1952, 81, (21), 403).—Describes apparatus developed by the National Research Corp., Cambridge, Mass., for the detn. of O, N, and H in a wide variety of ferrous and non-ferrous metals and alloys. Sensitivity as high as 1 part in 10^7 is claimed.

—J. H. W.

Determination of Non-Metallic Compounds in Metals. H. F. Beeghly (*Analyt. Chem.*, 1952, 24, (11), 1713-1721).—Known methods and reagents for the isolation and identification of non-metallic compounds in metals are considered. Displacement, reactions with halogens, reactions with inorganic acids, and electrolysis are reviewed with particular ref. to isolation of oxides, carbides, nitrides, and sulphides. A résumé is given of experimental data on metal-N compounds separated from C steels, using an ester-halogen reagent (a methyl acetate soln. of Br). 113 ref.

—F. M. L.

*The Solvent Extraction of Group IIIB Metal Halides. H. M. Irving and F. J. C. Rossotti (*Analyt.*, 1952, 77, (920), 801-812; discussion, 812).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. With the aid of the radio-nuclides ^{72}Ga , ^{111}In , and ^{204}Tl , the extraction of GaBr_3 and GaI_3 , InCl_3 and InI_3 , TlI_3 , TlCl_3 , TlBr_3 , and TlI_3 from the corresponding halogen acids have been studied. The prediction that InI_3 can be extracted into ether from HI of low normality has been confirmed and, based on this, a simple procedure for the sepn. of In from Ga, Be, and Fe has been developed.—F. M. L.

*The Stability of Metal Chelates in Relation to Their Use in Analysis. Henry Freiser (*Analyt.*, 1952, 77, (921), 830-840; discussion, 841-845).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. The acidic dissociation const. of a number of organic reagents in 50% aq. dioxan have been determined, and the chelate formation const. measured in the same solvent by the Bjerrum-Calvin technique for metals such as Cu, Ni, Co, Zn, Pb, Mg, Cd, La, and Ce^{IV} . The results are exhaustively discussed on a theoretical basis.—F. M. L.

Developments in the "Dead-Stop End-Point" Titration Technique. J. T. Stock (*Metallurgia*, 1952, 46, (276), 209-212).—A review, with 33 ref.—F. M. L.

Approaches Utilized in the Development of Spot Tests. Philip W. West (*Analyt.*, 1952, 77, (920), 611-616; discussion, 616-617).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A summary of some of the approaches that have been used to develop spot tests. 13 ref.—F. M. L.

Applications of Ion Exchange to Analytical Chemistry. Edward R. Tompkins (*Analyt.*, 1952, 77, (921), 970-981; discussion, 981-982).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A review, with 69 ref.—F. M. L.

Quantitative Inorganic Paper Chromatography. A. Lacourt, Gh. Sommereyns, and G. Wantier (*Analyt.*, 1952, 77, (921), 943-953; discussion, 953-954).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. The various factors influencing chromatographic sepn. of metals are described and discussed. A method of separating Fe, Ti, and Al into three spots, instead of the two previously attainable, is described.—F. M. L.

*Modification of the Cambridge Polarograph for Derivative Polarography. P. R. Pomeroy, R. A. White, and G. H. R. Gwatkins (*Metallurgia*, 1952, 46, (275), 157-163, 165).—An adaptor to the Cambridge Polarograph is described which enables the instrument to be used either as a derivative instrument, as suggested by Lévêque and Roth (*J. Chim. Phys.*, 1949, 46, 480; *M.A.*, 18, 208), or as a normal direct polarograph. The adaptor, which is inexpensive, is capable of determining the concentration of minor components which polarize after the main constituents. Other advantages are sepn. of close waves, measurement of poorly developed waves, and that de-aeration is usually unnecessary. An alternative form of electrode removes the oscillations due to drop size and, therefore, increases accuracy. The modified polarograph is especially suitable for the rapid analysis of Cu-base alloys.

—F. M. L.

Square-Wave Polarography. G. C. Barker and I. L. Jenkins (*Analyt.*, 1952, 77, (920), 685-695; discussion, 695-696).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A method is described for eliminating the undesirable effect of the double-layer capacity current on the sensitivity of an A.C. polarograph. A sq.-wave voltage is used in place of the usual sinusoidal polarizing voltage, and the amplitude of the A.C. component of the cell current is measured shortly before each sudden change in the applied voltage.—F. M. L.

Some Factors Controlling the Selectivity of Organic Reagents. H. M. Irving and R. J. P. Williams (*Analyt.*, 1952, 77, (921), 813-826; discussion, 826-829).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A theoretical discussion on the formation of metal complexes with organic reagents. 31 ref.—F. M. L.

*A Counter-Current Micro-Rotary Extractor as an Analytical Tool. R. Spence and R. J. W. Streeton (*Analyt.*, 1952, 77, (920), 578-582; discussion, 582-583).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A micro-form of rotary solvent extractor is described. Quant. extraction of U has been attained with columns 10-15 cm. long, both on a continuous basis and from 1-2 c.c. samples.—F. M. L.

Infra-Red, Ultra-Violet, and Raman Spectroscopy: Application to Analysis of Complex Materials. O. D. Shreve (*Analyt. Chem.*, 1952, 24, (11), 1692-1699).—A review, with 26 ref.

—F. M. L.

Determination of Surface Geometry and Structure by Microscopy and Diffraction. Charles Fulton Tufts (*Analyt. Chem.*, 1952, 24, (11), 1700-1704).—The use of light microscopy, electron microscopy, and electron diffraction in determining adequate surface descriptions in the analysis of materials for ingredients of unknown constitution, is described. 8 ref.

—F. M. L.

Analytical Applications of Radiochemical Techniques. James E. Hudgens, Jr. (*Analyt. Chem.*, 1952, 24, (11), 1704-1703).—A review, with 97 ref.—F. M. L.

The Practice of Analytical Chemistry. S. E. Q. Ashley (*Analyt. Chem.*, 1952, 24, (11), 1690-1692).—A review, with 13 ref.—F. M. L.

Research in Analytical Instrumentation. Ralph H. Müller (*Analyt.*, 1952, 77, (920), 557-563).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A review.—F. M. L.

The Value and Economic Importance of Chemical Analysis in Industry and Manufacture. L. H. Lampitt (*Analyst*, 1952, 77, (920), 564-572).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A review.—F. M. L.

A Contemporary Assessment of the Place of Classical Methods in Chemical Analysis. C. J. van Nieuwenberg (*Analyst*, 1952, 77, (920), 573-577).—Paper presented to the First International Congress on Analytical Chemistry, Oxford, September 1952. A review.—F. M. L.

12 — LABORATORY APPARATUS, INSTRUMENTS, &c.

(See also "Testing" and "Temperature Measurement and Control".)

Two Laboratory Furnaces for Melting Titanium Alloys. J. A. Rees and R. J. L. Eborall (*Metallurgia*, 1952, 46, (276), 186-190).—An account is given of a vacuum vertical graphite-resistor type and an arc-type melting furnace constructed at the laboratories of the British Non-Ferrous Metals Research Association.—F. M. L.

***A Simple Procedure for Producing Alloys with Volatile Components in a High-Frequency Furnace.** A. J. P. Meyer and P. Taglang (*J. Phys. Radium*, 1952, 13, (10), 485).—Components of the alloy, to be produced, are packed, without voids, into the bottom part of a refractory, tubular crucible which is then sealed by a magnesia plug and arranged within a long silica tube (A) forming a sliding fit. A second silica tube (B) closed at its bottom end rests on the magnesia plug and forms a nice sliding fit with A. Finally, the upper parts of the tubes A and B are sealed together with a suitable wax, forming a closure. The assembly is then placed within the solenoid of the H.F. furnace, and is able to withstand a high internal pressure without fracture. The device has been satisfactorily used for 2 years to prepare alloys of the types Co-Zn, Mn-Zn, Mn-As, Mn-Bi, Fe-P, Co-B, &c.

—J. S. G. T.

***Instruments for Measuring Heat Flux in Furnaces.** M. W. Thring (*Proc. General Discussion on Heat Transfer* (Inst. Mech. Eng. and Amer. Soc. Mech. Eng.), 1951, 342-344).—Instruments designed for studying (a) the phenomena of combustion and heat transfer and (b) means for obtaining optimum flame conditions in furnaces are briefly described and illustrated. These comprise: (1) a heat-flow meter consisting of a water-cooled calorimeter, embedded on one side of the end of a long water-cooled arm, for studying heat flow in furnaces; (2) a front-wall pyrometer for measuring the heating power of the flame heating a furnace; (3) a sensible heat meter in the form of a water-flow calorimeter for measuring the heat given up by a sample of heated gas withdrawn from the furnace; and (4) apparatus for measuring average radiating temp. of furnace flames, by the Schmidt (variable background), Kurlbaum, and Na line reversal methods.—J. S. G. T.

Electromagnetic Instruments for Measuring Coating Thickness, Which Are Based on [the Principle of] a Magnetic Circuit. J. H. Zaat (*Metallüberfläche*, 1951, [A], 5, (12), 185-191).—Math. Sources of error in the electromagnetic method for the detn. of the thickness of non-ferromagnetic coatings on a ferromagnetic base are analysed, and recommendations are made as to how they can be reduced. 6 ref.—E. N.

***A Sensitive Comparator for Measuring Wires.** J. C. Evans, R. S. Marriner, and I. G. Morgan (*Wire Ind.*, 1952, 19, (222), 551-552, 555).—Describes a pneumatic comparator for measuring the variation in dia. of wires as small as 0.001 in., of Cu or other soft metals which are susceptible to damage under micrometer anvil-pressures. The instrument enables a continuous record of the variation to be plotted as the wire is drawn through the comparator, and its performance is illustrated by records showing the varying dia. along the length of a 49 S.W.G. Cu wire both before and after it has been enamelled. The record is accurate to ± 0.00002 in. ($\pm 0.5 \mu$).—C. P. F.

***On the Problem of Studying the Properties of Metals and Alloys at Elevated Temperatures in Vacuo.** N. T. Gudtsov, M. G. Lozinsky, I. F. Zudin, N. A. Bogdanov, and M. P.

Matveeva (*Izvest. Akad. Nauk S.S.S.R.*, 1950, [Tekhn.], (1), 103-125).—[In Russian]. The methods and apparatus described permit the detn. of the microstructure of metals and alloys up to the m.p., their hardness up to 1000° C., and the rate of evaporation of a metal *in vacuo*. A brief survey of relevant past researches is followed by a description of the methods of heating test-pieces and measuring surface temp., together with details and a diagram of the vacuum test apparatus. A section on the structure of alloys revealed by heating *in vacuo* includes a discussion on etching a heated test-piece under vacuum, and the utilization of phenomena of surface evaporation to expose the structure on heating a metal at high temp. Test equipment for determining evaporation rate on heating metals under vacuum and for measuring the hardness of test-pieces when hot is described. Photographs illustrate microstructures of a number of steels.

—H. W.

A High-Resolution Surface-Profile Microscope. S. Tolansky (*Nature*, 1952, 169, (4298), 445-446).—T. describes a further development of the Schmalz light-slit microscope. The simple slit placed against the field iris was replaced by a fine wire or a glass graticule to give a fine dark line on a bright field. A graticule of parallel lines can be used to reveal profiles over an extended area. The technique can be used with any surface illuminating microscope if the glass reflector be suitably silvered to give an off-centre pencil; monochromatic light must be used. Structural details $< \lambda/2$ are resolvable, and magnifications up to $\times 4000$ may be used. The technique can be employed for the examination of crystal surfaces, and engineering-machined precision surfaces, and has been particularly useful in the precise measurement of the depth of hardness indentations.—R. S. B.

A Specimen-Treating Adaptor for the Electron Microscope. Nobuji Sasaki and Ryuzo Ueda (*Rev. Sci. Instruments*, 1952, 23, (3), 136-138).—A special adaptor is described which enables a specimen to be subjected to phys. or chem. treatment and then to be moved to the usual observation position without exposure to air. An example is illustrated when the same field of a specimen of MoO_3 is first reduced with H and then re-oxidized.—E. J.

***A Point-Focusing X-Ray Monochromator for the Study of Low-Angle Diffraction.** Leon Shenfil, Warren E. Danielson, and Jesse W. M. Du Mond (*J. Appl. Physics*, 1952, 23, (8), 854-859).—A beam of CuK X-rays from a small focal spot is reflected in turn from two Johansson-type bent-quartz crystals of small aperture, the axes of curvature being \perp . The monochromatic beam comes to a point focus. The specimen is placed between the second crystal and the focus, in an enclosure filled with He to reduce gas-scattering. The central blind spot subtends only $\sim \pm 10'$.—R. W. C.

***A Supraconducting Galvanometer.** A. B. Pippard and G. T. Pullan (*Proc. Cambridge Phil. Soc.*, 1952, 48, (1), 188-196).—A supraconducting tangent galvanometer comprising two deflecting coils each made of a single turn of supraconducting Pb wire, with a controlling magnetic field of ~ 0.01 Oe. and a total resistance of $\sim 10^{-7} \Omega$ is described. The instrument is designed for the measurement of thermoelect. voltages at temp. below 4.2° K., and will detect a current of 10^{-5} amp. corresponding to 10^{-12} V. The theory, design, construction, and performance of the instrument are given and illustrated.—J. S. G. T.

13 — PHYSICAL AND MECHANICAL TESTING, INSPECTION, AND RADIOLOGY

Watertown Arsenal Testing Machine Has 72 Year History of Service. — (*J. Metals*, 1952, 4, (10), 1038).—A brief description of the history and the modernization of the original Emery 1,000,000-lb-capacity hydraulic testing machine installed at Watertown Arsenal, Mass., U.S.A., during the 1870s. It will take compression specimens up to 30 ft. long.—E. N.

Fatigue Machines for Low Temperatures and for Miniature Specimens. W. N. Findley, P. G. Jones, W. I. Mitchell, and R. L. Sutherland (*Amer. Soc. Test. Mat. Bull.*, 1952, (184), 53-55).—The design and special features of three new types of fatigue testing machines are described: (1) A high-speed rotating-beam fatigue machine designed for operation at temp. as low as -320°F . (-196°C). This machine employs a vertical spindle and has a device for adjusting the alignment of the specimen. (2) A repeated-bending fatigue machine also for testing at temp. down to -320°F . It can be used for tests in bending, torsion, or combined bending and torsion. (3) A repeated-bending fatigue machine able to test miniature specimens $\frac{3}{4}$ in. long in either bending or torsion.—P. T. G.

***Fatigue Tests in Axial Compression.** N. M. Newmark, R. J. Mosborg, W. H. Munse, and R. E. Elling (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 792-803; discussion, 804-810).—The results are given of a preliminary investigation of the behaviour of materials subjected to repeated compressive loads. Materials used were grey cast Fe, 24S-T Al alloy, and steel. The testing machine was a W. M. Wilson-type fatigue machine operating at a speed of 290 c./min. In general, failures occurred only under high compressive stresses. With steel, for example, failures did not occur at < 5 million cycles until stresses of 85,000 lb./in.² or higher were applied. The endurance limit for all the materials was considerably higher in axial compression than in axial tension or flexure, particularly for steel. The results, under nearly uniformly distributed axial compressive loads, are in distinct contradiction to results obtained with notched specimens or with repeated bending tests. 5 ref.—P. T. G.

Penetration Hardness: Its Dependence on the Load and a Proposal for a New Definition. P. Grodzinski (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (9), 282-292).—[In German]. Cf. *M.A.*, 19, 861. The penetration hardness, defined as a stress (load/area of impression) is independent of the load over a fairly wide range (3-20 kg. in the Vickers diamond hardness test), but with the very low loads used in micro-hardness testing the hardness varies considerably with the load applied. The greater the proportion of elastic deformation in any test, the smaller is the final impression and the higher the apparent hardness; flattening of the indenter also becomes increasingly significant with very small impressions; thus the effect of load on the apparent hardness depends on the nature and detailed conditions of the test, including the hardness of the metal. The following definition is proposed; the hardness h is the load which produces an impression of unit size, $h = P/d^2$, where d = dia. of the indentation. In general, two measurements with different loads are required in order to determine the values for h and n from a double-log. plot. The hardnesses of a variety of substances were determined according to this definition and Meyer's criterion, and it is claimed that the new definition gives more consistent and sensitive differentiation. 29 ref.—K. S.

†Application of the Micro-Hardness Test to Watch Parts. H. Bückle (*Ann. Franç. Chronométrie*, 1952, 22, 229-246).—Four forms of sclerometer, especially designed for measuring the micro-hardness of specimens under loads of 1-100 g. and giving an impression of dia. 3-50 μ are discussed, and their operation described. They are operated in conjunction with a microscope for locating the desired test point. The laws of micro-hardness are compared with those of macro-hardness, and the appn. of micro-sclerometers for the detn. of the hardness of watch parts, including (1) spindles, toothed wheels, thin sheet metal, and "hands," (2) cementation zones,

screw threads, &c., and (3) for the identification of inclusions, segregates, and stresses, is described and illustrated. 15 ref.

—J. S. G. T.

***Interferometric Studies of Hardness-Test Indentations: Investigations on Tungsten Carbide, Steel, Duralumin, and Tin.** (Tolansky and Nickols). See col. 482.

***The Measurement of the Relative Hardnesses of Fine Powder Particles.** J. B. Matthews (*J. Inst. Metals*, 1952-53, 81, (6), 279-285).—The experimental technique originally devised by Chalmers (*ibid.*, 1941, 67, 295) for the detn. of the surface hardness of metallic strips, by their bombardment with a hard powder such as sand or carborundum, has been applied to the measurement of the relative hardnesses of different powder particles. The method depends on the decrease in specular reflectivity produced by the indentation of the reflecting surface by the bombarding powder particles, when the hardness of the surface is not far removed from that of the particles. Formal relationships have been derived connecting the decrease in reflectivity with the relative "hardness" of the particles.—AUTHOR.

What Can Be Learned from the Hardness Test?—I.-II. Howard E. Boyer (*Steel Processing*, 1952, 38, (5), 223-227; (6), 280-285, 298-299).—A general review of the development, principles, methods, and appn. of hardness testing.

—S. R. W.

