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THE INSTITUTE OF METALS—which is the technical and scientific society of the non-ferrous metal industries—was founded in 1908 to promote the science and practice of non-ferrous metallurgy in all its branches, and to facilitate contacts and the exchange of ideas among metallurgists, engineers, &c., throughout the world, by holding meetings and by the publication of literature. Its membership is international.

The main work of the Institute consists in the publication of a monthly periodical (free to all members) in which are included the *Journal*, *Metallurgical Abstracts*, and the *Bulletin*; in the publication of monographs; and the organization of scientific and technical meetings. Though in its *Journal* papers on purely ferrous metallurgy are excluded, a considerable proportion of the papers, and especially of the abstracts, are of equal concern to both ferrous and non-ferrous metallurgists.

Among their privileges, members may obtain the monthly *Journal* for £4 4s. 0d. (\$12.20)—or less in the case of Junior and Student Members—against £6 (\$17.25) to non-members, and they may buy one extra copy and a copy of any Monograph at 50% of the published price. The most economical way to obtain the publication is, therefore, to join the Institute; Librarians are admitted to membership.

JOURNAL OF THE INSTITUTE OF METALS WITH THE BULLETIN AND METALLURGICAL ABSTRACTS

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(a) THE JOURNAL

The *Journal*, which is issued monthly in one cover with the *Bulletin* and *Metallurgical Abstracts*, is now bound in annual volumes. It is obtainable in either form, and is now in its 81st volume. The principal contents are (a) papers recording the results of original research; (b) first-class reviews of, or accounts of, progress in particular fields; (c) papers descriptive of works, methods, or recent developments in metallurgical plant or practice; and (d) reports of scientific and technical discussions.

Volume 80 (1951–52) contained 85 papers, &c., 110 plates and 744 pp. of text. The contents of the volume are detailed on pp. 4–6. Specimen pages will be found in this booklet. For prices, see p. 2.

(b) METALLURGICAL ABSTRACTS

“To the metallurgist, both theoretical and practical, as well as to chemists, physicists and engineers, these volumes have become essential.”—*Nature*.

Abstracts have been published by the Institute since 1909. Up to 1933 they were included, with the papers, in the *Journal*, but since 1934 they have been separately bound annually in a new Series.

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THE BULLETIN

The *Bulletin* contains news of the Institute and of other scientific and technical societies, letters to the Editor on scientific and technical matters, and a selection of papers read before Local Sections of the Institute.

In 1951–52, 108 pp. of the *Bulletin* were published; the periodical can only be purchased in the monthly form, with the *Journal* and *Metallurgical Abstracts*.

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1951-52, Vol. 80

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Royal Society Warren Research Fellow, Oxford University

Seventh (revised) printing, 1950. 8vo. Cloth. Pp. 137, with 61 figs. 10s. 6d. (\$2.00), post free.

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ATOMIC THEORY FOR STUDENTS OF METALLURGY

By WILLIAM HUME-ROTHERY, O.B.E., M.A., D.Sc., F.R.S.
Royal Society Warren Research Fellow, Oxford University

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By G. V. RAYNOR, M.A., D.Phil., D.Sc.
Professor of Metal Physics, University of Birmingham

Second printing, 1949. 8vo. Cloth. Pp. 108, with 62 figs. 10s. 6d. (\$2.00), post free.

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NON-FERROUS METAL MELTING AND CASTING OF INGOTS FOR WORKING

A Symposium on Metallurgical Aspects of the Subject

8vo. 1949. Cloth. Pp. 168, with 19 plates and numerous figs in the text. 15s. (\$2.50), post free.

Press Comment :

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—*Engineering*.

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THE SOLIDIFICATION OF CASTINGS: A REVIEW OF THE LITERATURE

By R. W. RUDDLE, M.A.

Head of the Melting and Casting Section, British Non-Ferrous Metals Research Association

8vo. 1950. Cloth. Pp. 116, with 46 figs. 10s. 6d. (\$2.00), post free.

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METALLURGICAL APPLICATIONS OF THE ELECTRON MICROSCOPE

A Symposium

8vo. 1950. Cloth. Pp. 170, with 50 plates and numerous figs in the text. 21s. (\$3.50), post free.

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THE HOT-WORKING OF NON-FERROUS METALS AND ALLOYS

A Symposium on Metallurgical Aspects of the Subject

8vo. 1951. Cloth. Pp. 208, with 23 plates and numerous figs. in the text. 15s. (\$2.50), post free.

Press Comments :

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THE NON-DESTRUCTIVE TESTING OF METALS

By R. F. HANSTOCK, Ph.D., F.Inst.P.

Chief Physicist, High-Duty Alloys, Ltd., Slough

8vo. 1951. Cloth. Pp. 171, with 8 plates and 59 figs. in the text. 21s. (\$3.50), post free.

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In this book non-destructive testing is not narrowly interpreted as the application of radiography, magnetic and ultrasonic methods to the detection of flaws in metals. Although these methods, now well known and applied in many industries, receive consideration, other, less well-known, methods of examination are described with the object of providing a work of reference that may suggest alternative approaches to special problems of non-destructive testing. Particular methods of testing are seldom universally applicable, and one purpose of the monograph is to indicate the limitations within which a test may be expected to operate successfully.

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THERMODYNAMICS OF ALLOYS

By JOHN LUMSDEN, B.Sc., A.R.I.C.