The Measurement of Internal Friction in Metallurgical Research. K. M. Entwistle (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 651-655).—The importance of internal friction is stressed and an apparatus for making measurements on materials of low damping capacity over a wide frequency range is described. Aberrations which may occur due to slight asymmetry of section of the specimen are discussed.—D. M. P.

†The Measurement of Residual Stresses. J. J. Lynch (*Residual Stress Measurements (Amer. Soc. Metals)*, 1952, 42-96).—Residual stresses in metals are estimated indirectly by measuring the strains that exist in the metals; the strains are usually measured by mech. or X-ray methods, and the stresses calculated from elastic-theory formulae. Customary methods of residual-stress detn., most of which are approx., are described and discussed. A few qual. methods are also described. Mech. methods utilize: (1) observed changes of dimensions of the metal on the removal of layers of the metal, (2) changes of elect. resistance of the metal, determined by strain gauges, after boring the metal, (3) observed changes of curvature of strip on removing successive layers of the strip or during the process of electroplating, (4) observed changes of distances between gauge marks consequent upon cutting plates into strips, and (5) the observed changes between drilled holes due to boring an intermediate hole. X-ray methods utilize the fact that the atomic interplanar spacing is changed by stress. Qual. methods include etching or stress-corrosion techniques, magnetic and interferometric methods. 36 ref.—J. S. G. T.

***The Constancy of Calibration of Elastic Calibrating Devices.** W. C. Aber and F. M. Howell (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 1072-1084; discussion, 1084-1086).—The testing machines used by the Aluminum Company of America for regular inspection tension tests have been periodically calibrated during the past 30 years. The load-calibrating devices used for this purpose are described, and details are given of the results of calibration of them by the National Bureau of Standards over a period of years. Amsler calibrating boxes are used, consisting of hollow steel cylinders completely filled with Hg, the change of vol. of which is measured when the devices are loaded in either tension or compression. Periodic calibration of the boxes since 1933 showed that the calibration factor changed gradually but only at the rate of 0.1% every 3 years. The other devices used are loop dynamometers, the deflections of which are measured with dial gauges. These remained practically const. since first being

constructed and calibrated in 1944. It is important to use dial gauges that will repeat readings within narrow limits. 4 ref.—P. T. G.

The Increasing-Load Wire Abrasion Tester. H. T. McLean (*Wire and Wire Products*, 1952, 27, (9), 871-873, 928-929).—A method of testing the abrasion-resistance of enamel and synthetic-resinous coatings on coil-winding wire, is described. It was developed by the G.E.C. of Schenectady and is considered to be superior to the repeated scrape test used by that organization and others since 1941. The method consists of rubbing a length of the wire with the side of a steel sewing needle under progressively increasing loadings, and recording the load at which penetration through the coating to the Cu is detected by an elect. cut-out. It is claimed that the average spread ratio of results is less than half that of results from the earlier type of test. Tests can be made all round of a short sample of wire.—C. P. F.

The Metallurgist's Role in the Interpretation of Non-Destructive Testing. S. L. Henry (*Non-Destructive Testing*, 1952, 11, (1), 16-20).—Non-destructive inspection reveals only the presence, location, and possibly the extent, of a defect. The evaluation of its nature, cause and extent, the importance in service, and its possible prevention in future specimens calls for close collaboration between the metallurgist, the designer, the technician responsible for its detection, and the prodn. engineer. The met. procedures used may include macro- and micrographic examination, chem. methods, spectrography, and X-ray diffraction. Three case histories discuss the detn. of the nature and extent of defects revealed by magnetic particle inspection; another illustrates the met. follow-up on a shrinkage defect revealed by radiography. A further example shows how ultrasonic tests assisted the metallurgist in the selection of castings free from fatigue cracks, and how strain gauges applied to the same component assisted in its redesign.—L. M.

Magnetic and Electrical Methods of Non-Destructive Testing of Metal Components. Werner Jollinghaus (*Métaux, Corrosion-Ind.*, 1952, 27, (317), 34-43).—The principles of the more usual methods are briefly described, together with their limitations and advantages. 15 ref.—M. A. H.

***A New Method of Obtaining Permanent Records in Non-Destructive Testing for Surface Defects on Components.** W. Stauffer and A. Keller (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (5), 137-148).—[In German]. Photographs of surface defects revealed by magnetic crack detection or liquid-penetration methods are not always satisfactory, particularly if the surface is inaccessible, curved and therefore difficult to illuminate, or rough and corroded so that contrast is poor. Magnetic powder images can be improved and preserved by placing moistened paper on the surface to be examined before applying the powder or pressing the paper over the powder image to obtain a print. A transparent lacquer, applied in a solvent, is preferable to paper and can also be used in the liquid-penetration process; the solvent is also capable of dissolving the fluorescent liquid or dye so that a single appn. develops the image which is fixed in the lacquer as the solvent evaporates. The lacquer may be left on the surface and protects it against mech. damage and corrosion; it can be stripped off without difficulty and used as a permanent record; enlargement is possible, and photographic contact prints can be taken directly from the lacquer film. The method of appn. and some examples are described in detail, but there is no indication of the lacquer and solvent employed.—K. S.

Physical Aspects of Ultrasonic Testing of Metals. H. J. Seemann (*Métaux, Corrosion-Ind.*, 1952, 27, (317), 14-23).—The wave-lengths of elastic oscillations which can exist in solids are compared with the dimensions of textural elements in metals. Such oscillations are influenced by texture in polycryst. metals, owing to diffusion effects, the nature of which is not yet clear. 17 ref.—M. A. H.

Ultrasonic Flaw Detection. J. Tabin (*Prace Głównego Inst. Met.*, 1951, 3, (6), 517-526).—[In Polish]. The theory, techniques, and appn. of the method are reviewed with special ref. to the Hughes Mk III ultrasonic flaw detector. 13 ref.

—A. G.

The Belgian Method of Ultrasonic Examination of Materials. G. A. Homès, Y. Ots, and E. Symon (*Métaux, Corrosion-Ind.*, 1952, 27, (317), 24-33).—The method described is based on the measurement of intensity of transmitted or reflected impulses, not on timing of the reflection. Several types of probe and various techniques suited to various appn. are described.—M. A. H.

Photoelectric Scanning of Fluorescent Indications. S. A. Wenk, K. D. Cooley, and R. M. Kimmel (*Non-Destructive Testing*, 1952, 11, (1), 28-31).—An electronic device is described for scanning specimens subjected to inspection for cracks by penetrant oils, or magnetic particles, or the type which fluoresce under ultra-violet light. The fluorescent indications are transferred by a lens system and a rotating scanner to a photomultiplier tube and the signals observed on a cathode-ray tube.—L. M.

A Preliminary Report on the Picker-Polaroid Process in Industrial Radiography. J. A. Reynolds (*Non-Destructive Testing*, 1952, 11, (1), 24-27).—This process utilizes the Land-Polaroid method of obtaining a permanent image on paper about a min. after exposure, without a darkroom. The first (negative) image is formed on a sensitized paper (10 × 10 in.) lying in contact with an X-ray intensifying screen in a special cassette, which provides for the transfer of this exposed paper into a light-tight box. In the transference the exposed paper is brought face to face with a second sensitized paper and a viscous chemical (contained in a pod attached to one of the papers alongside the image area) is automatically spread between the papers. After 1 min. the two papers are stripped apart, and the positive image on the second sheet used for interpretation. The two sheets of paper, the intensifying screen, and the chem. pod are all originally enclosed in a light-tight envelope. Definition is equal to that obtained with very fine-grain X-ray films, the speed is ~70% of that of fine-grain X-ray films and the sensitivity is ~8% for Al exposed at 60 kV. The processing temp. is not critical, but the existing material (intended for medical use) has a restricted *d* range.—L. M.

Units Used in Industrial Radiography to Describe Strength of Cobalt-60 Sources. J. Kastner (*Non-Destructive Testing*, 1952, 11, (1), 21-23).—The following methods of expressing the strengths of Co⁶⁰ sources are described and critically examined: (1) nominal disintegration rate, expressed in terms of the Curie; (2) Ra equivalent, i.e. the weight of Ra in mg. having the same radiographic or ionization effect when used under similar circumstances; (3) the measured radiation output, or ionization effect, in terms of milliroentgens/hr. at 1 m. from the source (mrhm.); (4) radiation output, in mrhm., calculated from the true activity of the Co⁶⁰ source; and (5) apparent activity (in millicuries) calculated from the measured radiation output. These methods are compared and illustrated by ref. to a Co⁶⁰ source. K. concludes that the mrhm. is the most practical unit for radiography.—L. M.

Some Aspects of Cobalt Radiography: Errata. — (*Non-Destructive Testing*, 1952, 11, (1), 34).—Cf. O'Connor and Hirschfeld, *ibid.*, 1951, 10, (1), 33; *M.A.*, 19, 472).—L. M.

***The Possibility of Using Gamma Rays in the Radiography of Light Metals.** M. Robba (*Alluminio*, 1952, 21, (4), 353-362).—R. has carried out experiments in support of his theory that γ -radiography could be used for the examination of light metals as well as for heavy metals. The variation with λ of the ratio of scattered radiation to absorbed radiation was studied and tests carried out using a Pb screen. R. concludes that γ -rays are in fact feasible under suitable conditions. 5 ref.—I. S. M.

15 — FOUNDRY PRACTICE AND APPLIANCES

*Recent Developments in the Metallurgy of Aluminium Piston Alloys with Hypereutectic Silicon Content. Emma Maria Onitsch-Modl (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 325-337).—The effect of various addn. before casting on the tendency of Al alloys to coarse primary solidification and segregation has been investigated in the laboratory and foundry. The influence of melting and casting temp., freezing conditions, compn., and the duration of the effect of addn. was examined and the results tabulated. It is assumed that metallic addn. increase the number of nuclei present and that other addn., such as halides, reduce the number of nuclei giving fine-grained castings if undercooling is promoted. 15 ref.—D. M. P.

*Investigations on the Solidification Process of Duralumin in a Water-Cooled Sheet-Iron Ingot Mould. M. Schneider and E. Zalesiński (*Prace Głównego Inst. Met.*, 1951, 3, (6), 491-500).—[In Polish]. A theoretical study is presented of the solidification of Duralumin during gradual submersion of the sheet-Fe ingot mould into cold water, account being taken of the heat loss by radiation and the solidification process in the lower part of the ingot. Temp.-distribution curves along the axis of the ingot are plotted for ingot radii of 150-400 mm. It is considered that in order to obtain a shallow solidification front the speed of immersion must not exceed 30 mm./min. for ingots of large sections, and 40 mm./min. for small sections. —A. G.

Difficulties in Machining and Poor Mechanical Properties of Aluminium-Silicon Die-Castings. — (*Fonderie*, 1952, (82), 3191-3193).—Poor mech. properties and machinability are often found in thin die-castings of Al alloys contg. 10-15% Si. The methods of overcoming these defects in melting under a low-m.p. flux and modifying with Na are described.—J. H. W.

Brazing Offers Economy in Making Aluminium Castings. William G. Gude (*Foundry*, 1952, 80, (10), 124-125).—A new method of making complex Al alloy castings is described, in which the design is broken down into several relatively simple parts each of which is cast separately. The parts are subsequently brazed together with Al brazing alloy to form the complete casting. The method is illustrated by a description of the steps in the prodn. of a cylinder block for an automobile engine.—R. W. R.

*Phosphorus Deoxidation of Molten Copper. W. A. Baker (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 268-293).—Preliminary experiments showed that deoxidation of Cu by P results in the formation of a slag of the type $x\text{Cu}_2\text{O} \cdot y\text{P}_2\text{O}_5$, which forms as molten globules that rise to the surface of the melt, and gave indications of the compn. of the slag with O and P contents ranging from 0.001 to 0.1%. Metal and slag of a suitable compn. estimated from the preliminary experiments were heated together, and the equilibrium between the O and P contents (wt.-%) of the metal can be represented by the equation $\log [P][O]^{2.5} = 0.01177T - 25.18$ (where T is the abs. temp.). At the f.p. of Cu with ~0.03% P the O content is <0.001%. If the deoxidation is carried out under a charcoal cover, it is concluded from a consideration of furnace conditions and the max. C solubility that the O content at solidification is determined by the residual P content of the melt. 6 ref.—D. M. P.

Segregations in Lead Bronze Bush. — (*Metal Ind.*, 1952, 81, (22), 427-428).—A number of points in melting procedure required simultaneous attention before Pb segregation on the outside of a Pb-bronze bush was avoided.—J. H. W.

Extinguishing Magnesium Fires with Boron Trichloride. — (*Foundry*, 1952, 80, (8), 257-259).—The use of BCl₃ as a fire extinguisher in Mg foundries is described.—R. W. R.

Titanium Casting Research Tests Shell-Moulded Refractories. J. G. Kura (*Iron Age*, 1952, 170, (18), 88-92).—The most promising shell-moulded refractory for Ti castings is a mixture of stabilized ZrO₂ and fused ZrO₂ contg. 4% resin and without mould washes. The best mould wash for SiO₂ moulds appears to be a colloidal graphite dispersion.—J. H. W.

[Discussion on a Paper by W. E. Kuhn:] Production of Titanium Ingots by Melting Sponge Metal in Small Inert-

Atmosphere Arc Furnaces. — (*J. Electrochem. Soc.*, 1952, 99, (12), 555).—See *M.A.*, 19, 807.—G. T. C.

[Discussion on a Paper by H. L. Gilbert, W. A. Aschoff, and W. E. Brennan, II:] Arc Melting of Zirconium Metal. — (*J. Electrochem. Soc.*, 1952, 99, (12), 557-558).—See *M.A.*, 20, 45.—G. T. C.

Production of Serviceable Non-Ferrous Castings by Exploiting Mould-Reaction Effects. W. A. Baker (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 321-324).—A review. The flow of metal from the portions of castings which are last to solidify and the resultant formation of shrinkage cavities may be suppressed by the evolution of gas in the intergranular channels which obstructs the flow of metal. The gas content must be small and evenly distributed, and it is found that H formed by mould/metal reaction may fulfil these conditions.—D. M. P.

Induction-Furnace Melting of Corrosion-Resistant Alloys. B. Spindler (*Foundry*, 1952, 80, (8), 110-113).—S. describes induction-furnace melting techniques used in the prodn. of stainless steel and Ni-base alloy castings at an American foundry.—R. W. R.

*Investigation of Casting. VIII.—Metal Flow in a Horizontal Quadrilateral Mould. Gorô Ohira (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (7), 410-412).—[In Japanese, with diagrams in English].—S. R. W.

Expansion of Die-Castings in the Cavity. L. C. Barton (*Mech. World*, 1952, 132, (3400), 222-223).—B. discusses the causes of the non-ejection of die-castings contg. inserts and concludes that for a casting of given cross-sectional area, there is a critical insert cross-sectional area at which sticking will begin. A table giving safe insert dia. for castings of various dia. is presented.—R. W. R.

Designing for Die-Casting. — (*Mass Prodn.*, 1952, 28, (8), 80-82).—Some examples are cited of the correct way of designing parts to be made by die-casting.—R. W. R.

Forming Processes for Metals. [Die-Casting and Pressing]. W. M. Halliday (*Mass Prodn.*, 1951, 27, (10), 56-59, 74).—H. compares the relative economics of the die-casting and pressing processes, with special ref. to the design of the component.—R. W. R.

Forming Processes for Metals. [Die and Tool Requirements in Die-Casting and Pressing]. W. M. Halliday (*Mass Prodn.*, 1951, 27, (11), 75-82, 86).—H. discusses component design and die and tool requirements in die-casting and pressing; the relative economics of the two processes are considered.—R. W. R.

Weight Estimation for Die-Casting. H. K. Barton (*Mech. World*, 1952, 132, (3399), 166-167).—B. describes how the weight of complicated die-castings may be estimated from drawings by means of planimetric measurement.

—R. W. R.

The Precision Casting Process. S. C. Churchill (*Mass Prodn.*, 1952, 28, (8), 62-69).—C. reviews the techniques employed in precision casting and discusses the scope and appn. of the process.—R. W. R.

Investment Casting. Roy W. Tindula (*Foundry*, 1952, 80, (9), 193-194, 196, 198, 201, 204, 207-208).—A report issued by the U.S. Dept. of Commerce, in which the various investment-casting processes are reviewed and their merits assessed. 73 ref.—R. W. R.

Precision Casting. — (*Indian Engineering*, 1951, 129, (3), 122-123).—A short description of the lost-wax technique. —S. R. W.

Forming Processes for Metals. [Precision Investment Casting.—I.—II.] W. M. Halliday (*Mass Prodn.*, 1951, 27, (12), 54-59; 1952, 28, (1), 53-58).—[I.—] H. briefly reviews the methods, appn., and limitations of precision investment casting. [II.—] H. concludes by describing the reprodn. of the wax patterns, the investment procedure, and investment materials, the removal of the wax pattern, and the pouring of the casting.—R. W. R.

Develops New Process for Casting Stock Bushings. J. Gilbert Hill (*Foundry*, 1952, 80, (9), 98-99).—A method is

described for casting bushings in an Al mould lined with a 1-in.-thick layer of core sand.—R. W. R.

Shell Moulding: The Process As It Affects Non-Ferrous Castings. — (*Metal Ind.*, 1952, 81, (23), 441-444).—Cf. *M.A.*, 20, 373. In shell moulding a light shell of sand bonded by a phenolic resin is used instead of the customary moulding box. The appn. of this process to non-ferrous casting and its advantages are discussed.—J. H. W.

Gating for Shell Moulding [Croning Process]. Walter A. Sokolosky (*Foundry*, 1952, 80, (8), 92-93).—Cf. preceding abstract. S. describes a number of methods of running and gating castings made by the "C" process.—R. W. R.

Core Serves as Gate and Riser. Ben F. Sweet (*Foundry*, 1952, 80, (9), 96-97, 236).—In the method of casting described, for gear blanks and other wheel-shaped castings, a crucible-shaped core is placed over the central boss; there are several holes in the bottom of the core. The casting is run by pouring metal into the core, which is filled to near the top. The metal in the core feeds the underlying casting through the relatively small holes in the base of the core, which also enable the core to be knocked off when solidification is complete.—R. W. R.

Refractory Permanent Moulds. J. B. McIntyre (*Foundry*, 1952, 80, (8), 102-103, 228, 232).—McI. reviews the materials which have been used or suggested for the construction of permanent moulds; among the materials discussed are sintered Fe, Al alloys, graphite, graphite treated with ethyl silicate, and C bonded with furfuraldehyde or bentonite.—R. W. R.

Statuary to Electronics via Plaster Moulding. Frank Pfister (*Foundry*, 1952, 80, (9), 86-91).—Describes the manufacture of precision and artistic bronze and Al alloy castings at the Gorham Mfg. Co., U.S.A. Details are given of the prepn. of the plaster moulds in which these castings are made.—R. W. R.

What Causes Moulding Green Strength? Clyde A. Sanders (*Foundry*, 1952, 80, (10), 108-109, 283-286).—An elementary account of the theories advanced to account for the plasticity and green strength of moulding sands.—R. W. R.

Selection, Testing, and Use of Bonding Clays in Synthetic Moulding Sand. W. W. Kerlin (*Foundry*, 1952, 80, (8), 86-91, 223-224, 226).—K. describes the structure and properties of the clays commonly used as a bond in synthetic sands and discusses methods of assessing their suitability for this purpose.—R. W. R.

Sand Reclamation by Wet Methods. Ronald Webster (*Foundry*, 1952, 80, (10), 238, 240).—A short discussion.

—R. W. R.

Sand Reclamation at the Eddystone Plant. Karl S. Howard and Clyde B. Jenni (*Foundry*, 1952, 80, (9), 92-95, 272, 274, 276).—Sand-reclamation techniques in use at the foundry of the General Steel Castings Corp., Eddystone, Pa., are described.—R. W. R.

Band-Sawing Non-Ferrous Castings. H. J. Chamberland (*Foundry*, 1952, 80, (9), 112-113, 220).—The removal by band sawing of gates and feeders from Al, Mg, and Cu-base castings is discussed, and a number of recommendations are made.—R. W. R.

How to Develop Cast Products. R. J. Franck (*Foundry*, 1952, 80, (10), 120-123, 205).—A scheme for the design of castings is presented, in which casting design is broken down into several stages, including customer contact, analysis of the properties required in the casting, design of the prototype, method of casting, and the prodn. of samples, met. and engineering examination of sample (including stress analysis), modification of design, and customers' approval for prodn.—R. W. R.

Accuracy is Byword in Fine-Hardware Foundry. — (*Foundry*, 1952, 80, (9), 106-107, 212, 214).—Moulding techniques at the foundry of the Chautauqua Hardware Corp., U.S.A., are described.—R. W. R.

Simple Correlation in the Foundry. W. K. Bock (*Foundry*, 1952, 80, (8), 104-109).—The use of statistical methods for establishing correlations between foundry variables is discussed in an elementary manner.—R. W. R.

Departmental Teamwork Improves Casting Production. Edwin Bremer (*Foundry*, 1952, 80, (8), 96-101, 267-269).—A description is given of the techniques and prodn. methods in use in a modern American (non-ferrous) jobbing foundry.

—R. W. R.

New Non-Ferrous Foundry. — (*Metal Ind.*, 1952, 81, (22), 424-426).—Describes the lay-out and plant at the George Kent Ltd. foundry in Luton, Beds.—J. H. W.

Your Quality Control Programme: Is It Effective? Kenneth MacKay Smith (*Foundry*, 1952, 80, (10), 188, 190, 192-193).—The functions and value of quality control systems in the foundry are discussed.—R. W. R.

Patternmaking Today. M. J. Kellner (*Foundry*, 1952, 80, (10), 102-103, 203).—A discussion of recent advances in patternmaking techniques.—R. W. R.

Zinc and Aluminium Die-Casting. (—). See col. 542.

Handbuch der Schmelz- und Legierungspraxis in der Metallgiesserei. (Schulenburg). See col. 541.

17 — FURNACES, FUELS, AND REFRACTORIES

[Discussion on a Paper by W. E. Kuhn:] **Development of Graphite Electrodes and Study of Heat Losses with Different Electrodes in the Single Electrode Inert-Atmosphere Arc Furnace [for Melting Titanium].** — (*J. Electrochem. Soc.*, 1952, 99, (12), 555-556).—See *M.A.*, 20, 205.—G. T. C.

Rotary Melting Furnaces. — (*Indust. Gas (Lond.)*, 1952, 15, (180), 356-358).—A brief description is given of a rotary furnace including figures for the melting times and the consumption of gas with various weights of red brass, gunmetal, Al, and Cu. The life of the firebricks with various melts of ferrous and non-ferrous metals, and recommendations for suitable linings for the different metals are quoted.—C. P. F.

Electrode Salt Baths: Wild-Barfield Equipment. — (*Wire Ind.*, 1951, 18, (213), 785-786, 789).—Temp. from 550° to 1350° C. can be maintained in an electrode salt bath for a variety of treatments, the rapid transfer of heat, uniformity of heating, and the clean finish of the work ensured by the protective nature of the salts being advantages not found in other types of equipment. Various types of salt bath, some self-contained with elect. equipment and portable, are described and illustrated.—C. P. F.

Value of Furnace Research Shown at Electric Furnace. C. L. West (*Steel Processing*, 1952, 38, (7), 344-350).—Furnace equipment and a continuous roller-hearth strip-line at the Electric Furnace Co., Salem, O., available for research purposes, are briefly described.—S. R. W.

Heat Transmission in Furnaces. R. J. Sarjant and D. Smith (*Proc. General Discussion on Heat Transfer* (Inst. Mech. Eng. and Amer. Soc. Mech. Eng.), 1951, 356-358).—A furnace designed, more especially, to study the best release and transfer from the flame, the flame structure and heating of the charge, with a view to deciding the heating schedule of a furnace, as far as possible, without recourse to empiricism, is described and illustrated. The furnace is constructed as a sectionalized calorimetric, simulating the operation of an indust. continuous furnace, and the necessary instrumentation is briefly described.—J. S. G. T.

Proper Heat Applied to Galvanizing Pot. Max Mysell (*Western Metals*, 1952, 10, (8), 46-48).—The construction of a gas-fired galvanizing furnace is described. The furnace is equipped with automatic temp. control.—T. G.

Recent Applications of High-Frequency Induction Heating in the Forging Industry. P. D. Jenkins (*Metallurgia*, 1952, 46, (275), 119-124).—A review.—F. M. L.

Furnace Atmospheres: Their Generation and Use. William F. Barstow (*Steel Processing*, 1949, 35, (2), 91-94, 96-97).—A brief review.—S. R. W.

High-Temperature Ceramic Materials. H. B. Michaelson (*Product. Eng.*, 1951, 22, (8), 120-123).—The properties and uses of various ceramic refractories and metal-ceramic combinations are described. 12 ref.—M. A. H.

18 — HEAT-TREATMENT

†The Heat-Treatment of Aluminium and Its Alloys. A. von Zeeleder (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (7), 209-219; (8), 255-264).—[In German]. The types of heat-treatment and the furnaces employed in the prodn. of Al alloys are reviewed. Prolonged homogenization (24 hr.) before hot working leads to a fine grain-size after the final anneal; in consequence the high rate of heat transfer of salt baths offers no advantage in ingot heating, and their use is confined to soln. heat-treatments. Centrifugal fans employed in modern air-circulation furnaces use 10-20% of the current input for heating. A vertical conveyor furnace occupying little floor space and said to be very efficient is illustrated together with more conventional furnaces. A special anneal at 20-30% cold work before the final cold rolling ensures a medium fine grain-size in deep-drawing sheet which prevents coarsening of the grain in subsequent drawing and annealing.

—K. S.

The Continuous Thermal Treatment of Aluminium-Alloy Strip. Marcel Lamourdedieu (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 361-375).—See *M.A.*, 19, 871.

Rohr Gets Accurate Temperature Control of Aluminium Alloys by Solution Heat-Treatment. W. H. Wynne (*Western Metals*, 1952, 10, (3), 32-33).—The use of salt baths for the heat-treatment of Al alloys is described, and recommended temp. for various alloy compn. are given.—T. G.

*Studies on Quenching Media. IV.—The Cooling Abilities of Water and Aqueous Liquids. V.—The Cooling Abilities of Fatty Oils. Masayoshi Tagaya and Imao Tamura (*Nippon Kinzoku Gakkai-Si (J. Japan Inst. Metals)*, 1952, 16, (2), 107-111; (6), 342-346).—[In Japanese, with tables and graphs in English]. [IV.—] Results on the cooling abilities of various liquids obtained by an apparatus and method described in previous reports (*ibid.*, 1951, 15, 535, 538, 589) are recorded in a table. When water is used the temp. must be kept as low as possible. The characteristic temp. is high for soln. of a non-volatile solute and low for soln. of a volatile solute. The average cooling rate between 700° and 200° C. in colloidal soln. varies from the rate in water to that in oil according to the concentration. [V.—] A low temp. for the start of convection and high characteristic temp. are two properties desirable in a quenching oil. Experiments have shown that: (i) the latter is higher in an oil consisting of polar mol., e.g. fatty acid, than in an oil consisting of non-polar mol., e.g. hydrocarbons; (ii) the higher the mol. wt. of a fatty oil, the higher are the two temp.; (iii) the smaller the unsaponifiable matter the higher is the characteristic temp.; (iv) I raises the two temp.; (v) high acid value in a fatty oil lowers the two temp.; and (vi) when mol. in any oil have a tendency for condensation or polymerization with each other, the cooling ability of such oil is great.—AUTHORS.

19 — WORKING

*Recent Results of Research on Rolling and Their Application in the Rolling Mill to the Hot and Cold Rolling of Metals, Especially Aluminium-Base Light Alloys. O. Emiecko (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (6), 189-206).—[In German]. With the aid of a special experimental rolling mill, supplemented by accurate measurements carried out during prodn. rolling, evidence was collected on the simultaneous roll pressure and torque in cold rolling of Cu, brass, Al, Duralumin, and deep-drawing steel. Earlier work on hot rolling of Al alloys is reviewed and nomograms are given determining these factors for different sizes and conditions of the material, reductions/pass, and roll dia.; the speed of rolling is ignored because E. is convinced that it exerts no influence on these factors. It is generally assumed that the rolling force may be supposed to act at a point half-way along the portion of the metal actually held between the rolls; this can now be checked accurately by the use of the experimental values, and is found to apply to annealed mild steel but not to Cu or Al alloys or cold-worked material. 13 ref.—K. S.

*Deep-Drawing Limits for Rectangular Aluminium Boxes. Toshisada Ishikawa (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 405-411).—See *M.A.*, 19, 809.

The Cause of Check Marks on Copper Wire. B. I. Ström and B. G. Waller (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 338-354).—It has been shown that "check marks" occur on the surface of drawn Cu wire even when the die profile is correct. They appear in the zone of oxide segregation originating from the cast bar and are formed on the outer surface of the wire where the tensile stress is greatest as it is wound on to the blocks. Check marks can be prevented by removing the oxidized layer by scalping the bar or by shaving the rod with a special die. They can be reduced by heating the bars before rolling in a weakly reducing atmosphere, avoiding faults in rolling, subjecting the rods to prolonged pickling, and by reducing the max. tensile stress encountered in the drawing process. 6 ref.—D. M. P.

The Fabrication of Copper Wire. Sidney Rolle (*Wire and Wire Products*, 1952, 27, (1), 35, 37-47, 76, 83).—The Mordica Memorial Lecture delivered at the Wire Association Convention, Chicago, 1951. R. details the chronological development of Cu wire from 8000 B.C. to the present day, with tables of world prodn. since 1800, and describes the mining, concentrating, smelting, and refining of Cu, and the rolling of rods. Pickling, shaving, welding, and drawing of rods,

with developments in practice since 1900, are described, and details are given of drawing techniques for the finest sizes of Cu wire. *Bibliography.*—C. P. F.

Production of Copper and Aluminium Wire in Australia. Clement Blazey (*Wire Ind.*, 1952, 19, (226), 937-941).—An illustrated description of the wire industry in Australia since 1918, and of the works and methods of Metal Manufacturers, Ltd., Port Kembla, N.S.W., who make bare and insulated wire for elect. use. Chem. and spectrographic analyses of Cu wires made from four different brands of wire-bar are listed.—C. P. F.

A Method of Production of Bimetallic Copper-Steel Wires. Z. Misiolki and R. Wusatowski (*Prace Inst. Met.*, 1952, 4, (1), 49-65).—[In Polish]. After degreasing, etching, &c., Armco Fe (C 0.029, Mn 0.05, Si 0.027, P 0.0087, and S 0.035%) cores 68.5 mm. in dia. or DSA steel (C 0.08, Mn 0.41, P 0.013, S 0.023, Cu 0.17%, and traces of Si) cores were cold pressed into electrolytic (99.8%) Cu tubes 400 mm. long, and of 89 mm. outside dia. produced in a Mannesmann mill. These were then heated to 900° C. for 3½ hr. and rolled down to bimetallic wire 3 mm. in dia. The rolling process is described with details of the calibration of the rolls, number of passes, and intermediate heat-treatment. Elect. and mech. properties are listed and plotted of the 30:70 (30% Cu in the final cross-section area of the wire) and 40:60 wires, which show that bimetallic wires can successfully compete with expensive high-conductivity bronzes, effect Cu saving, and permit larger distances between the supporting poles owing to their high strength properties.—A. G.

Machining Copper and Copper-Base Alloys. Bartlett West (*Modern Machine Shop*, 1951, 23, (10), 100-108, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126).—A general account is given of the machinability of a wide range of Cu alloys.—E. J.

Processing Titanium. Frank Charity (*Modern Machine Shop*, 1951, 24, (3), 168-170, 172, 174, 176, 178).—A general account is given of the properties, machinability, and uses of Ti and its alloys.—E. J.

Wyman-Gordon Co. Leader in Aircraft Forging. I.—North Grafton Heavy Press Plant. II.—The Worcester Plant. John C. McComb (*Steel Processing*, 1952, 38, (9), 435-443, 446-455; (10), 510-512).—[L.—] A description of a plant for forging Al alloys. The technique of forging a structural part of a main bulkhead, a wing spar, a jet-engine impeller, and a landing gear trunnion, in an 18,000-ton Meta press,

is given. [II.—] A plant producing steel and light-alloy forgings, using hydraulic presses and steam drop-hammers, and extrusions, is described. A short history of the Wyman-Gordon Co., Mass., is appended.—S. R. W.

Forming Processes for Metals [Cold Heading]. W. M. Halliday (*Mass Prodn.*, 1951, 27, (6), 47-57).—H. describes the principles of cold heading and discusses the advantages and limitations of the process.—R. W. R.

Specialty Die-Designs for Stamping and Forming. I.—The Marform Process. II.—The Guerin Process. III.—The Sol-A-Die Process. Lester F. Spencer (*Steel Processing*, 1952, 38, (3), 121-127; (4), 180-185, 190-191, 194; (5), 234-239, 257).—[I.—] A detailed description of the process giving the advantages, the controlling factors, and the limitations (cf. *M.A.*, 20, 297). [II.—] A detailed description of a process which utilizes a thick rubber pad in place of the usual steel female die and a form block, the shape of the latter conforming to that required in the finished part. This was the original process from which the Marform process was developed. The many advantages over the conventional methods, the controlling factors, and limitations of the process are given. [III.—] A multiple-die process developed in order to form complex and irregular sheet-metal parts from sheet metal with low limits of elongation. The method is advantageously employed when the prodn. quantity required is small and does not warrant the use of complicated and expensive press tooling. It involves the prepn. of a wax pattern in a plaster cast which is quite flexible so that the same pattern can be used for the various stage dies if a series of dies is necessary. Rubber cushions and Pb can be used in the first die, but this is rare. Zn-alloy dies with a Pb punch are more common. Advantages and limitations of the method are discussed.—S. R. W.

New Forming Process Demonstrated. John C. McComb (*Steel Processing*, 1950, 36, (2), 80-83).—The advantages and a comparison of the Marform process and the Guerin process are given. See preceding abstract.—S. R. W.

New Stamping Process Developed at Douglas Aircraft. Thomas A. Dickinson (*Steel Processing*, 1952, 38, (6), 277-279).—A method developed in America which combines the low costs of the Guerin process with prodn. virtues of older stamp techniques is described, and the advantages are given. It is particularly adapted to fabrication of steel, Ti, Al, and Mg alloys.—S. R. W.

How to Hot-Form a Dimple. Thomas A. Dickinson (*Steel Processing*, 1952, 38, (4), 172-174).—The "flow-form dimpling" process avoids the undesirable tendency of some high-quality Al, Mg, Ti, and steel alloys to work-harden and crack when rivet holes are dimpled by cold coining dies. Heat is applied by elect. resistance units integral with punch and die posts. It is believed that material up to 0.25 in. thick can be processed and although cold dies can be used, dimples made with hot dies have 15% greater mech. strength.—S. R. W.

Forming Processes for Metals [Deep Drawing and Impact Extrusion]. W. M. Halliday (*Mass Prodn.*, 1951, 27, (7), 76-84).—The deep-drawing and impact-extrusion processes are described and their merits and appn. discussed.—R. W. R.

The Calculation of Speed in the Rolling Process. Z. Wusatowski (*Prace Inst. Met.*, 1952, 4, (1), 1-47).—[In Polish]. Theoretical assumptions made by various investigators in the calculation of rolling speed and the effects of forward- and back-slip are reviewed. Formulae for the angle of neutral plane, based on Orowan's expressions for cases of inhomogeneous deformation and slipping along the whole arc of contact are presented (i) for rolling without spread (using Cook and Larke's forms of Orowan's formulae) and (ii) for hot rolling with spread (using Orowan and Pascoe's theory). Theoretical results are compared with test results obtained by various investigators, full agreement being reached with Korolev and Svede-Shvets's data for hot rolling without spread. Practical methods of rolling-speed calculation with examples are presented for the rolling of bars, sections, sheet, and strip in non-continuous and continuous mills. Formulae are derived for the mean effective dia. and mean

coeff. of elongation for the whole profile, based on the values for different parts of the section. 46 ref.—A. G.