Research Department, Imperial Smelting Corporation, Ltd.

8vo. 1952. Cloth. Pp. 399, with 110 figs. 35s. (\$5.50), post free.

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" His presentation of the argument is excellent."—*The Times Review of Industry*.

" The book satisfies a need which has been felt for some time by workers in the field of alloy equilibria. . . . Mr. Lumsden is to be congratulated on having brought it (the information in the book) together and knitted it into a pattern in such an exceptionally able manner."—*Foundry Trade Journal*.

This book deals with thermodynamics as a means of correlating, codifying and cross-checking diverse physico-chemical measurements on metals and alloys. The theory is developed from first principles, with the mathematics kept as simple as possible, but care is taken to avoid misleading over-simplification on such matters as the statistical interpretation of entropy. By selected examples, it is shown how a comprehensive free-energy equation, derived from a suitable set of experimental measurements, can be reliably used to calculate all the equilibrium properties of a system.

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THE COLD WORKING OF NON-FERROUS METALS AND ALLOYS

A Symposium on Metallurgical Aspects of the Subject

8vo. 1952. Pp. 207, with 20 plates and numerous figs. in the text. 15s. (\$2.50), post free.

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"The Institute is providing invaluable aid to the works' metallurgist by the organization and publication of these symposia."—*Bulletin of the British Non-Ferrous Metals Research Association.*

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EQUIPMENT FOR THE THERMAL TREATMENT OF NON-FERROUS METALS AND ALLOYS

A Symposium

4to. 1952 (Dec.). Cloth. Pp. 104, with 14 plates and numerous figs. in the text. 15s. (\$2.50), post free.

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PROPERTIES OF METALLIC SURFACES

A Symposium

8vo. 1953. *In the Press.* Cloth. Pp. 350 approx., with numerous illustrations. Price not yet fixed (will be about 40s. or \$6.00).

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ACTIONS IN SOLUTIONS, by M. T. Simnad (*Carnegie Institute of Technology, Pittsburgh, Pa.*). THE INFLUENCE OF MACHINING AND GRINDING METHODS ON THE MECHANICAL AND PHYSICAL CONDITION OF METAL SURFACES, by P. Spear, I. R. Robinson, and K. J. B. Wolfe (*The B.S.A. Group Machinability Laboratory, B.S.A. Tools, Ltd.*). THE EFFECT OF LUBRICATION AND NATURE OF SUPERFICIAL LAYER AFTER PROLONGED PERIODS OF RUNNING, by F. T. Barwell (*Mechanical Engineering Research Organisation, Department of Scientific and Industrial Research*). THE CRYSTALLINE CHARACTER OF ABRADED SURFACES, by P. Gay and P. B. Hirsch (*Cavendish Laboratory, Cambridge*). THE EFFECT OF SURFACE CONDITIONS ON THE MECHANICAL PROPERTIES OF METALS, MAINLY SINGLE CRYSTALS, by E. N. da C. Andrade (*Royal Institution*). THE EFFECT OF SURFACE CONDITION ON THE STRENGTH OF BRITTLE MATERIALS, by C. Guiney (*University College, Cardiff*). THE INFLUENCE OF SURFACE CONDITION ON THE FATIGUE STRENGTH OF STEEL, by R. J. Love (*Motor Industry Research Association*). THE INFLUENCE OF SURFACE FILMS ON THE FRICTION AND DEFORMATION OF SURFACES, by F. P. Bowden and D. Tabor (*Cambridge University*). DIFFUSION COATINGS, by D. M. Dovey, I. Jenkins, and K. C. Randle (*The General Electric Co., Ltd.*). THE NATURE AND PROPERTIES OF THE ANODIC FILM ON ALUMINIUM AND ITS ALLOYS, by H. W. L. Phillips (*The British Aluminium Co., Ltd.*). CHEMICAL BEHAVIOUR AS INFLUENCED BY SURFACE CONDITION, by U. R. Evans (*Cambridge University*). THE EFFECT OF METHOD OF PREPARATION ON THE HIGH-FREQUENCY SURFACE RESISTANCE OF METALS, by R. G. Chambers and A. B. Pippard (*Royal Society Mond Laboratory, Cambridge*). GENERAL DISCUSSION.

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

A Symposium

4to. 1953. *In the Press.* Cloth. Pp. 100 approx., with 14 plates and numerous illustrations. Price not yet fixed (likely to be 15s. or \$2.50, post free).

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ON THE FOOT-HILLS OF THE PLASTIC RANGE*

By PROFESSOR H. W. SWIFT,† M.A., D.Sc., M.I.Mech.E.

SYNOPSIS

In this lecture the author attempts a survey of the activities of the several classes of pure and applied scientists engaged in the general field of metal plasticity. He discusses the present state of knowledge and the extent to which research is at present able to make its contribution to the various technological processes involving plastic deformation. A classification is suggested of the most profitable directions of inquiry appropriate to the mathematician, the metal physicist, and the engineering scientist, and an appeal is made for the co-ordination of programmes and for the presentation of reports and results in a form intelligible to other scientific workers and to those more directly concerned with plastic processes in industry. The methods of mathematical plasticity are illustrated by simple examples of shear-line fields and flow grids. The limited success of more elementary methods of analysis by engineering investigators is illustrated by the deep-drawing of a cylindrical shell. An appeal is made to the metal physicist for a more realistic model of lattice structure, and for a systematic study of stress/strain relations on a wider front than heretofore.

I.—INTRODUCTION

PLASTIC deformation forms the basis of one of the oldest of the industrial arts and one of the youngest of the applied sciences. From the earliest historical times man has applied to malleable metals the group of compressive operations which include forging, coining, and hammering, for over a thousand years he has been drawing wire, and for over a century he has been drawing tubes and sheet metal. Yet little attempt had been made before the present century to formulate the principles of plastic deformation or to correlate them with the properties of metals. It is true that the basic equations of theoretical plasticity were laid down by Lévy in 1871, but so little attention did they attract that they are generally credited to von Mises, who re-enunciated them over 40 years later. And although Tresca introduced the shear-stress criterion for plastic flow in 1868, this is still commonly attributed to Guest in 1900, though he subsequently did his best to live it down.

Von Mises, of course, made other notable contributions to the theory of plasticity, and was one of the leaders of the German school which was mainly responsible for experimental and theoretical developments up to the beginning of the last war. The transfer of Continental workers to America—by cold extrusion before the war and by wire-pulling since—carried the initiative across the Atlantic for a time, but the emergence of a theoretical group at Fort Halstead during the war and the development of experimental groups under the energetic leadership of certain of the British industrial research organiza-

tions have done much to restore the balance, and in so far as results are to be judged by weight rather than volume, there is probably at the present time a greater potential of applicable theory and experiment in this country than anywhere else. Whether the appetite of industry in this country as a whole is as keen, or its digestive organs as efficient, as elsewhere is perhaps another question.

But this question must not be held to imply any doubt as to the technological skill of those engaged in the metal-forming industries in this country. There can be no doubt on this score in the mind of anyone who has visited an automobile press shop and witnessed the transformation of a flat sheet into a motor-car wing in a single stroke. Neither the man who casually presses the button nor his mate who idly applies an oily rag at the right spot on the sheet has anything to learn from Charlie Chaplin in the matter of masterly nonchalance. And it is no less impressive in an anonymous back-street works to follow the fortunes of an aluminium slug which within ten minutes of entering the shop is extruded, screwed, capped, twice enamelled and stoved, and despatched with a colourful tribute to a wonderful shaving cream, but no clue to the identity of those who produced its still more wonderful container.

Such examples are a tribute to the enterprise, courage, resourcefulness, and intuitive skill of those engaged in the metal-forming industries, but they do not prove either that industrial development has reached finality or that the principles underlying it are so well understood that they can be applied with confidence to fresh types of problems as they arise.

* Delivered at the Annual Autumn Meeting, Oxford, 15 September 1952.

† Professor of Engineering, University of Sheffield.

HIGH-TEMPERATURE OXIDATION CHARACTERISTICS 1436 OF A GROUP OF OXIDATION-RESISTANT COPPER-BASE ALLOYS *

By J. P. DENNISON,† Ph.D., B.Sc., JUNIOR MEMBER, and
PROFESSOR A. PREECE,‡ M.Sc., F.I.M., MEMBER

SYNOPSIS

The influence of small separate additions of aluminium, beryllium, chromium, magnesium, and silicon on the high-temperature oxidation of copper has been examined, these alloying elements having been chosen because their oxides have a high electrical resistivity. The composition and microstructure of the scales formed were studied and correlated with the rates of oxidation.

The effectiveness of the additions in conferring oxidation-resistance was in the decreasing order: beryllium, aluminium, magnesium, silicon, chromium.

Alloys having rates of oxidation less than that of copper showed divergences from the established parabolic and exponential laws. These divergences may be accounted for by a consideration of the relative rates of diffusion of copper and of the alloying element through the oxide layers.

I.—INTRODUCTION

THE results described in the present paper were obtained in a general investigation of the high-temperature oxidation characteristics of a selection of binary copper-base alloys. The alloying elements chosen were aluminium, beryllium, chromium, magnesium, and silicon.

Earlier investigations by Wagner¹ and by Price and Thomas² have demonstrated the importance, among other things, of a high electrical resistivity in the oxide film if protection against continued oxidation is desired. The elements chosen have a much higher affinity for oxygen than that of copper; their oxides are refractory, and, with the exception of that of chromium, possess high electrical resistivity.

Relatively little detailed information is available concerning the exact nature of the oxide/metal interface or the constitution of the oxides formed on these alloys, especially in the temperature range 400°–700° C. It was decided therefore to begin with the simple binary alloys before proceeding to the more complex compositions.

In view of the recent publication of a comprehensive review of the literature on the oxidation of copper by Tylecote,³ only references directly connected with the present work are included.

II.—EXPERIMENTAL WORK

1. MATERIAL AND PROCEDURE

The alloys listed in Table I were prepared by melting electrolytic copper under charcoal and adding the alloying element in the form of a master alloy. Bars

of 1-in. dia. were cast by the Durville process, hot rolled to ½-in. dia., and machined to a smooth finish.