The Design and Use of Tungsten Carbide Rolls for Cold Rolling Metals. R. T. Beeghly (*Iron Steel Eng.*, 1950, 27, (9), 83).—A general review of the uses of WC rolls for cold rolling non-ferrous metals and steel. Properties, rolling speeds, and amount of reduction are dealt with and installation hints given.—I. S. M.

Modernization of an Old Draw-Bench for Cold-Drawn Bars. Nils L. Gripenberg (*Proc. First World Met. Congress (Amer. Soc. Metals)*, 1951, 355-360).—A description of the addn. and refinements carried out to increase the prodn. of an existing plant.—D. M. P.

The Standardization and Testing of Wire-Drawing Dies. A. Pomp (*Schweiz. Archiv angew. Wiss. Techn.*, 1952, 18, (3), 97-101).—[In German]. Provisional German specifications for sintered-carbide wire-drawing dies are discussed. For lubrication with dry soap there is a single cone on the entry side of the bearing to ensure that the lubricant is forced against the surface of the wire in the wedge between the profiles; with liq. lubricants, it is necessary to allow greater access to the die hole and a second, wider cone on the entry side is included in the design. Methods of measuring the internal dimensions and checking the profiles of dies are discussed. Feeler and opt. devices are described, particular attention being paid to the "Alfamer" and the images produced in this instrument by dies with perfect profiles and those with various kinds of defect: curvature of the conical profile is revealed by diffuseness of the ring, lack of concentricity is immediately obvious, and longitudinal draw marks in the die result in radial lines in the image.—K. S.

***Control of Die Profiles [by Measurement of Die Load and of Partly Drawn Wire].** J. G. Wistreich (*Wire Ind.*, 1952, 19, (218), 131).—An investigation at the British Iron and Steel Research Association Metal Working Laboratories indicates that neither the "wire-bearing" nor the "die-load" inspection method can be relied upon, and that resort should be made to a direct measurement of die-profiles. Eight dies were measured by two independent investigators, and Cu wire test-pieces were drawn. Measurements were made on a Zeiss fiducial micrometer, by shadow projection, on a profilometer, and on an instrument based on the Alfamer. A table of results shows that whereas all 8 dies were within the usual tolerance of ± 0.001 in., 7 should have been rejected, since parallel portions differed as much as a factor of 4 $\frac{1}{2}$ and average angles by as much as 3°. 3 ref.—C. P. F.

The Perfect Profile: A Yardstick. Frances Mortimer (*Wire and Wire Products*, 1952, 27, (8), 783-784, 827).—A description of the method of measuring wire-drawing die bores using an instrument developed by the British Iron and Steel Research Association. The instrument consists of a feeler arm pivoted with a probe at one end and a plane reflecting surface at the other. Measurements are made by two micrometer screws reading directly to 0.0001 in. in vertical and horizontal directions. An auto-collimator is used as a null indicator. The die is held in a rotating chuck with a dividing plate for 6° intervals. The micrometer drives are connected to a pen mechanism enabling a curve of the die profile to be plotted against rectangular co-ordinates.—C. P. F.

Wear of Tungsten Carbide Dies. — (*Wire Ind.*, 1952, 19, (218), 132).—Autoradiographs of Cu wire drawn through a radioactive WC die indicate that particles worn from the die may appear as a fairly uniform band or background of deposits, or as individual deposits of greater intensity. After decay, indications that the uniform deposit is mainly Co and the individual deposits mainly W have been observed. Three regions of wear and two different ways in which wear may take place are distinguished. Wear in the "ring" in the entrance bell is more severe than a polishing action in the taper and parallel bearing regions.—C. P. F.

[Machining by] Method "X". — (*Mass Prodn.*, 1952, 28, (10), 77-79).—A short account of a method of precision machining which depends upon the removal of metal as the result of the mech. effect of an elect. spark of high c.d.

—R. W. R.

20 — CLEANING AND FINISHING

(See also "Protection" and "Electrodeposition".)

The Surface Treatment of Aluminium. H. J. Meijer (*Polytechn. Tijdschr.*, 1952, 7, (23/24), 393a-399a; (25/26), 431a-435a; (27/28), 464a-466a).—A detailed treatment of all aspects of Al surface protection and decoration. Cleaning by solvent, alkaline, acid, and other methods is described, with special ref. to soldered and welded joints. Mech. surface treatments discussed include hammering, sand-blasting, and mech. polishing; chem. surface treatment processes mentioned include the Alodine and Jirotko treatments. A special section deals with anodic oxidation and electrolytic polishing. Cu-, brass-, Ni-, Sn-, and Cr-plating and protection by applying organic films are also included. Tables show compn. and mech. properties of cast and wrought Al alloys, and the effect on Al of more than 100 organic and inorganic substances.—I. S. M.

Developments in Finishing Aluminium Castings. A. P. Fenn (*Metal Ind.*, 1952, 81, (19), 367-369).—Describes the treatment applied to Al castings to give decorative effects or added protection and to provide a surface with some special characteristic such as high resistance to wear.—J. H. W.

The Properties of Araldite Lacquers [for Use on Aluminium]. P. A. Dunn (*Light Metals*, 1952, 15, (169), 131-133).—Araldite lacquers, based on ethoxylene resins, are surface coatings suitable for direct appn. to Al surfaces. When cured at ~180° C., they show high resistance to many chem. agents, including common inorganic acids and alkalies. Erichsen cupping tests show that the coating can be subject to appreciable forming without fracture, and shear tests indicate an adhesive strength of 3200 lb./in.². They are particularly advantageous for use on collapsible tubes.—A. W. B.

Patina Colouring of Metal [Copper] Art Ware. K. Stark (*Metalloberfläche*, 1952, [B], 4, (1), 7-8).—Brief notes on the chem. compn. and the methods of appn. of soln. for giving Cu-base articles patina finishes of various shades.—E. N.

Magnesium Finishes for Aircraft Evaluated. Howard D. Childers (*Iron Age*, 1952, 170, (23), 157-161).—Numerous finishes, much better than those used in current aircraft prodn. were developed as a result of the study of Mg finishes available for prodn. appn. Several pigmented vinyl-type primers gave 2-3 times more protection than current methods with thicknesses of only 1-1.5 mil.—J. H. W.

Finishing Magnesium. John Starr (*Metal Finishing*, 1952, 50, (10), 62-64).—Methods of finishing Mg are briefly reviewed, but little detailed information is given.—G. T. C.

Processes for the Surface Finishing of Magnesium Components. Frank Spicer (*Mech. World*, 1952, 132, (3398), 102-105).—S. lists and compares the various methods for the surface treatment of Mg alloys.—R. W. R.

Economical Finishing with Vacuum Metallizing. George W. Carr (*Metal Finishing*, 1952, 50, (11), 60-64).—The technique of vacuum metallizing is briefly described and some typical appn. mentioned.—G. T. C.

Alkali Cleaner "Life". H. K. Hunt (*Metal Finishing*, 1952, 50, (10), 72-73).—The life of a metal cleaner is discussed in so far as it is affected by saponification, conversion to carbonates, dirt load, drag-out, vol. of soln., and absorption.—G. T. C.

The Dip-Polishing Process. G. Hermes (*Metalloberfläche*, 1952, [B], 4, (1), 8-10).—In the dip, or hydraulic, polishing process, the article (or articles), so fixed that it rotates itself, is immersed in a rotating drum contg. the polishing medium; the frictional effects set up by the high-speed flow of liq. on the surface of the article result in a polishing action. The development, construction, and operation of a large prototype machine are described and illustrated. The drum is 4 m. in dia. and makes 45 r.p.m.; the centre shaft supports 12 equally spaced arms, each capable of carrying 2 of the articles to be polished; the polishing period is 93 sec. For brass and nickel silver the polishing medium is a mixture of pumice powder, sawdust, and oil; for Fe and stainless steel, emery powder is substituted for the pumice. The machine can produce finely polished surfaces at only $\frac{1}{10}$ the cost of normal methods. It has, however, some disadvantages, e.g. the polishing medium becomes warm on prolonged operation, reaching a temp of ~60° C. after 1 hr., while the presence of metal particles (rubbed off the articles) impairs its efficiency and necessitates a very heavy and robust machine. The limiting factor in the appn. of the process may be the uneven polishing of irregularly shaped articles, a factor which is not always overcome by the recommended method for minimizing this difficulty, i.e. by operating the machine discontinuously—stopping and restarting after an interval of 1-5 sec.—E. N.

Grinding and Polishing Agents. W. Burkart (*Metalloberfläche*, 1952, [A], 6, (1), 1-4).—Various types of abrasives are described, and their structure illustrated by photomicrographs; they include: (1) for grinding—silica sand, pumice, corundum, emery, alundum, and carborundum, and (2) for polishing—Tripoli powder, various chalks, Fe₂O₃, Cr₂O₃, and Al₂O₃.—E. N.

Lapping. Hans H. Finkelnburg (*Metalloberfläche*, 1952, [A], 6, (1), 9-14).—An illustrated review, dealing with: (1) abrasives for wet and dry lapping, and their cutting and surface-finishing properties, and (2) types of lapping machines, including those for flat surfaces, and for accurately finishing very small holes.—E. N.

Economical Bright Polishing of Round Articles Before Electroplating. W. Hofmann (*Metalloberfläche*, 1952, [B], 4, (1), 1-5).—The principles of, and equipment for, the bright polishing of disc- and cylindrical-shaped articles, in large numbers, are described and illustrated. The machines are very similar to those used for centreless, cylindrical, and internal grinding.—E. N.

Some Recent Overseas Developments in Surface Finish. C. A. Gladman (*Australasian Eng.*, 1952, (Aug.), 61-71).—A review of the following: boundary lubrication, theory of friction, effect of finish on the load-carrying capacities of journal and thrust bearings, relation between finish and performance of piston rings and cylinder bores, the life of cutting tools, corrosion and fatigue of metals. 56 ref.

—T. A. H.

Improving the Standard of Finishing. — (*Mech. World*, 1952, 132, (3397), 65-66).—Discusses corrosion and other tests for assessing the durability of the finishes applied indust. to metals and other materials.—R. W. R.

21 — JOINING

Wire Stitching. D. Y. Gastoué (*Rev. Aluminium*, 1952, (188), 196-197).—Where high mech. strength is not important, economies over riveting and welding can be achieved in joining thin sheets by wire stitching. The method is described in principle.—A. W. B.

The Araldite Bonding of Light Metals. — (*Aluminium*, 1952, 28, (1/2), 14-19).—Cf. *ibid.*, 1951, 27, 40; and Parker, *J. Roy. Aeronaut. Soc.*, 1951, 55, 153; *M.A.*, 20, 211 and 51.—M. A. H.

Synthetic Resin Adhesives. — (*Light Metals*, 1951, 14, (164), 593-603).—Lectures delivered at an Aero Research Summer School held at Cambridge, Sept. 1951. See *M.A.*, 19, 688.—P. R.

The Present Position of Light Metal Riveting Abroad [Outside Germany]. E. W. Pleines (*Aluminium*, 1952, 28, (1/2), 2-10).—P. reviews riveting methods in use in countries outside Germany, including rivet forms, materials, and tools.—M. A. H.

Furnace Brazing: Atmospheres Set the Pace. Samuel Damon (*Steel*, 1952, 130, (18), 102-104, 127-128).—Developments are described of protective atmosphere furnaces for the brazing of many metals and alloys.—E. J.

Aluminium Brazing Sheet Used in Radiator Studies. — (*Steel*, 1952, 131, (1), 96-97).—A note on the use of Al for automobile radiators. The sheet used is 3S with brazing alloy on one side and an Alclad coating on the other, giving corrosion protection to the assembly.—E. J.

Soldering of Aluminium. L. Rostosky (*Aluminium*, 1952, 28, (1/2), 10-14; also *Schweissen u. Schneiden*, 1952, 4, (2), 42-45).—A brief historical survey is followed by a review of current hard- and soft-soldering techniques, which are described in detail, with examples of appn.—M. A. H.

Ultrasonic Soldering in the Foundry: Light Alloy Casting and Pattern Repairs. — (*Metallurgia*, 1952, 46, (277), 251-252; also *Engineering*, 1952, 174, (4529), 647; *Found. Trade J.*, 1952, 93, (1891), 617; *Metal Ind.*, 1952, 81, (25), 484).—The use of the ultrasonic soldering iron for the surface treatment of faulty light-alloy castings and for alteration and repair of Al patterns is reviewed.—F. M. L.

The Application of Ultrasonic Soldering Techniques. Alan E. Crawford (*Light Metals*, 1952, 15, (168), 102-104).—C. describes the principles of ultrasonic soldering and its appn. to the repair of Al castings and patterns. 8 ref.

—A. W. B.

[Nickel] Plating as an Aid in the Brazing of Stainless Steel. (Korbelak and Okress). See col. 499.

Solder Simplified. — (*Canad. Metals*, 1952, 15, (6), 60, 62).—Brief notes on the appn. of solder, properties of solder alloys, and fluxes.—W. A. M. P.

Bimetallic Molecular Bonding [Al-Fin Process]. — (*Canad. Metals*, 1952, 15, (3), 40).—Cf. *M.A.*, 20, 300. Brief details are given of the "Al-Fin" process for bonding Al alloys to various ferrous alloys.—W. A. M. P.

[Joining] Aluminium/Copper Branch Lines in Open-Air Conductors. G. Dassetto (*Aluminium*, 1952, 28, (1/2), 31-32).—A simple method of joining Cu branch lines to Al cables is described, which overcomes corrosion due to galvanic action.—M. A. H.

***New Welding Process Developed for Joining Small Aluminium Wires.** P. B. Dickerson and C. R. Dixon (*Automotive Ind.*, 1952, 107, (5), 50-51, 100, 102).—Investigations have been made into the rapid arc welding of Al wire ranging from 0.007 to 0.25 in. in dia. The welds are relatively easy to make with simple equipment, and have excellent corrosion-resistance. The source of power is a number of Pb storage batteries arranged in series to provide 24-48 V. The use of A.C. has not yet been fully investigated. The electrode is a graphite button in a holder; W and Cu are also satisfactory electrode materials. Both electrode and earth pliers (holding the work) are connected to the power, and a simple arc is struck between the wires and the electrode. No surface prepn., flux, or protective atmosphere is necessary. The first experimental work was done with the electrode positive, on the theory that an electron flow from the work and a positive ion bombardment of the Al would result in an elect. cleaning action; good welds were also obtained with straight polarity, however, up to No. 10 gauge. The weld bead is not very strong, and mech. support (e.g. twisting, wrapping a wire round the assembly, &c.) is needed. Cu, W, Fe, steel, brass, Nichrome, Chromel, Alamel, and Constantan have also been welded experimentally, but in the case of Cu the brittle alloy formed is rendered more ductile when Cu is <20% by using an Al sleeve or wire to provide an excess of Al weld bead.—I. S. M.

The Flash-Butt Welding of Light-Alloy Sections. A. Klopfert (*Rev. Aluminium*, 1952, (185), 51-56).—K. discusses the joining of sections, particularly by flash-butt welding, with special ref. to windows. The comparative economics of flash-butt and A-arc welding are examined in relation to labour time required, and some details of the technique are given.—A. W. B.

Cold Pressure Welding [of Aluminium]. — (*Aero Digest*, 1952, 64, (1), 69).—The "Koldweld" process, which is a

method of welding without the use of heat or electricity, is applicable to all non-ferrous metals, particularly Al and its alloys. Typical appn. is in welding screw studs to the sides of utensils for the attachment of knobs and handles. Some success has been achieved in cold-welding thin sheets of 75S-T Al alloy but not yet with sufficient strength to make it acceptable.—H. Pl.

Advances in Aluminium Welding. — (*Light Metals*, 1951, 14, (163), 547-551).—Summaries of papers presented at the International Welding Congress organized in 1951 by the Institute of Welding.—P. R.

SIGMA Welding Aluminium. Murry R. Maynard (*Canad. Metals*, 1952, 15, (5), 50-51).—Cf. *M.A.*, 20, 53. The shielded inert-gas metallic-arc (SIGMA) welding of Al is described. This process is considered to be more satisfactory than the Heliarc inert-gas shielded W-arc process.

—W. A. M. P.

The Welding of Light Metal Cables by the Alutherm Method. R. Frey (*Aluminium*, 1952, 28, (1/2), 28-31).—F. describes the welding of light alloy and composite cables and wires by means of a thermit reaction in a cartridge surrounding the butted components of the joint.—M. A. H.

***Welding Iron-Bearing Alpha Aluminium Bronze.** F. Emery Garriott (*Weld. J.*, 1952, 31, (1), 18-28).—Tests on Fe-bearing α Al bronze conforming to A.S.T.M. Standard B-169-48T show that it can be welded successfully by the C-arc, metal-arc, inert-arc, and submerged-arc processes. Consumable and non-consumable electrodes can be used in the gas-shielded process. A mixture of He and A is recommended. The mech. properties of the welds are shown to be comparable to those of the base metal, except for a lower ductility. The good corrosion-, erosion-, cavitation-, and wear-resistance qualities of the metal are retained in the welds. Appn. illustrated include screw conveyors, conveyor housing used in synthetic alcohol prodn., centrifugal separators, heat exchangers, fractionating towers, and steam-jacketed kettles for the prodn. of esters from alcohol. Gas welding is not applicable, since no satisfactory flux has been found. 5 ref.—K. B.

Heliarc Welding Finds Its Stride [for Welding Magnesium]. Gilbert C. Close (*Modern Machine Shop*, 1951, 23, (10), 84-90, 92, 94).—The use of the Heliarc process for the welding of Mg and other metals is described.—E. J.

Welding Magnesium [by the Aircomatic Process]. Harold Robinson (*Canad. Metals*, 1952, 15, (7), 48, 50).—R. discusses the welding of Mg by an inert-gas shielded metallic-arc process (Aircomatic).—W. A. M. P.

***Welding of High-Alloy [15:35 Chromium-Nickel] Castings.** R. David Thomas, Jr. (*Weld. J.*, 1952, 31, (1), 27S-32S).—Cracks in 1-in.-thick welds in 15:35 Cr-Ni (Type HT) castings are reported in each of 24 test-plates welded by four foundries, using a variety of techniques and electrodes. A test plate for determining weldability and qualifying procedures has been developed. Transverse welds have a U.T.S. of 40,000-45,000 lb./in.² at 1400° F. (760° C.) and 17,000-21,000 lb./in.² at 1800° F. (980° C.).—K. B.

How We Weld Titanium. Thomas R. Bradley (*Machinist (Eur. Edn.)*, 1952, 96, (48), 1948-1950).—B. gives information on the resistance and machine Heliarc fusion methods of welding 75A, and Rem Cru 130, and 70 Ti.—J. H. W.

Titanium Alloys Flash Welded Easily. I. A. Oehler (*Steel*, 1952, 131, (2), 84-85).—A summary of data presented by O. at the Titanium Fabrication Conference, Minerals and Metals Advisory Board, Cleveland, U.S.A. Using techniques similar to those used for Al alloys, satisfactory flash-butt welds can be easily made, and cracking is avoided if the welded part is immediately annealed after welding. Ti alloys have been successfully flash welded to Al alloys and steels.—E. J.

Preparation of Metals for Argon Arc (Nertal) Welding. Charles Guinard (*Rev. Aluminium*, 1952, (188), 207-213).—This account, in the form of practical notes, gives details of the current required with and without backing plate, A flow, filler wire dia., and edge prepn. for sections of 1-12 mm., using single- and double-pass techniques with one and two operators.—A. W. B.

Submerged-Arc Automatic Welding. — (*Mass Prod.*, 1952, 28, (12), 72-74).—A short description of the "Union-melt" submerged-arc welding process, in which the equipment can be either used as a semi-automatic unit or guided manually.—R. W. R.

Resistance-Welding Applications Increase. — (*Steel*, 1952, 131, (3), 91-96, 98).—The advantages of resistance-welding processes are described, as well as typical examples of their uses.—E. J.

Selection of Welding Processes. P. L. Pocock (*Mech. World*, 1952, 132, (3398), 122-124; (3399), 183-185).—P. briefly describes the salient features of the following welding processes: [I.—] C arc, inert-gas arc, shielded arc, automatic metallic arc, twin arc, atomic H, and the "E.H". [II.—] Gas welding, water-gas welding, thermit welding, and resistance welding.—R. W. R.

Slope Control for Resistance Welding. W. B. Hills (*Electronics*, 1952, 25, (5), 124-125).—Slope control, the gradual increase of welding current to its final value, provides welding consistency and improves quality, particularly where the initial resistance of the weld is high or inconsistent. Details

are given of the principle and the construction of a slope-control unit which allows a change in heating of from 100 to 4%. Controlled firing of the power tubes in the contractor is obtained by phase-shifting the triggering voltage of each power tube with respect to its anode voltage. A typical appn. of the control unit is in the welding of Cr-plated Cu-Bo alloy spring strip to Ag-backed contacts, the Cr plating being undisturbed by welding.—D. M. L.

Development of Fused Metallized Coatings. Harrison S. Sayre (*Weld. J.*, 1952, 31, (1), 35-39). Investigations conducted into the development of materials, techniques, and procedures for the appn. of fused coatings are reviewed. A surfacing alloy contg. Ni 65-75, Cr 13-20, and B 3-5% with a combined max. of 10% Fe, Si, and C has been developed.—K. B.

Hard-Facing of Steam Valve Seats and Discs. Oscar E. Swenson (*J. Amer. Soc. Naval Eng.*, 1951, 63, (2), 488-495).—S. discusses general welding procedure, and the use of non-ferrous hard-facing alloys for trimming high-temp. steam valves. U.S. Naval service tests for hard-facing alloys are briefly described.—W. A. M. P.

22 — INDUSTRIAL USES AND APPLICATIONS

Aluminium as a Shipbuilding Material. E. C. B. Corlett (*Trans. N.E. Coast Inst. Eng. Ship.*, 1952, 68, (5), 221-248; discussion, (7), D87-D106; and (abridged) *Metal Ind.*, 1952, 80, (9) 163-167; *Metallurgia*, 1952, 45, (269), 121-126; *Light Metals*, 1952, 15, (169), 133-135; *Engineering*, 1952, 173, (4496), 413-414; *Shipbuilder*, 1952, 59, (528), 492-496; *Motor Ship*, 1952, 32, (384), 516).—The various Al alloys suitable for shipbuilding are discussed, and the fabricated forms in which these alloys are available are described. Methods of welding these materials are considered. The design of Al ships' structures is discussed in some detail, and an outline of a code of practice for the design of these structures is presented. A new set of sections is proposed, and geometric details of these are given. Some details of the use of Al alloys in the new liner "United States" are given. Many design data are contained in appendices. 19 ref.—R. W. R.

The Liners "Marseilles City" and "Tunis City" Pierre Vidal (*Rev. Aluminium*, 1951, (180), 320-328).—These two liners of 9378 tons, built in France, use the Al-5% Mg alloy for all the super-structure above the boat-deck. The funnels, hand-rails, lifeboats, and other items are also in the same material. Painting practice, based on dipping large sections and plates in a proprietary chem. soln. followed by a chromate primer, is described.—A. W. B.

Light-Alloy Luxury Yacht Built on Two-Way Tension System. — (*Metallurgia*, 1952, 46, (274), 88).—The construction of a yacht by the stressed-skin technique is described.—F. M. L.

New-Type Survey Vessel "Ain-el-Bahr". — (*Light Metals*, 1951, 14, (156), 117-119).—A light-alloy survey vessel designed on the "two-way tension" principle (*ibid.*, 1946, 9, 283; *M.A.*, 14, 77) is compared with companion craft built of teak. Specification requirements for both vessels are given, with details of materials used in the light-alloy launch, which requires half the power with $< \frac{1}{2}$ the displacement and ~40% the draught of the teak vessel.—P. R.

[Use of Light Alloys in] The '51 Barge. — (*Light Metals*, 1951, 14, (162), 477; 1952, 15, (175), 320; also *Engineer*, 1952, 194, (5040), 299-300; *Engineering*, 1952, 174, (4518), 269; *Sheet Metal Ind.*, 1952, 29, (306), 914; *Shipbuilder*, 1952, 59, (530), 604; *Metallurgia*, 1952, 46, (275), 134; *Metal Treatment*, 1952, 19, (84), 418).—Extruded light-alloy components are assembled, for shipping, into half-sections of barges for use on inland waters of Belgian Congo. The main frames are integral with the plating. Advantages include easy fabrication, accurate sizing of components, easy assembly, lightness, and resistance to corrosion.—P. R.

Aluminium Alloy Cargo Lighter. — (*Engineer*, 1952, 193, (5026), 699).—A description of a 60-ft. Al alloy cargo lighter for service with the Royal Pakistan Navy.—D. K. W.

Aluminium-Alloy Launch for the Royal Navy. — (*Engineering*, 1952, 173, (4500), 540).—Describes a 26-ft. launch built on the stressed-skin principle.—D. K. W.

The Light-Alloy Superstructure of the River Boat "Lady Wright". — (*Rev. Aluminium*, 1951, (181), 373-374).—Approx. 35 tons of Al, Noral 65S-T sheet, and 51S extrusions were used to replace 70 tons of steel in the superstructure of this 565-ton vessel.—A. W. B.

Light Alloy Smoke Stacks. André Chevrier (*Rev. Aluminium*, 1952, (184), 18-23).—C. discusses the tech. and economic advantages of Al in the construction of ships' funnels, with particular ref. to the "United States" and the "Caronia". Materials used are of the Al-Mg-Si and Al-5% Mg types.—A. W. B.

The 17th [French] Marine Exhibition. André Chevrier (*Rev. Aluminium*, 1951, (183), 459-465).—Describes the appn. of Al in marine Diesel engines, light craft, and auxiliary equipment, as seen at this exhibition.—A. W. B.

Aluminium in Irrigation. Ernst Ramser (*Aluminium Suisse*, 1952, 2, (1), 14-23).—[In French and German]. Presented to the Swiss Aluminium Congress, 1951. R. discusses the advantages and economics of irrigation in horticulture, with particular ref. to Al equipment as compared with steel.—A. W. B.

A Turbine-Driven Lawn Sprinkler. C. K. Wilson (*Die-Castings*, 1949, 7, (8), 32-34, 54-55).—A description of a lawn sprinkler built mainly of Al die-castings.—S. R. W.

Durability of Aluminium and Its Alloys: [Use in] The Chemical Industries. — (*Light Metals*, 1951, 14, (163), 541-546; (164), 639-643; (165), 662-667).—Protective methods for light alloys used in chem. industries include oxidation, use of inhibitors (notably Na_2SiO_3 in alkaline media), cathodic protection, and painting or lacquering. Uses reviewed in detail include storage and transport of chemicals; condenser tubing (for which a clad alloy is now available in the U.S.A.); chem. manufacturing plant, especially in Germany; rayon prodn.; sewage disposal; manufacture of explosives; fertilizers, soap, and paint; biochem. apparatus; containers for H_2O_2 , HNO_3 , dil. H_2SO_4 , aldehydes, many organic acids, compounds, and distilled water.—P. R.

***Aluminium and Some of Its Alloys in the Wine Industry.** L. Gentilini and G. Missier (*Alluminio*, 1952, 21, (2), 130-134).—Unprotected 99.5% Al, Aluman, Peraluman 35, and Anticorodal were tested by immersion in three different types of wine ("Prosecco", "Merlot", and "Raboso di Piave")

at 20° C. for 30 days and at 40° C. for 7, 15, and 30 days. The specimens showed some loss in weight, and the wines acquired a metallic taste, making them unfit for consumption. Subsequently, "Raboso di Piave" wine was stored for one month at 14°-16° C. in 1-litre flasks made of Aluman, M.B.V. treated and internally coated with "Periplast" (a thermo-setting phenol resin). The bottles were not attacked, and the quality of the wine was not affected.—I. S. M.

Aluminium Containers for Beer Transport. W. Linicus (*Aluminium*, 1952, 27, (3), 70-73).—Desiderata for beer drums and cans are listed, and the tech. development and tests of such articles fabricated in Al are described.—M. A. H.

Aluminium and General-Line Containers. — (*Light Metals*, 1951, 14, (156), 139-147; (157), 195-206).—Materials, plant, prodn., finishing, and types of "general-line" containers, made in Al for a wide range of goods not requiring sterilization, are reviewed in an article reproduced from Development Bulletin No. 12 of Aluminium Laboratories, Ltd.—P. R.

Aluminium in the Canning Industry. D. Nickelsen and J. S. Buschmann (*Aluminium Suisse*, 1952, 2, (2), 41-54; and *Aluminium*, 1952, 28, (11), 383-391).—[In French and German]. N. and B. review historically the development of the use of Al cans in Norway. The first period (1933-39) saw the use of pure Al and the 1½% Mn alloy for canning and the introduction of high-pressure autoclaves in the processing. The second phase (1939-49) was marked by the use of anodized Al strip for which lacquer sealing was subsequently developed. The third period (starting in 1949) saw the introduction of an Al-0.5% Mg alloy which was anodized and lacquered by a continuous process (N., *Fourth Internat. Mech. Eng. Congress, Stockholm, Preprint, 1952*; *M.A.*, 20, 269). A particular feature of this method is the incorporation of methyl cellulose in the dil. H₂SO₄ bath to eliminate degreasing and the sealing of the strips directly in a lacquer immediately after anodizing. Prodn. of cans by deep drawing is briefly reviewed. The causes of unsatisfactory service life with Al cans are analysed, a list of foods preserved in them is given, and the account concludes with a price comparison of Al and tinned-steel cans in various countries.—A. W. B.

The Aluminium Food Can in Europe. — (*Modern Metals*, 1952, 8, (2), 26-28, 30-32).—Discusses the successful use of Al as a packaging material for foodstuffs. The various types of can, materials used, corrosion difficulties, &c., are described.—R. J.

Aluminium Display Trays [for Butcher's Shops]. — (*Aluminium Suisse*, 1952, 2, (2), 69).—[In French and German].—A. W. B.

Packaging in Metallic Foil. W. A. Harrington (*Light Metals*, 1951, 14, (162), 503-508).—The use of metal or laminated foils in wrapping and packing is reviewed under main headings of min. thickness of material, ornamenting, limitations of machinery, laminated wrappings especially for food, definitions of wrapping and packaging, packaging foils, coating compared with lamination, heat-sealing of packets, and polythene-Al laminates for vacuum-sealing.—P. R.

Fabricating Aluminium for Textile Equipment. Floyd A. Lewis (*Light Metal Age*, 1951, 9, (9/10), 18, 24, 26, 27, 29, 33).—An account of the use of Al and its alloys for parts of traditional American textile equipment that were formerly manufactured from cast Fe, steel, or wood. Their use in new machines sp. designed to deal with synthetic fibres is also discussed.—H. A. H.

Aluminium Parts Help Increase Production [in Textile Industry]. — (*Textile Ind.*, 1952, 116, (2), 185, 186).—J. R.

[Aluminium in] The Manufacture of Paper. Pierre Prévot (*Rev. Aluminium*, 1951, (183), 433-438).—The use of Al in paper manufacture is described, with particular ref. to Al-Mg filter plates, cast Alpac rolls, and ventilating ducting on hot-air dryers.—A. W. B.

Production and Use of Light Metal Semi-Products in the U.S.A.—II. P. Brenner (*Aluminium*, 1951, 27, (2), 44-49).—Cf. *ibid.*, (1), 12; *M.A.*, 20, 47. The more commonly used alloys and their appn. are described in this report of a visit to the U.S.A. under O.E.E.C. auspices.—M. A. H.

Aluminium Coins. W. P. Kohler (*Aluminium Suisse*, 1951, (2), 64-65).—[In French and German]. Examples are given of coins from 12 different states made from Al or the Al-3½% Mg alloy.—A. W. B.

New Possibilities of the Application of Activated Aluminium [Aluminium Amalgam]. A. Romwalter and A. Hauer (*Acta Techn. Acad. Sci. Hungar.*, 1951, 2, (1), 43-58).—[In German]. Activated Al is an Al amalgam produced, according to Wislicenus, by washing Al with an aq. soln. of HgCl₂, then with H₂O, followed by alcohol, and then ether, and finally drying in air. The chem. dynamics of the two chem. reactions $2Al + 3H_2O \text{ (vapour)} \rightarrow Al_2O_3 + 3H_2 + 204,450 \text{ cal.}$, and $2Al + 1.5O_2 \rightarrow Al_2O_3 + 378,000 \text{ cal.}$, are described and discussed. Activated Al is especially applicable for the dehydration of gases and many organic liquids, and it is particularly useful for the dehydration of absorptive gels, e.g. SiO₂ and Al₂O₃ gels.—J. S. G. T.

Applications of Copper-Clad Aluminium. — (*Metallurgia*, 1952, 46, (273), 39-40).—A review of the available forms and appn. of Cu-clad Al.—F. M. L.

Applications of Light Metals. — (*Light Metals*, 1951, 14, (165), 686-689; 1952, 15, (166), 35-36; (167), 63-65).—A classified bibliography under 24 main headings is given of articles published in *Light Metals* from June 1949 to December 1951, inclusive, on the appn. of Al and Mg and their light alloys.—P. R.

Beryllium Alloys in Engineering. Walter Deisinger (*Fourth Internat. Mech. Eng. Congress, Stockholm, Preprint, 1952*, 13 pp.; and *Metal Ind.*, 1952, 81, (11), 203-205 (in English); also *Metal*, 1952, 6, (15/16), 436-440 (in German)).—A review of the properties and appn. of Cu-Be, Cu-Co-Be, and Ni-Be alloys. 15 ref.—D. M. P.

Cobalt. John V. Beall (*Trans. Amer. Inst. Min. Met. Eng. (in Min. Eng.)*, 1951, 190, (1), 17-24).—The resources, prodn. in Canada, uses as an alloying element, and the effect of the emergency defence policy on these uses, are reviewed.—S. R. W.

Industrial Applications of Stellite. B. J. Mackenzie (*Canad. Metals*, 1952, 15, (3), 48, 51-52).—A brief account of the properties and appn. of Stellite (Co 65, Cr 25, W 10, and C 1.0-2.5%).—W. A. M. P.

Economic Factors in the Use of Copper-Base Die-Castings. — (*Die-Castings*, 1949, 7, (10), 40-43, 74-75).—S. R. W.

Centrifugally Cast Bronze-Back Bearings for Heavy-Duty Operations. L. M. Tichvinsky (*Trans. Amer. Soc. Mech. Eng.*, 1951, 73, (5), 391-398; discussion 398).—The art of centrifugally casting bronze-backed bearings for use in heavy-duty Diesel engines was introduced into America by the U.S. Navy at the end of the war. T. describes the performance and salient points of manufacture of this type of casting, and a comparison is made with sand castings. Steps for the improvement of mech. properties include better temp. control, high rates of pouring, atmosphere control, more suitable mould materials, and attention to spraying technique.—H. Pl.

Magnesium in Aircraft.—I. R. Smallman-Tew (*Canad. Metals*, 1952, 15, (7), 22, 24).—A brief account of the use of Mg and Mg alloys in aircraft construction.—W. A. M. P.

Magnesium in the Textile Industry. Bernard Raclot (*Rev. Aluminium*, 1952, (186), 97-100).—R. describes the use of Mg alloys in warp beams, cops, bobbins, and parts of loom and mule spinning machinery seen at the 1952 Textile Exhibition at Lille. Consumption figures for Mg in various appn. in the industry are given.—A. W. B.

Fabricating the Magnesium Star of the Festival of Britain. — (*Light Metal Age*, 1951, 9, (9/10), 12-14).—Some details are given of the manufacture of the Mg star used at the Festival of Britain.—H. A. H.

Magnesium in Photo-Engraving and Printing. — (*Light Metals*, 1951, 14, (155), 82-89).—Lightness, resistance to stresses sustained in direct printing, deep, clean, and economical etching, and easy working are claimed for "Zomag", a proprietary Mg-base alloy for engravers' plates. The technique of additional handworking and of soldering is described (Swayze, *ibid.*, 1947, 10, 188; *M.A.*, 15, 75).

Rotary plates for newspaper printing, with Mg-alloy dummy plates, weigh only 20% of the usual stereotype cast. Favourable reports are cited on the durability of Zomag plates in book and magazine printing.—P. R.