TABLE I.—*Compositions of Alloys Used.*

Element	Alloy Content		Copper, %	Remainder, by Difference, %
	Nominal, %	Actual, %		
Aluminium	2	2.05	97.90	0.05
	4	4.03	95.91	0.06
	6	5.96	94.00	0.04
	8	8.08	91.87	0.05
	10	9.90	90.04	0.06
Beryllium	1	1.05	98.92	0.03
	2	2.00	97.96	0.04
Chromium	0.5	0.50	99.46	0.04
	1.5	1.20	98.77	0.03
Magnesium	1	0.90	99.07	0.03
Silicon	2	2.03	97.93	0.04
	3.5	3.55	96.40	0.05

Specimens cut from these bars were exposed at the required temperatures to ordinary air and, in the preliminary part of the investigation, to the products of combustion of paraffin containing 2% sulphur burnt with a 60:1 air-to-fuel ratio to give an atmosphere of the following composition: N₂ 78, O₂ 17, H₂O 3, CO₂ 2, and SO₂ 0.11%.

It was found that only when the fuel contained sulphur was there any difference in the rate of oxidation. This difference, which was slight, was directly proportional to the sulphur content of the combustion atmosphere, and was apparent only at temperatures

* Manuscript received 24 June 1952.

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THE CONSTITUTION OF CHROMIUM-MANGANESE ALLOYS BELOW 1000° C.*

1447

By W. B. PEARSON,† D.F.C., M.A., D.Phil., MEMBER, and
W. HUME-ROTHERY,‡ O.B.E., F.R.S., MEMBER

SYNOPSIS

The constitution of chromium-manganese 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 composition), and high-temperature X-ray photographs show that both the high-temperature, σ' , and low temperature, σ , modifications have characteristic " σ " structures resembling that of the σ -iron-chromium phase. The phase appears to be stable down to 523° C., and no signs of a eutectoid decomposition could be found. The solid solubility of manganese in chromium diminishes markedly below 1000° C., the temperature 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 -manganese; 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 manganese in chromium 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 composition in the region of Mn_2Cr . The lattice spacings of the solid solution of manganese in α -Cr have been determined.

I.—INTRODUCTION

THE equilibrium diagram of the system chromium-manganese was determined in 1949 by Carlile, Christian, and Hume-Rothery¹, and was shown to contain a wide solid solution of manganese in chromium followed by a phase denoted θ , which was shown later² to possess the same crystal structure as the σ phase in the system chromium-iron, and is therefore called σ in the present paper. The σ phase was shown to be formed by a peritectic reaction, and this was confirmed by Zwicker,³ although in an earlier paper⁴ this author had regarded the σ phase as involving a eutectic. The diagram of Carlile, Christian, and Hume-Rothery in the region 0-70 at.-% manganese was determined § only above 1000° C., although these authors noted that changes occurred on annealing at low temperatures, and this was confirmed by Zwicker,³ who showed the solubility of manganese in chromium to diminish greatly below 1000° C. The two investigations were not, however, in exact agreement where they overlapped, and as the purity and exact composition of Zwicker's alloys were not indicated,|| a further study of the system has been made, and has shown that non-equilibrium structures are produced when previously homogenized alloys are re-annealed at low temperatures. It is probable that conditions

of true equilibrium will require annealing treatments of several years, and the present paper is submitted to describe the structures obtained after annealing periods of the order of 5-71 days.

II.—EXPERIMENTAL TECHNIQUE

The manganese and chromium used were high-purity, electrolytic, hydrogen-reduced metals, and were melted in thoria-lined alumina crucibles in an H.F. induction furnace, using slight modifications of the methods described by Carlile, Christian, and Hume-Rothery, and by Pearson and Hume-Rothery.⁶ The ingots were homogenized by heating in hydrogen for more than 2 hr. at 15°-20° C. below the solidus. Subsequent annealing treatments were carried out by standard methods^{1,6} in sealed evacuated tubes. Powder X-ray-diffraction films were used to determine lattice spacings by standard methods. Phases were identified by drawing a file across the actual surface examined under a microscope, and where the specimen had been annealed and quenched from a high temperature, the filings were not annealed, because this resulted in loss of manganese. At lower temperatures filings were annealed in the ordinary way. Seventeen alloys in lump form, and eleven batches of annealed filings were analysed by Johnson, Matthey and

* Manuscript received 15 October 1952.

† Low-Temperature Solid-State Physics Department, National Research Council, Ottawa, Canada; formerly Inorganic Chemistry Laboratory, Oxford.

‡ Royal Society Warren Research Fellow, and University Lecturer in Metallurgical Chemistry, Oxford.

§ As pointed out later,⁵ owing to a mistake in drawing, the phase boundaries in one diagram were extended to low temperatures where they had not been determined.

|| The alloys do not seem to have been analysed, although loss of manganese is known to occur on melting and on annealing.