Nickel. John V. Beall (*Min. Eng.*, 1951, 3, (8), 664-673).—The resources, prodn., alloys contg. Ni including some of their properties, and the effect of the defence programme on its uses, are briefly reviewed.—S. R. W.

Titanium in Aircraft Production. William S. Cockrell (*Light Metal Age*, 1951, 9, (11/12), 10-12).—A review of the discovery of Ti and of its properties and potentialities in the aircraft industry. Experiences with the hot- and cold-working and spot welding of 0-018 and 0-037 in. Ti sheet are very briefly detailed.—H. A. H.

Fabricating [and Use of] Titanium. — (*Modern Metals*, 1952, 8, (2), 21-23).—Describes some experimental results obtained by an American aircraft company during their investigation into the suitability of Ti for high-temp. appn. General properties are described; the outstanding drawback is the inability to withstand high temp. for prolonged periods, and ceramic coatings are being investigated.—R. J.

Some Factors Determining the Choice of Materials and Methods for Mass Production of Non-Ferrous Articles. B. Starck (*Fourth Internat. Mech. Eng. Congress, Stockholm, Preprint*, 1952, 14 pp.; and (abridged) *Metal Ind.*, 1952, 81, (10), 187-190).—[In English]. A discussion of the economies in material and machining time resulting from the use of non-ferrous die-castings, forgings, and extruded sections.

—D. M. P.

Non-Ferrous Metals in Locomotives. J. D. Glen (*Metal Ind.*, 1952, 80, (26), 527-529).—Abstract of a paper read before the Scottish Local Section of the Institute of Metals. G. summarizes the chief uses of non-ferrous metals in the manufacture of locomotives.—J. H. W.

Non-Sparking Tools. L. Bernhardt (*Engineer*, 1952, 194, (5032), 6-7).—The dangers attached to the use of conventional ferrous tools in areas exposed to inflammable gases or dusts are emphasized, and the various high-strength non-ferrous alloys with appn. in this field, e.g. Cu-Be, Al bronze, Monel, &c., are listed, together with their principal mech. properties.

—D. K. W.

Solid-Type Bearings in High-Speed Freight Service. E. S. Pearce, R. J. Shoemaker, and I. E. Cox (*Trans. Amer. Soc. Mech. Eng.*, 1950, 72, (1), 1-8; discussion, 8).—A construction which may operate successfully on the railway may fail under the adverse conditions in the test plant. The adverse test plant conditions are: (1) laboratory tests are conducted in still air in contrast to high-velocity air conditions in service; (2) test loading is static, whereas in service, the load is "alive" and varying; (3) in a laboratory test there is no benefit of lateral motion of the axle in distribution of lubricant between the journal and the bearing, whereas in actual service the axle is const. moving laterally, so enhancing the distribution of lubricant; and (4) speeds can be high and for extended periods of time not obtainable in practice. Rates of acceleration and deceleration, to and from high speeds, are attained that are not obtainable in practice. The loads imposed on car journal bearings are well within the safe load limits of Pb-base bearing linings. The low elastic modulus of bearing Babbitt metals has made possible their use under conditions of const. fluctuations of alignment. The high plastic yield of Pb-base lining relieves the localized pressure caused by these conditions, thereby avoiding seizure and failure. Shock loads caused by improper dimensional conditions of the wedge and bearing, are the cause of spread linings—but closer tolerances of the collateral journal box parts should solve this problem.—H. Pl.

Heat-Resisting Alloys for Use in Jet Engines. — (*Indust. Heating*, 1952, 19, (1), 48, 50, 154).—A brief illustrated account of the facilities for creep- and stress-rupture testing and for special heat-treatments available at the Research Laboratory of the International Nickel Co., Bayonne, N.J.—D. M. L.

High-Temperature Steels and Alloys for Gas Turbines: Research and Development in England. Erich Franke (*Werkstoffe u. Korrosion*, 1951, 2, (10), 378-386).—A review,

the material for which has been mainly derived from a Symposium of the Iron and Steel Institute on this subject held in 1951. 35 ref. Cf. *M.A.*, 20, 313.—E. N.

Gas Turbines. Maurice Victor (*Rev. Aluminium*, 1951, (181), 409-426).—Primarily a description of French, British, U.S., and Russian gas-turbine units and their performance. Materials are given very little mention.—A. W. B.

Conservation of and/or Substitution for Critical Jet-Engine Materials. N. E. Promisel (*J. Metals*, 1952, 4, (7), 698-702).—The conservation and/or substitution of Ni, Co, and Nb in alloys and coatings are discussed under the headings: (1) substitution of less critical materials; (2) scrap recovery; (3) repair, re-use, and increased life and efficiency of components; (4) more efficient manufacturing processes to minimize scrap; (5) closer control of alloy compn. to avoid unnecessary surplus of critical ingredients; and (6) redesign of components to require less critical materials, in quantity and type.

—E. N.

Applications of New Materials and Technological Processes in Typewriter and Calculator Production. Oddino Maritano (*Fourth Internat. Mech. Eng. Congress, Stockholm, Preprint*, 1952, 13 pp.).—[In French]. Materials, including cast and sintered Fe, light alloys, free-cutting and cold-rolled steels, and plastics, and processes including die-casting of Fe and light alloys, magnetic inspection of steel bars, Cu brazing, and powder metallurgy, used in the manufacture of components of typewriters and calculating machines are briefly reviewed. Owing to novelty, tech. limitations, cost, the possibility of deformation of components due, especially, to dimensional variations, powder metallurgy has not, as yet, been so widely applied as desirable in this branch of technology, for which it would appear to be ideally suited.—J. S. G. T.

Construction Materials in the Paper Industry. — (*Chem. Eng.*, 1950, 57, (9), 211-212, 214-219; (10), 217, 218, 220-223; (11), 255, 256, 258, 259, 261, 264; (12), 223-224, 226, 228, 230, 232, 234, 236; 1951, 58, (1), 217, 218, 220-222, 224-226).—A symposium in which materials of construction are evaluated for various services in the paper industry. Pb, Ni and its alloys, Worthite, Ta, and Durimet 20 are among materials discussed.—S. R. W.

Dependable Driving and Braking Mechanism Built with Die Castings. — (*Die-Castings*, 1949, 7, (12), 28-31, 54).—A description of the use of die-casting in the prodn. of a wire recording unit.—S. R. W.

Close-Fitting Parts Without Machining. — (*Die-Castings*, 1949, 7, (8), 16-18, 53).—Two Zn and two Al die-castings are given as examples of parts which are required to go together with a slip fit and can be assembled without machining the surfaces.—S. R. W.

Mechanical Springs. A. S. Lindsay (*J. Trans. Soc. Eng.*, 1951, 42, (2), 89-100).—The various forms of springs and their manufacture are described briefly. The compn. and phys. properties of some materials used are indicated.—S. R. W.

Woven Wire Cloth. H. W. H. Icough (*J. Trans. Soc. Eng.*, 1949, 40, (2), 65-79; discussion, 79-84).—The manufacture and uses are described.—S. R. W.

How to Overcome Materials Shortages in Product Design and Manufacture. H. R. Clauser (*Materials and Methods*, 1951, 34, (1), 89-112H).—Materials and Methods Manual No. 72. A comprehensive review of design economy, scrap recovery, and use of substitute materials. Non-ferrous metals in short supply include Ni, Cu, Al, Sn, Zn, Cd, and Co. A table is included giving suggested substitutes for scarce materials used in a wide variety of manufactured articles.—J. W. C.

Printing with Metallic Inks. Frederick T. Day (*Canning Ind.*, 1951, 21, (249), 28-29).—A description and the use of tinted gold (bronze) and silver (Al) inks in printing on wrappers, &c., is given.—S. R. W.

Report of [A.S.T.M.] Committee B-4 on Electrical Heating, Resistance, and Related Alloys. — *Proc. Amer. Soc. Test. Mat.*, 1951, 51, 145-146).—T. G.

Report of [A.S.T.M.] Committee B-1 on Wires for Electrical Conductors. — (*Proc. Amer. Soc. Test. Mat.*, 1951, 51, 133-143).—T. G.

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By John Wulff, Howard F. Taylor, and Amos J. Shaler.
9 × 6 in. Pp. viii + 624, illustrated. 1952. New York: John Wiley and Sons Inc. (\$6.75); London: Chapman and Hall, Ltd. (54s.)

This book is intended primarily for engineering students, which means engineering in the sense used in Britain. The three authors are on the teaching staff of the Metals Processing Laboratory at the Massachusetts Institute of Technology, and they state that the manuscript was successfully tried out in the classes over a period of years. The first fourteen chapters deal with the principles involved in the processing of articles by casting, welding, and mechanical working, whilst the second half describes practical operations. Three chapters outline the standard phase diagrams for binary alloys, so that the next one on "Industrial Non-Ferrous

Alloys" proceeds to include quite complicated systems—even the regions which are unlikely to be of use to the engineer. Extraction metallurgy and the mathematics of deformation are not dealt with. It can safely be said that if an engineering graduate is *au fait* with the contents of this book, then his metallurgical knowledge is adequate.

The plan of the work follows that of many American volumes in that each chapter comprises numbered paragraphs of information, followed by a useful list of questions, and terminating with a list of reference books—as distinct from original papers. The text as a whole is very readable, and the illustrations are clear and convincing. It is a pleasure to see that Table I of the Appendix on Sources of Metallurgical Information by no means ignores British publications.

Having said so much, the reviewer has hunted down certain favourite hobby-horses in the Index. Manganese steel is not listed, and yet one would have thought that this

austenitic alloy would have interested the engineer. Low-alloy steels do not appear at first hand in the Index, though some of them are listed in Table II of the Appendix. Under alloy steels there is the sub-division "low alloy", which then refers us to "carbon steels". We turn to carbon steels and are directed to p. 290 for the "effect of alloying elements". But by some curious slip, p. 290 describes sand reclamation, and we have not yet found where the low-alloy steels are described. Nodular cast iron is listed for p. 400, but all we learn there is that nodular iron shrinks more than grey iron. On p. 131, however, it is announced that "... after years of dreaming about spheroids of graphite instead of flakes or nodules the metallurgist finally found a way to make them". And on p. 133, under "Spherulitic Graphite", there is quite a suitable reference to the use of cerium and magnesium. For a work which emphasizes casting, it is surprising to find no mention of Modification under M, though tucked away on p. 101 there is reference to melting under a flux of sodium fluoride, which "... modification refines the grain and improves the mechanical properties. It also displaces the eutectic as shown in figure 7. 3". Continuous casting is dealt with, but the Durville process does not appear to be mentioned. The illustrations for the chapters on moulding are suitable and attractive.

The engineering student is told on p. 451 that "it is necessary to determine whether a metal is weldable". This depends upon its "weldability", which is here defined as the ability to produce a sound union to meet engineering requirements. The subject is left rather vague, with no risks taken that the hardness of the intermediate zone in a steel joint had better not exceed a certain value. British and American limits differ in this respect, and it would have been interesting to see where the authors fixed the red line. They do not suggest a limit, but indicate that safety in welding can be predicted from the $T-T-T$ curve of the steel. This is surely asking a lot of the average student of engineering.

Apart from these criticisms, the book very satisfactorily fulfils the requirements for which it was compiled.

HUGH O'NEILL.

Elementary Metallurgy. By W. T. Frier. Second edition. $8 \times 5\frac{1}{2}$ in. Pp. x + 258, with 129 illustrations. 1952. New York: McGraw-Hill Book Co., Inc. (\$4.50); London: McGraw-Hill Publishing Co., Ltd. (38s. 6d.)

This book provides a general introduction to metallurgy for students who have little previous knowledge of chemistry or physics and follows the plan usual in such publications, with a customary emphasis upon ferrous materials (120 pages are devoted specifically to iron and steel, compared with 24 to non-ferrous alloys). There are inconsistencies in the degree of knowledge assumed, and in some cases (notably in describing the iron-carbon system) conceptions are introduced which are explained only further on in the text—which is puzzling to the uninitiated.

The writing is careless in places: e.g. on p. 103 we read: "Notice that most of the Physical Properties Charts reproduced in this book were normalized before heat-treatment", and on p. 187, "Suppose we have two metals, M and N, that react to form the diagram in Fig. 102". For a revised edition there are too many misprints and obvious slips.

In the chapter on steel-making we are told that in the Bessemer converter molten lime floating on top of the bath removes SO_2 and that in the open-hearth furnace the bricks of the roof melt first "because heat rises". There is no mention of tilting open-hearth furnaces or induction furnaces. In dealing with the production of ingots there is no reference to anti-piping compounds, and in the caption to Fig. 64 we are told to "Notice rim on (d)"—but the rim is not there.

The treatment of moulding is inadequate, and sintering is described as heating to incipient fusion. On p. 203 occurs the sentence: "With all the striving for saving in weight in aircraft... the storage batteries still have the same heavy lead plates common to all storage batteries, and the gasoline is weighted down with tetraethyl lead for its anti-

knock qualities". In the chapter on testing there is a misleading emphasis upon the significance of chemical analysis, which is already too widespread a misconception.

The author is not always wise in the choice of definitions for quotation, e.g. on p. 26 part of the definition of steel is an alloy "that is ductile when cooled slowly but is rendered relatively hard and brittle when cooled rapidly". Most of the photomicrographs are very good, but Fig. 35 shows almost featureless black areas as the pearlite in a 0.4% carbon steel, and a rather unusual form of the lead-tin eutectic (Fig. 110) has the caption: "Practically all eutectics show this structure".

There are many misleading statements in the chapters on physical metallurgy. We are told on p. 55 that "Glass is an example of a solid solution", and there is no indication of the coring effect in solid solutions. The description of a peritectic reaction on p. 188 is far from lucid. The effect of grain-size on strength is incorrectly explained, and it is not true to say the breaking into smaller grains is the explanation of work-hardening. The elongated grains in a cold-drawn metal are described on p. 148 as "in the condition of a stretched piece of rubber, and given an opportunity, they come back to normal". The account of precipitation-hardening is far too brief.

The price of this book is high, and compares unfavourably with that of much better publications available in this country.

S. J. KENNETT.

Metallurgical Equilibrium Diagrams. By W. Hume-Rothery, J. W. Christian, and W. B. Pearson. (Physics in Industry Series.) $9\frac{1}{2} \times 6$ in. Pp. 311, with 239 illustrations. 1952. London: The Institute of Physics, 47 Belgrave Square, S.W.1. (50s.)

Many of the older books on physical metallurgy gave outlines of methods used in constructing equilibrium diagrams, but left it to the experimenter to work out details and to introduce refinements leading to greater precision. Accounts of many of these refinements have been published, but some of the papers are not readily accessible, and even today many papers on alloy constitution are open to the criticism that insufficient precautions had been taken to ensure high accuracy, or that conclusions had been drawn which were not warranted owing to the limitations of the methods followed. Consequently, a book of which the major part deals with experimental methods, their applications, and their limitations, compiled by authors of international reputation in this field, will fill a long-felt need.

The book opens with a short section on the theory of binary systems. The reactions which may occur on heating or cooling are described and their graphical representation discussed, whilst emphasis is laid on the points where, owing to sluggishness in reaching equilibrium, amount of phase present, or the slope of the lines bounding phase fields, experimental accuracy may be difficult to attain. A similar section, dealing with ternary alloys, occurs towards the end of the book. The rest of the book is devoted entirely to experimental methods, particularly those of which the authors have personal experience. A general section on refractories and pyrometry is followed by an account of methods recommended for determining the liquidus, giving details of the design and construction of furnaces suitable for work over specified ranges of temperature with controlled rates of heating and cooling. Next, the authors describe methods suitable for determining the solidus, and for investigating reactions below the solidus, again emphasizing the limitations of each method and the precautions needed for maximum accuracy. These include microscopy, X-ray diffraction, dilatometry, electrical resistivity, and magnetic measurements.

The book is intended for honours students and research students in metallurgy, but in the reviewer's opinion it is invaluable for everyone—whether in the universities, research institutes, or industry—working on constitutional or allied problems.

H. W. L. PHILLIPS.

X-Ray Crystallographic Technology. By André Guinier. Translated by T. L. Tippell. Edited by Kathleen Lonsdale. $9\frac{1}{2} \times 6$ in. Pp. xiii + 330, with 145 figures and 16 plates. 1952. London: Hilger and Watts, Ltd. (Hilger Division). (56s.)

The literature of X-ray crystallography has been extended during the last ten years by a surprising number of valuable new books, each written by authors among the most outstanding workers on the subject. It is fortunate that in a group of books written with this authority, each should have its own approach to the subject, or make such a selection of topics that, without much overlap, the books are largely complementary. Guinier's "Radiocristallographie", which was published in France in 1945, and was then very well reviewed (for example, by W. A. Wood, *Met. Abs.*, 12, 383) is one of these books which, by its choice and treatment of matter, has a particular appeal to workers in physical metallurgy.

The translation which has now appeared is straightforward but holds closely to the original text, although there is a slight tendency to introduce a casual terminology, such as "A D-S line appears. . . ." An occasional paragraph about, or illustration showing, apparatus made in this country has been added. The most notable change is from the weak dark paper of the original book to the clear printing and good paper of this well-bound translation, which now provides the work in a form able to endure the hard usage it should get. It is a pity that in re-drawing the line figures to make these improvements a few slips have escaped correction.

In this book we are given lucidly, although perhaps so tersely that reading must be done carefully, sufficient background to be able to understand as well as to use most of the X-ray crystallography which interests metallurgists. The book covers diffraction by single crystals and powders, with the applications of such methods to studies of texture, of crystal structure, and of imperfections and amorphous materials. Guinier, naturally, gives a particularly good section on monochromatic work.

To illustrate the level of the book, it may be worth recording that in one of its five "parts" there are 8 pages about the fundamentals of crystallography, 7 on X-ray reflection by lattice planes, followed by 18 pages on structure factors and reflection intensities (opening with an account of the reciprocal lattice); then there are 13 pages on the lattices of the cubic, hexagonal, and tetragonal systems, these being chosen because they cover so great a proportion of practically important materials.

In other sections experimental methods for single-crystal and powder diffraction and studies of texture and structures are handled in similar detail. The last part of the book describes work on amorphous materials and crystal imperfections, and it is only here that lack of the developments in the years since 1945 puts a tinge of out-of-dateness upon the book. This is, however, an unimportant blemish on an elegant and valuable book.

G. A. GEACH.

Handbuch der Schmelz- und Legierungspraxis in der Metallgiesserei. Von A. Schulenburg. 21×15.5 cm. Pp. 298, with 112 illustrations and 44 tables. 1952. Berlin SW29: Fachverlag Schiele und Schön. (DM 18.—)

In recent years quite a number of books of this kind have been published, which deal with the melting and alloying, and often casting as well, of most of the common non-ferrous casting alloys. All too frequently these books tend, in the reviewer's opinion, to fall between two stools—they give neither sufficient practical detail to be of much value to the foundryman, nor an account of the scientific principles involved adequate to satisfy the metallurgist. Unfortunately the present book is certainly no exception to this. For example, the author describes a number of furnaces used in melting light alloys and alloys of the heavy metals, but does not give sufficient information to tell the practical man what he really wants to know, viz. what furnace is best suited to

do a particular job. The descriptions of the metallurgical principles behind the various operations are particularly poor, especially since in his preface the author states that the book is intended for the foundry expert. Indeed, it is sometimes difficult to resist the conclusion that the author is himself not altogether clear about the scientific basis for some of the operations he describes. He gives a good example in discussing the degassing of light alloys where he states:

"Degassing also takes place through oxidation where one uses chlorine in the form of chlorides, instead of oxygen-carriers. If one uses oxygen, in the way we have discussed in connection with heavy metals, the hydrogen will be oxidized to steam, but this is again soluble in the metal". In fact, the action of chlorine is almost entirely physical rather than chemical, and hydrogen dissolved in aluminium cannot be oxidized to steam.

The book is divided into two main sections, the first dealing with the heavy metals copper, nickel, zinc, lead, and tin alloys, and the second with light alloys. Each section begins with a short description of the basic metals and continues with fairly extended accounts of the furnaces and other equipment used in melting, and pyrometry. Fluxing, degassing, and deoxidation are considered briefly, and then follow the tedious descriptions of the compositions, properties, &c., of individual alloys that are almost invariably found in books of this kind.

Many subjects of importance are treated very sketchily, if at all. For example, the degassing of light alloys and the modification of aluminium-silicon alloys are dismissed in less than one page each; the grain refinement of light alloys is scarcely even mentioned. The degassing of the heavy metals is dealt with in three pages, with a further five pages on deoxidation; only one method of degassing is considered, and the reasons for deoxidizing are scarcely mentioned. In some instances the book is misleading. A case in point is the description of aluminium-magnesium alloys, where it is indicated that the silicon content may rise as high as 1% in alloys containing 9% magnesium, thus ignoring recent work done in this country.

The book cannot be recommended.

R. W. RUDDLE.

Zinc and Aluminium Die-Casting. Report of a Productivity Team Representing the British Zinc and Aluminium Die-Casting Industry which Visited the United States of America in 1951. $9\frac{1}{2} \times 7\frac{1}{4}$ in. Pp. x + 98, with 31 illustrations. 1952. London: Anglo-American Council on Productivity, 21 Tothill Street, S.W.1; Oxford: The Zinc Alloy Die-Casters Association, Lincoln House, Turl Street; Birmingham (2): The Light Metal Founders' Association, 25 Bennetts Hill. (4s., post free.)

Pressure die-casters in this country have tended to be secretive as to their methods, and the present Report may well become a turning point in the history of the industry. A change of outlook in this respect can result when a group of technicians, representing every phase of the business and recruited from firms in all parts of the country, have, for a fairly considerable time, lived closely together, visited many die-casting firms at home, and travelled extensively in the stimulating atmosphere of technical achievement in the U.S.A.

The Report deals with its subject in most thorough detail. Production methods, materials, business methods, and human relations within the industry have been investigated with commendable diligence.

It would perhaps be expecting too much for all that is said and recommended to be accepted without question, and it seems necessary, in fairness to the trade interests of this country, to enlarge upon the statement claiming that output per man hour in the U.S.A. might be assessed as 30-40% higher for zinc and 20-30% higher for aluminium. It is not suggested the figures are an exaggeration; in fact under certain circumstances the reverse is true, but it is desirable that the following pertinent factors should receive more

mention: (a) The production rates quoted are not necessarily typical, but are associated almost exclusively with castings for the U.S.A. automobile trades, where quantity production by our standards is even more phenomenal than the quoted U.S.A. production rates. (b) The production rates referred to are usually achieved only by a limited number of the top-grade trade shops specializing in this class of business. Evidence of the truth of this statement may be found in a number of British pressure die-casting foundries, where, job for job, there are many instances of comparable production rates.

A number of recommendations are made which, if adopted, should do much to improve productivity, and to comment upon the more important ones may not be out of place.

(1) Time and/or Motion Study is recommended upon the grounds that it can facilitate production, and reduce operator fatigue. This certainly must be very true, and perhaps if there is one factor more than another contributing to the high productivity level of certain U.S. die-casters, it is Time and/or Motion Study. The reasoning behind this statement is that, given reliable studies, intelligent analysis will reveal shortcomings of methods and tooling. Recognition of the problem is the great thing, for it is then usually possible to remedy.

(2) The wider use of unit and nest dies and of standard components in die construction is recommended. The use of nest dies as a means of increasing machine productivity is undoubtedly good advice, particularly when taken in conjunction with a further recommendation that larger machines should be built. The warning should be given, however, that there are many practical difficulties, and it would have been helpful had the U.S. procedure in this matter been referred to in some detail.

(3) The team recommend that more attention be paid to obtaining correct and uniform die temperatures by providing adequate waterways and overflow wells. The more extensive use of water cooling is a significant indication of high production rates. Effective dissipation of surplus heat is a fundamental of rapid production and likewise is the need for a correct and uniform die temperature, and only massive die construction in conjunction with adequate water cooling can provide these conditions.

(4) Reference is made, among other recommendations appertaining to molten metal, to the importance of automatic control of metal temperature. It is a significant feature of American light alloy foundries, large or small, that the holding pot from which metal is transferred to any form of mould, irrespective of process, is invariably automatically temperature controlled. This is rightly looked upon as an essential and not a refinement.

(5) With the improvements of die-casting machines and dies, fettling may at times be the costlier operation, so that the recommendation to give more consideration to the wider use of power trim presses is opportune. In this connection it is usual to think of the crank press when talking in terms of power presses, and it is worthy therefore of mention that the hydraulic press is now finding considerable favour in the U.S. for trimming.

Frequent reference is made to the use of low-frequency induction furnaces for melting and/or holding, and whilst these are desirable in some respects, especially as a means of improving working conditions, it is evident from the relatively few in use in the U.S. that high capital cost is a deterrent.

The statement that little attention is paid to fuel economy among the U.S. die-casters comes as a surprise, especially as the large producers of zinc die-castings do their own alloying largely as the means of eliminating a melting charge, for after alloying, in their case it is customary to convey the molten material direct to the casting machine.

The team, unfortunately, did not succeed for various reasons in their investigations of permanent mould methods. It is undoubtedly true, as reported, that the process is, to a

large extent, overshadowed by the die-casting (pressure) process. Nevertheless, reported production rates of pistons indicates that where a true demand exists, the process is capable of being mechanized to yield very high production rates.

H. W. FAIRBAIRN.

Atomic Power: An Economic and Social Analysis. By Walter Isard and Vincent Whitney. 9 × 6 in. Pp. xi + 235, with 14 illustrations and 27 tables. 1952. New York: The Blakiston Company (\$4.75); London: George Allen and Unwin, Ltd. (37s. 6d.)

Here is a book on atomic power written by two American authors, one a distinguished professor of sociology, the other an equally distinguished lecturer in economics. Despite the admirable picture of electronic orbits found on the dust cover, it contains practically nothing about mathematical nuclear physics. Instead, it attempts to answer a number of questions such as: What effect will the harnessing of nuclear energy to produce power have on established industries? What changes in the social structure of the world will be caused thereby? What are the difficulties involved in the international control of atomic energy? Will atomic power actually compete with other sources of power? And many others.

A lot of woolly thinking has gone to the making of this book, and it is not surprising that no very definite and clear-cut answers are given to all, or indeed any, of these questions. Chapter I, devoted to "the technical background", refers to the location of all the atomic-energy plants in the U.S.A. I can imagine Mr. Stalin tearing out pp. 20-22 of this book, and having it pigeon-holed at the Kremlin for possible later reference. In this chapter I learn on (p. 14), that "the velocity of the fission fragments corresponds to a temperature of about 600 billion degrees C." Yes, billions. Compared with this temperature Mr. Churchill's estimate of the temperature attained in the recent explosion of the British atomic bomb makes one feel freezing. Well, anybody's guess in this matter is as good as any other's.

Now let me illustrate the sort of statements made by the authors in this book. Turn to p. 25 and read "It should be kept constantly in mind that no significance whatsoever is attached by the authors to the specific numerical estimates of the cost of atomic power which appear in the following pages". Notice particularly the word *whatsoever*. Now just before this we read, "The uncertainties involved in the development and use of nuclear energy are so great that the most able scientist, armed with the last available piece of declassified information, cannot really predict even a meaningful range of the cost of atomic power at future stages of development". Just one more out of the many statements of this kind which I have noted during my careful reading of this book. On p. 71, I find "The variables to be faced in considering the possible effects of atomic power on the location of industry and agriculture are so many that, even within a rigid frame of economic analysis, present conclusions must be stated largely in terms of probabilities or even of speculations". I have noted about 40 other passages of this kind to which I had desired to refer. But time and space are running out, and I must desist and spare you.

Industrialists will be interested to learn that the coming of nuclear power is unlikely to affect the location of the glass industry (pp. 88, 89), the iron and steel industries (p. 109), but may affect the location of the aluminium industries. Whether industrialists will accept the authors' conclusion on these matters is quite another matter. The rest of the book is devoted to cultural resistances to atomic power, atomic power and economic development, and an industrializing economy for Brazil.

The book is extremely well printed on very good paper, is provided with a detailed index, but it is rather high in price.

J. S. G. THOMAS.

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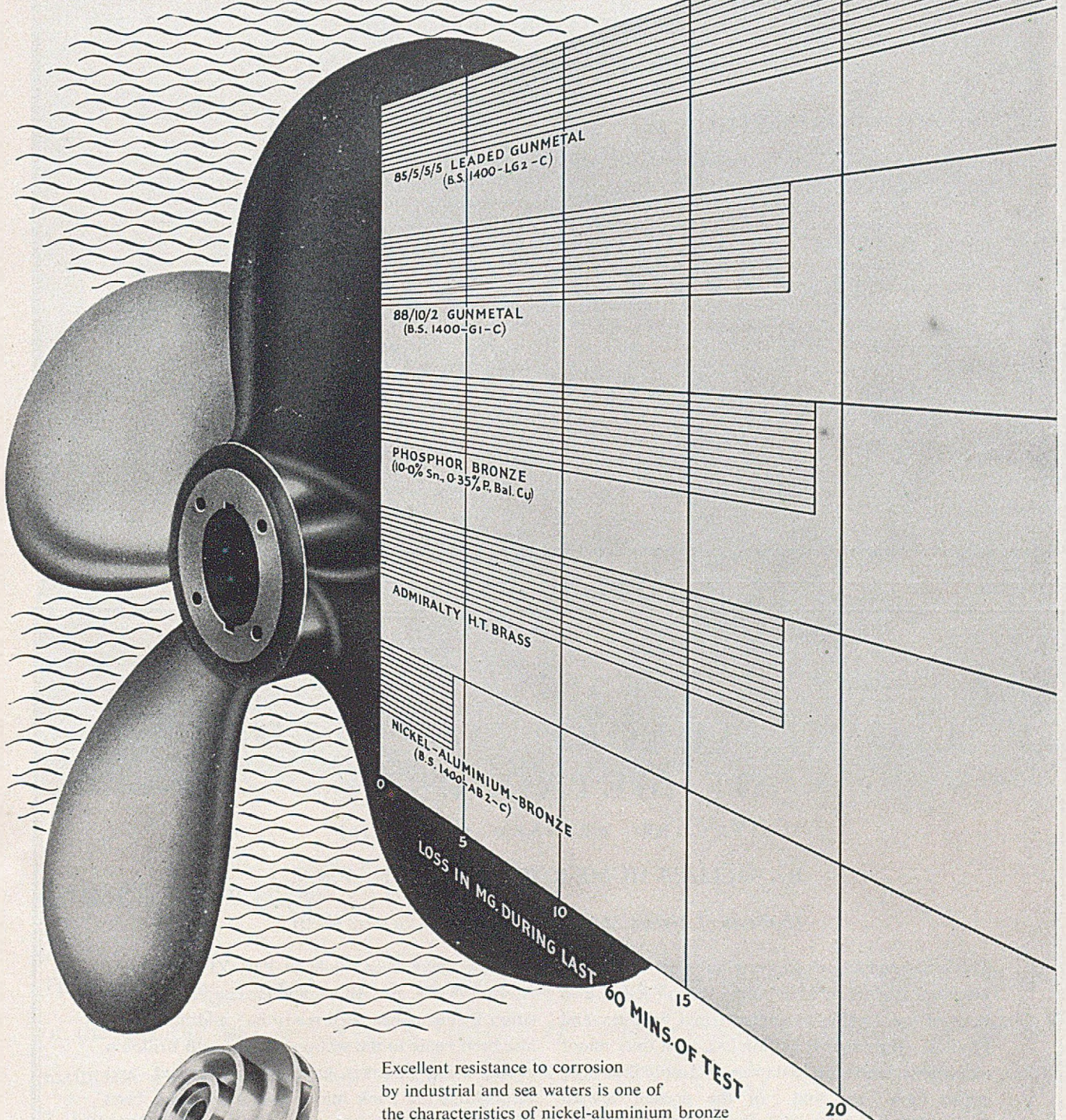
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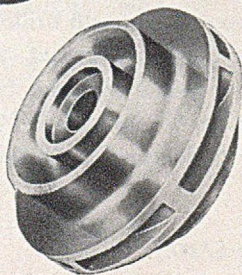
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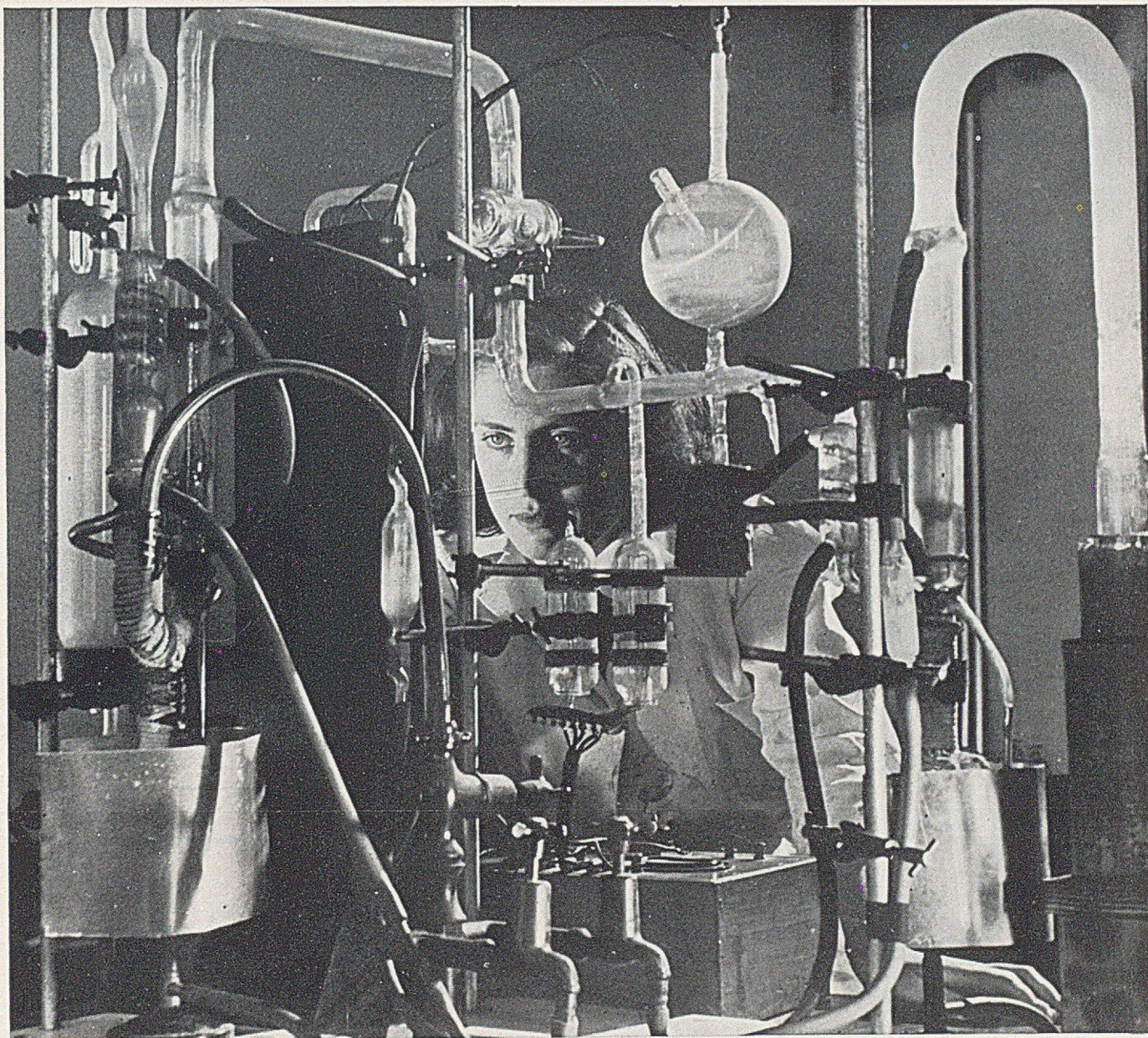