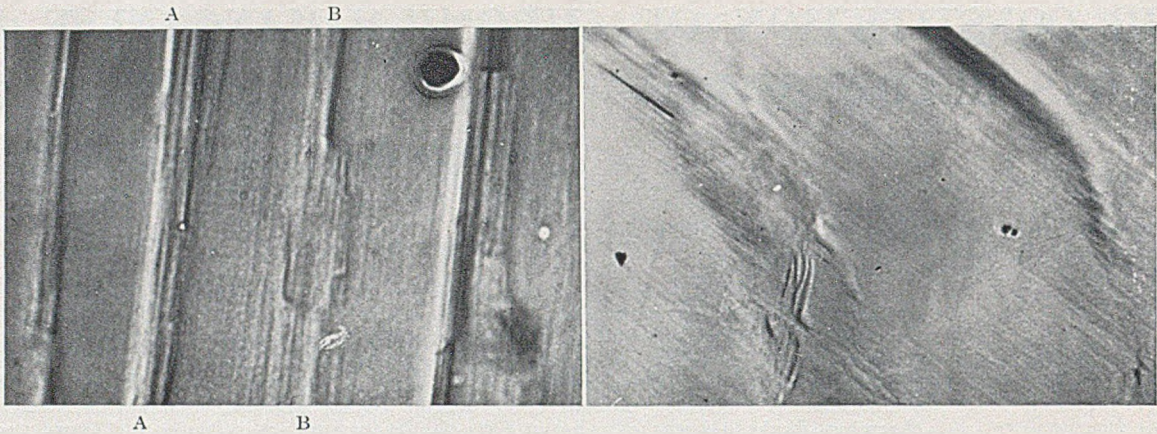


FIG. 19.—Prominent Slip Bands in Coarse-Grained Specimen at 4% Extension. $\times 750$.

FIG. 20.—Bends in Prominent Slip Bands Similar to Region Circled in Fig. 15. Coarse-grained specimen at 13.8% extension. $\times 750$.

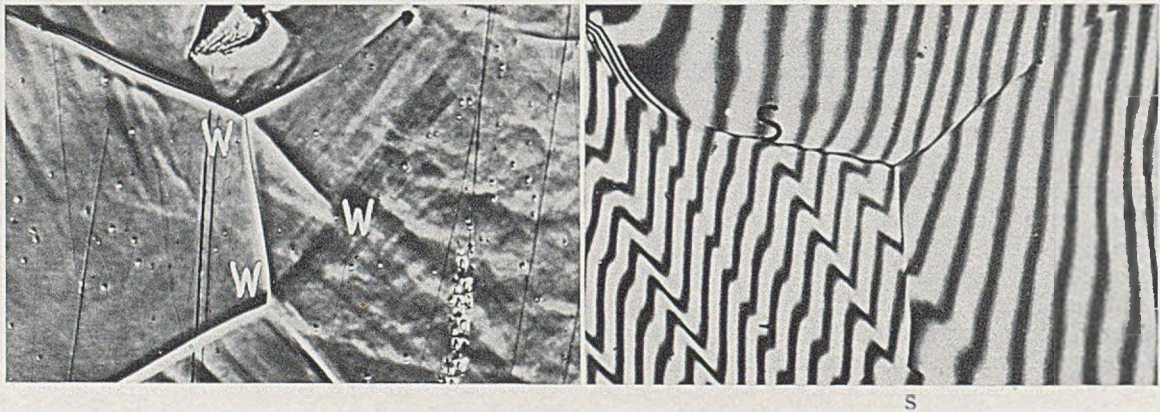


FIG. 21.—Phase-Contrast Micrograph, Showing Movement of Wedge *WWW* Due to Slip Induced at Neighbouring Grain Corners by Grain-Boundary Movement. Fine-grained specimen at 1.67% extension. $\times 500$.

FIG. 22.—Interference Micrograph, Showing Prominent Slip Bands (*SS*) at Low Extension. Fine-grained specimen at 1.95% extension. $\times 500$.

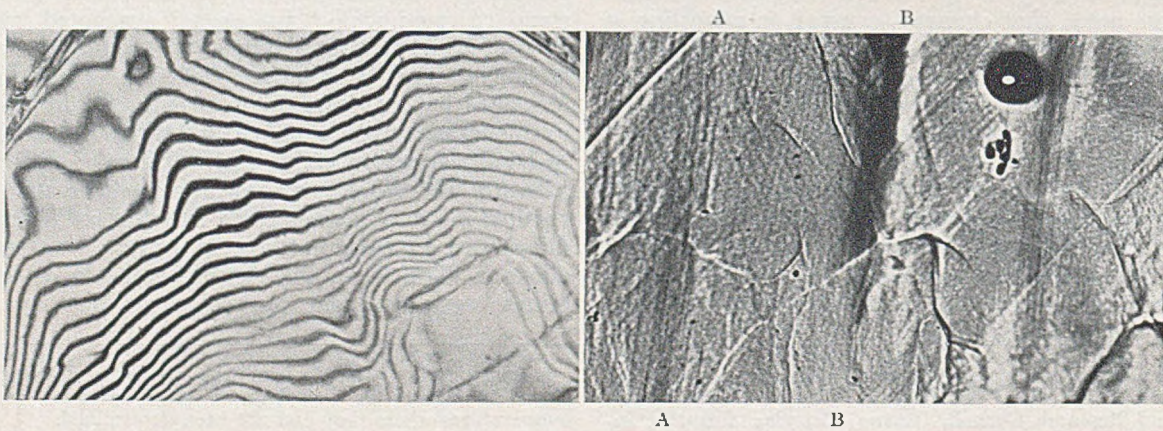


FIG. 23.—Interference Micrograph, Showing Appearance at Large Extension. Fine-grained specimen at 19.8% extension. $\times 500$.

FIG. 24.—Same Field as Fig. 19 at 23.6% Extension. $\times 750$.