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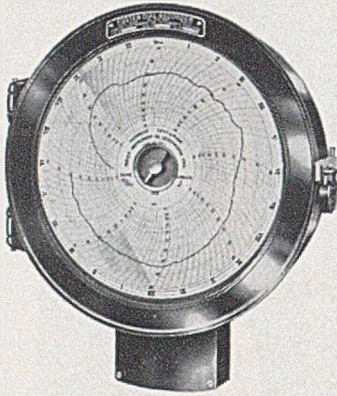
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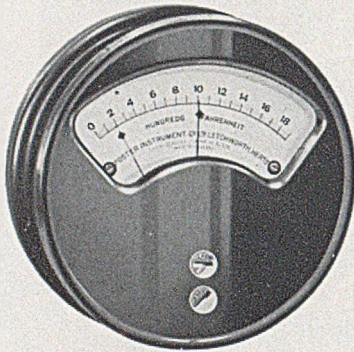
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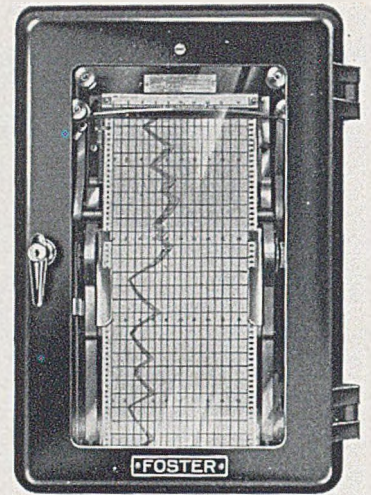
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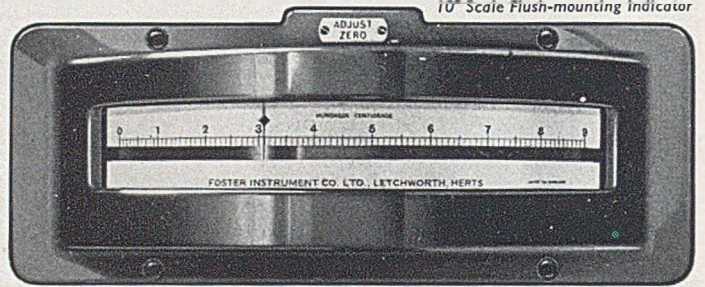


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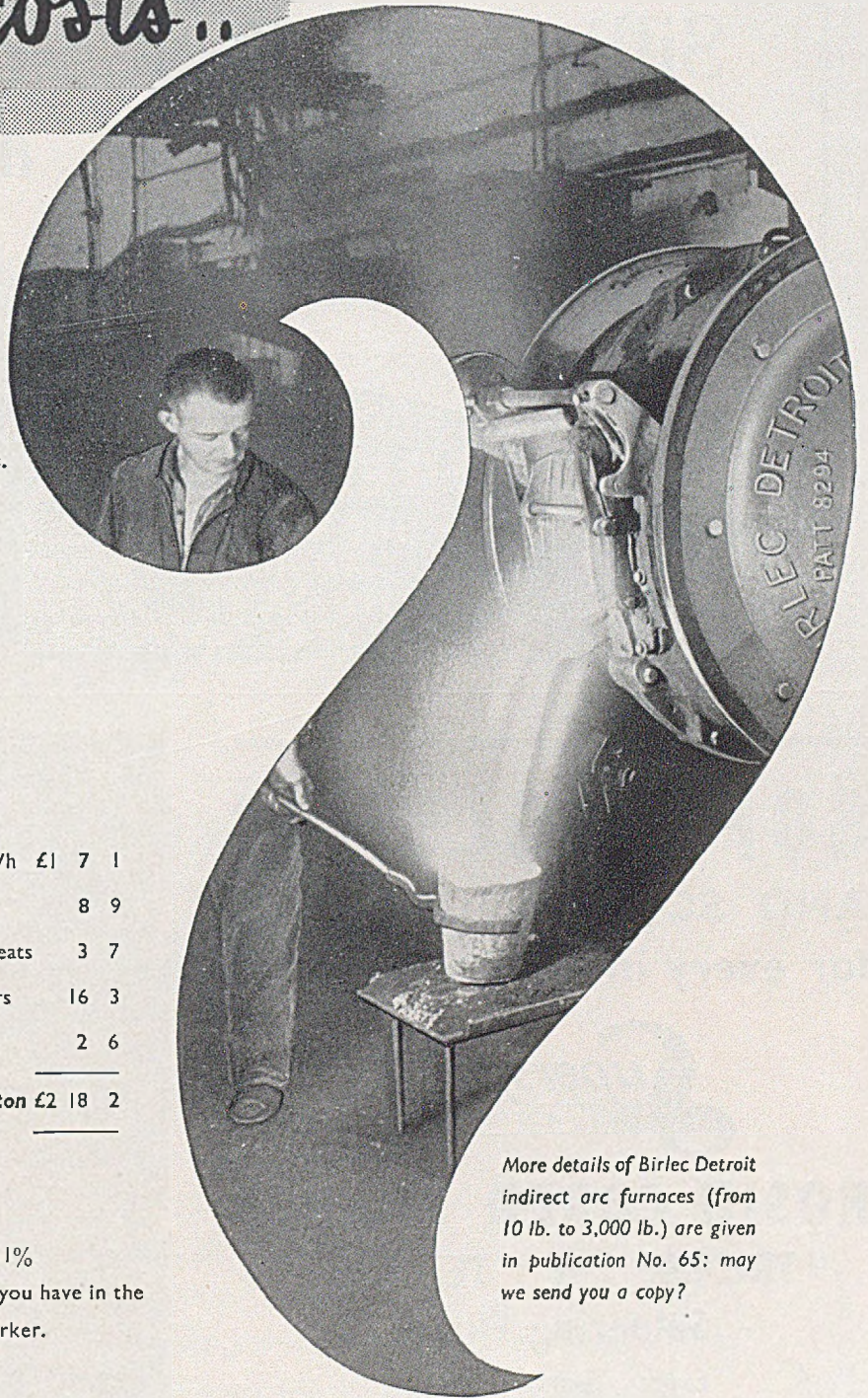
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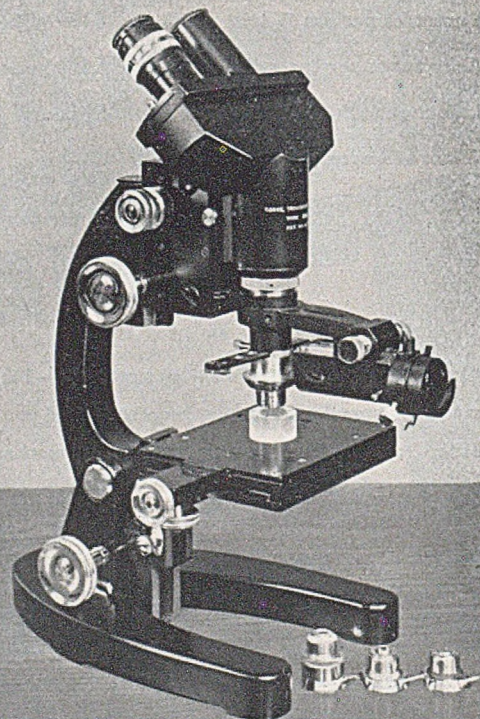
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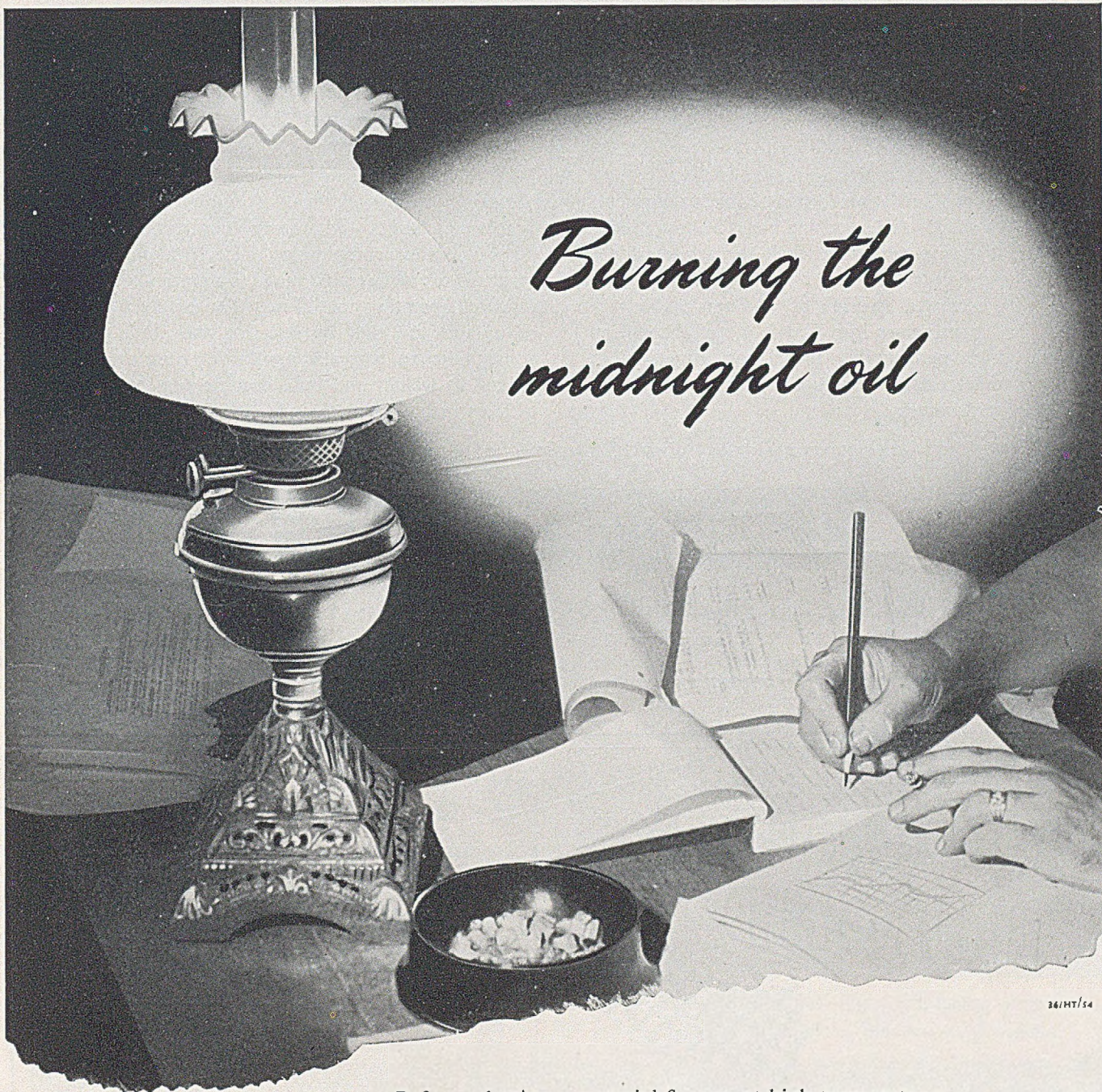
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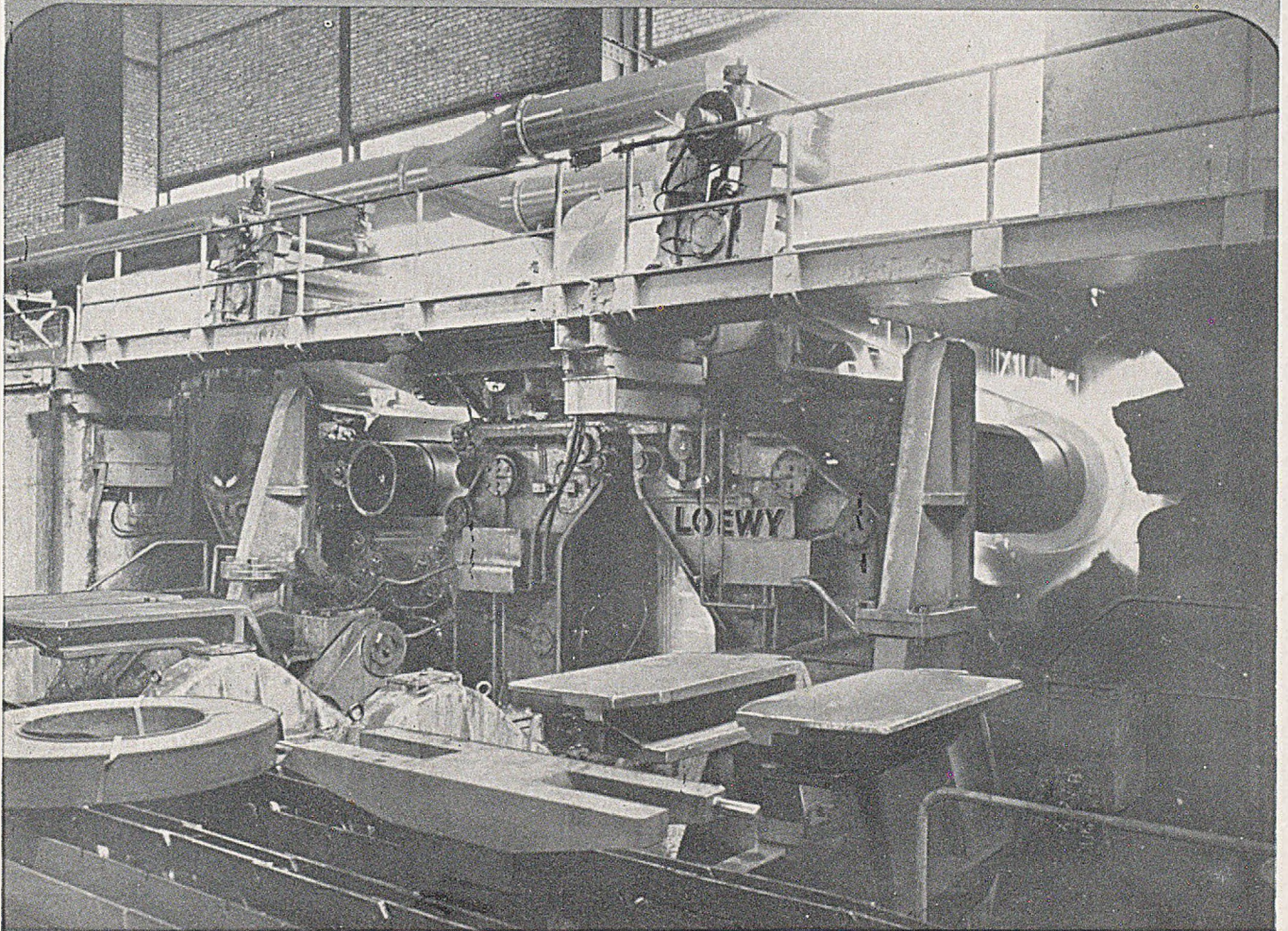


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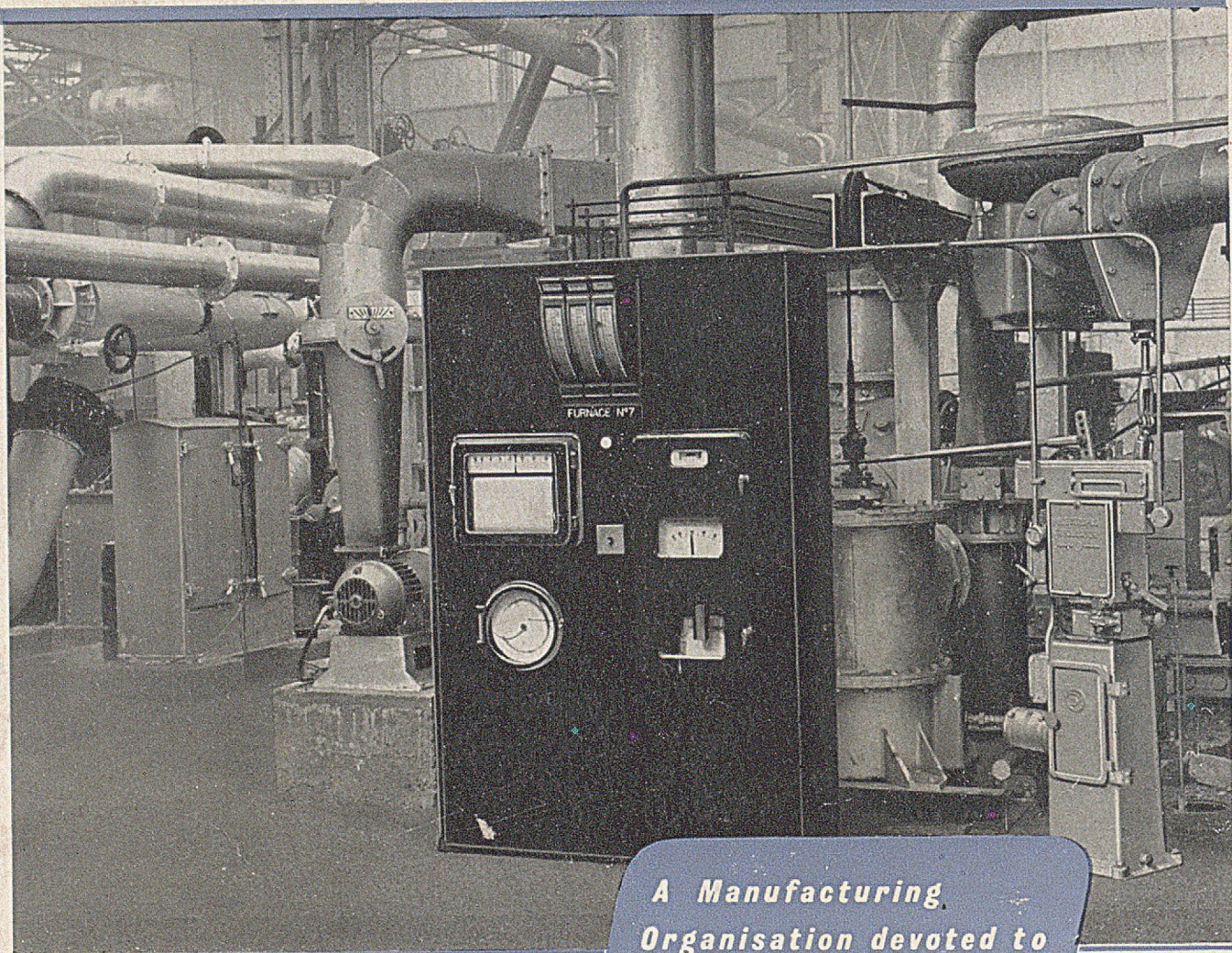
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