METALLURGICAL ABSTRACTS

GENERAL AND NON-FERROUS

VOLUME 20

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PART 5

1 — PROPERTIES OF METALS

***Thermal Expansion of Aluminium and Some Aluminium Alloys.** (Hidnert and Krider). See col. 331.

***The Absolute Determination of the Condensation Factors of Molecular Jets of Antimony on a Surface.** Marcel Devienne (*Compt. rend.*, 1952, 234, (1), 80-81).—By the use of radioactive Sb, it has been found that the condensation factor for Sb deposited on a Cu surface is 0.74 for a layer 40 Å. thick and 0.55 for a layer 14 Å. thick.—N. B. V.

***Thermal Dependence of Elastic Constants of Electrodeposited Chromium.** H. Pursey (*Nature*, 1952, 169, (4291), 150).—An investigation has been made of the transition near 37° C. in the thermal dependence of the elastic const. of electrodeposited Cr recently reported by Fine, Greiner, and Ellis (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, 191, 56; *M.A.*, 19, 2). Variations of Young's modulus (E) and the modulus of rigidity (G) with temp. between 10° and 80° C. were studied, using a resonance method, on a tube of electroformed Cr annealed at 544° C. At the lower frequencies in the range 15-160 kc./s. the results are similar to those of F., G., and E., who used a tube annealed at 1000° C.; at higher frequencies in this range the magnitude of the fluctuation is reduced, although the min. in the E /temp. curve remains const. at 36.5° C. The G /temp. curve shows a stationary portion between 36.5° and 42.5° C. and is independent of frequency. The results correspond to a process which varies the bulk modulus as a single-valued function of temp. with a time-const. of ~10 microsec.—R. S. B.

***A Study of the Annealing Kinetics in Cold-Worked Copper.** Dwain Bowen, R. R. Eggleston, and R. N. Kropf (*J. Appl. Physics*, 1952, 23, (6), 630-635).—Samples of pure Cu wire cold-drawn to 97% reduction in area were pulse-annealed for successive periods at each of a number of temp. in the range 100°-250° C. Measurements of resistance were made at temp. in the range 4°-30° K. Matthiessen's rule was obeyed in that the abs. change of resistance as measured in a given annealed specimen was independent of temp. of measurement up to ~20° K. This means that lattice distortions due to cold work change the scattering cross-section for electron waves but not the number of carriers, and hence the residual resistance due to cold work \propto concentration of lattice distortions. On this argument, and applying rate theory, the order of the annealing reaction was determined by finding which order was most nearly consistent with all the results. A fourth-order reaction is strongly indicated, with an activation energy of 28.3 kg.cal./mole. This implies that four lattice distortions co-operate in each unit process of recovery. No mechanism for this is suggested. It is assumed throughout that recovery of resistance is a single-stage process.—R. W. C.

***The Thermal and Electrical Conductivity of Copper at Low Temperatures.** R. Berman and D. K. C. MacDonald (*Proc. Roy. Soc.*, 1952, [A], 211, (1104), 122-128).—The thermal and elect. conductivities— κ and σ , resp.—of high-purity Cu (Ag ~0.0005, Ni <0.0002, and Pb <0.0004%), annealed in He for

6 hr. at 450° C., have been determined continuously from 90° to 2° K. The results show a pronounced min. in the elect. resistance at ~10° K., and a similar but smaller anomaly in the thermal resistivity at about the same temp., with a corresponding small deviation in the Wiedemann-Franz law at the lowest temp. At temp. (T) between ~12° and 30° K., κ (in W./cm./°K.) follows the law $1/\kappa = 0.212/T + 2.5_5 \times 10^{-5}T^2$, while σ (in Ω -cm. $\times 10^{-6}$) is well represented by the equation $1/\sigma = (1/189.6) + 2.64 \times 10^{-10} T^5$. As in the case of Na (*ibid.*, 1951, [A], 209, 368; *M.A.*, 20, 137) marked disagreement with theory was found in the temp. variation of: (1) κ —no evidence being found of the predicted min. at ~80° K. ($T/\Theta \sim 0.25$) and (2) the Lorenz number, $\kappa/\sigma T$. 12 ref.—E. N.

Temperature/Resistance Chart for Electrical Copper. A. E. Maine (*Electronic Eng.*, 1952, 24, (289), 111).—A chart is constructed for determining rapidly the change of resistance with temp. of a unit wound with Cu wire; alternatively, the new temp. may be found from a knowledge of the original temp. and the ratio of the resistance change.—H. Pl.

***Study of an Old [Copper] Bus-Bar.** A. Romwalter and F. Macher (*Acta Techn. Acad. Sci. Hungar.*, 1952, 3, (3/4), 355-357).—[In German]. Comparison of the spectra and metallographic structure of two samples (a) and (b) of a Cu bus-bar, forming part of the D.C. supply system of the Hungarian town of Sopron, through one part of which, (a), D.C. had passed for 30 years while no current had passed through the other part, (b), showed that (a) had suffered no structural or chem. change during the long period of passage of D.C. through it.—J. S. G. T.

***Observations on the Bauschinger Effect in Copper and Brass.** H. Schwartzbart, M. H. Jones, and W. F. Brown, Jr. ([*U.S.*] *Nat. Advis. Cttee. Aeronautics, Research Memo.*, 1951, (E51D13), 37 pp.; *Appl. Mechanics Rev.*, 1952, 5, 398).—For any tensile prestrain between 0.905 and 0.65, the stress at 0.001 plastic strain in subsequent compression is ~0.7 of that at the same scalar strain for simple compression. The stress subsequently rises at a rate that is slower for a larger prestrain and levels off || the compression curve at ~0.01 strain in compression. The subsequent compression stress/strain curve levels off || and below the virgin compression curve by more and more as the prestrain increases. For large tensile prestrains, there is an appearance of a Y.P. in subsequent compression. Stress-relief annealing caused the tension and compression curves following tensile prestrain and heating to approach each other in Cu, indicating relief of residual stress, but both curves were raised in brass, probably owing to strain-ageing. Longitudinally pre-stretched material had different tensile curves in the longitudinal and transverse directions. The difference was similar for isotropic and for cubically aligned sheet. This effect was related to the Bauschinger effect, according to previous work. Since the cubically aligned sheet presumably does not develop residual stresses

* Denotes a paper describing the results of original research.

† Denotes a first-class critical review.

generally overlapping atomic orbitals, corresponding overlap integrals have been neglected in the literature. The construction of molecular orbitals when taking the overlap integrals into consideration is simplified if the orthonormalized functions given by a presented equation are considered as

the real atomic orbitals; the soln. is worked out in detail for various methods of treating mol. and crystals, and it is shown that the overlap effects are responsible for the repulsive forces in ionic crystals and add interesting new features to molecular and crystal properties.—J. R.

6 — CORROSION AND RELATED PHENOMENA

*The Dissolution of Metals Over the Temperature Range 25° to -60° C. II.—The Dissolution of Cadmium in Hydrochloric Acid-Methyl Alcohol-Water Solutions. A. B. Garrett and J. R. Heiks (*J. Phys. Colloid Chem.*, 1952, 56, (4), 449-451).—Cf. *ibid.*, 1950, 54, 437; *M.A.*, 19, 5. Data have been obtained for the rate of dissoln. of Cd in methanol-water-hydrochloric acid soln. under static and dynamic conditions, in the presence and absence of a depolarizer over the temp. range 25° to -60° C. The energy of activation of the static depolarized process is in the order of 4000 cal./mole and of the non-depolarized process is ~10,000 cal./mole. The non-depolarized dissoln. process is first-order with respect to the acid concentration.—D. M. D.

Chromium Carbide Provides High Corrosion-Resistance. J. D. Kennedy (*Steel*, 1952, 131, (5), 92-94).—Describes a new sintered product contg. Cr carbide 83, WC 2, and Ni 15%. Its properties include high abrasion and heat resistance, and high corrosion-resistance to H₂SO₄.—E. J.

*The High-Temperature Oxidation of Some Cobalt-Base and Nickel-Base Alloys. A. Preece and G. Lucas (*J. Inst. Metals*, 1952-53, 81, (4), 219-227).—A description is given of the oxidation characteristics of Co and Ni, and of a number of alloys based on these metals, in the temp. range 800°-1200° C. A simple apparatus was designed to supply an atmosphere similar in compn. to that produced in gas turbines, paraffin contg. 2% S being used as fuel. Reactions occurring within the scales are compared with those that take place when mixtures of oxides are heated at similar temp. Of the reactions noted, spinel formation is shown to be detrimental to the formation of a protective oxide layer. The effects of a number of minor alloying elements, viz. V, B, Nb, Be, Ti, Zr, Ca, Ta, Al, Ce, Si, and Th, on the oxidation of a Co-32% Cr alloy are described. Several elements increased the resistance to oxidation, in particular Th and Si; V and B, however, were highly deleterious, owing to the formation of low-m.p. oxides. The rate of oxidation of Co shows a sharp decrease in the region of 950° C., and this coincides with the upper limit of stability of Co₃O₄. It appears that the presence of this oxide at the outer surface of the scale increases the rate of O transfer to the underlying CoO. From a consideration of scale structure and the occurrence of internal oxidation in a number of the alloys, it is suggested that O diffusion through the scale occurs to a considerable extent.—AUTHORS.

*Corrosion-Resistance of Copper Alloys Containing Chromium [and Nickel]. Tetsutaro Mitsubishi and Manabu Ueno (*J. Mech. Lab. (Tokyo)*, 1950, 4, (2), 50-53).—[In Japanese]. A report on the corrosion-resistance of Cu-base alloys contg. Cr 5-25 and Ni 5-25%.—AUTHOR.

*Scaling of Lead in Air. Elmer Weber and W. M. Baldwin, Jr. (*J. Metals*, 1952, 4, (8), 854-859).—A study has been made of the oxidation of Pb (~99.94%) at temp. of 250°-800° C., i.e. covering both the solid and the quiescent liq. metal, X-ray analysis being used to determine the nature of the oxide films formed. Solid Pb, between 254° and 321° C., obeys a single parabolic law of wt. increase/time, the scale formed being β (red, tetragonal) PbO. Liq. Pb scales according to three successive parabolic relations, the time of transition becoming shorter with increasing temp. The first parabola has a low const.; the scale (sooty black in colour) is thin and yields diffraction lines of Pb₂O₃, Pb, and α (yellow, orthorhombic) PbO. The second parabola has a much higher const.; the scale contains Pb₂O₃, and β - or ($\alpha + \beta$)-PbO, according as to whether the temp. is < or > 486° C. (the equilibrium temp.

of β - and α -PbO), resp. The third parabola has a const. only slightly lower than that of the second; the scale consists of β -PbO if formed below 486° C. or ($\alpha + \beta$)-PbO if formed above. The results are discussed in relation to those of Gruhl (*Z. Metallkunde*, 1949, 40, 225; *M.A.*, 17, 418), but no mention is made of the more recent work of Hofmann and Mahlich (*Werkstoffe u. Korrosion*, 1951, 2, 55; *M.A.*, 19, 603). 18 ref.—E. N.

*Electron-Diffraction Study of Nickel Surfaces Tarnished in the Course of Heat-Treatment in Hydrogen. Shiro Ogawa and Denjiro Watanabe (*Sci. Rep. Research Inst. Tohoku Univ.*, 1952, [A], 4, (1), 41-47).—[In English].—Ni plates for use in vacuum tubes, annealed in H at ~900°-1000° C. often tarnish and acquire a milk-white appearance, which considerably reduces their commercial value. This tarnishing and the milk-white appearance have been shown by electron-diffraction studies to be due to the presence of silicates of light metals. Silicates, e.g. (Mg, Ca)SiO₃ and Mg₂SiO₄, must be removed during melting, as if even a small amount remains dispersed throughout the material, it may gradually collect in the grain boundaries during heat-treatment of the Ni and cause tarnishing of the surface.—J. S. G. T.

Material Problems in Chemical Process Equipment [Use of Tantalum and Titanium]. L. Piatti (*Sulzer Tech. Rev.*, 1952, (1), 21-34).—In a general description of the problems of materials for the chem. industry, the corrosion and erosion attack of ferrous and non-ferrous alloys is discussed. Included in the survey are details of the use of Ta and Ti.—J. J.

*Studies in the Corrosion of Metals Occasioned by Aqueous Solutions of Some Surface-Active Agents. III.—Tin. T. K. Ross (*J. Appl. Chem.*, 1952, 2, (9), 526-531).—Cf. Holness and R., *ibid.*, 1951, 1, 158; *M.A.*, 19, 36. [Part II deals with mild steel.] The action of dil. aq. soln. of representative anionic, cationic, and non-ionic wetting agents on sheet Sn has been studied, using (1) distilled water and (2) London tap-water with and without Zeolite softening treatment. The effects of varying the temp. and pH of the soln. were also investigated. Most of the anion-active agents were corrosive towards Sn, exceptions being sulphonated castor oil, which was practically inactive, and Na alkylarylsulphonate, with which attack was very slight. With two of the cationic compounds moderate corrosion, increasing with increasing concentration, was noted, but no attack on Sn immersed in triethanolamine soln. was observed, though a precipitate of Mg(OH)₂ was deposited on the Sn when these soln. had been made up with tap-water. The sample of the non-ionic group examined produced no measurable attack, but the whole surface of the Sn specimens was in many cases covered with coloured films after immersion. In general, tap-water soln. were less corrosive than those in distilled or softened water, and the effects of pH changes were very variable. The results are graphically expressed, and a mechanism is suggested.—J. R.

*Study of [Corrosion of] Zinc Casting Alloys. Kazuo Katori and Kingo Naoki (*J. Mech. Lab. (Tokyo)*, 1952, 6, (1), 26-30).—[In Japanese]. Cf. *ibid.*, 1950, 4, 268. An investigation of cracking phenomena on test-pieces exposed to air for 3 years is reported. Results differed considerably from those obtained in steam tests for 100 hr., and the difference increased with poorer qualities of alloy. Mg content of the alloy had little effect.—AUTHORS.

[Corrosion-Resistance of] Metals for High-Pressure Hydrogenation Plant. G. A. Nelson (*Trans. Amer. Soc. Mech. Eng.*, 1951, 73, (2), 205-211; discussion, 211-213).—After exposure for about one year to a temp. of 500° C. and a pressure of 2840 lb./in.² in an NH₃ catalyst chamber, the Hastelloys

band saws are described, and details are given of tooth spacing, cutting angles, &c. Figures are then given for recommended cutting speeds appropriate to various alloys, and suitable cutting lubricants are mentioned. For circular saws a high-speed steel with a hardness around Rockwell 60C is preferred. With a double-relieved blade thicknesses up to 300 mm. dia. can be cut with a blade 2 mm. thick. The latter part of the account is devoted to a detailed description of various blades and saws, including small portable saws for site use and large automatic saws, either mech. or hydraulically operated, such as would be used for billet cutting.—A. W. B.

Fabricating Aluminium Washing Machine Tubs.—*Canad. Metals*, 1952, 15, (2), 46.—A brief note.—W. A. M. P.

Titanium Sheet-Metal Parts Successfully Made. Andrew N. Eshman (*Iron Age*, 1952, 170, (3), 132-135).—Commercially pure RC-70 and RC-130A Ti alloys are fabricated for fuselage sections in place of stainless steel where operating temp. are $>800^{\circ}\text{F}$. (425°C).—J. H. W.

Titanium: It Can Be Forged and Drawn. Carter C. Higgins (*Steel*, 1952, 131, (10), 92-93).—Using the same dies as those used for other materials, Ti can often be cold pressed satisfactorily. Existing Ti alloys cannot be deep-pressed, however, and more pressure is usually required. H. also details other properties of Ti and its alloys.—E. J.

Calculations on the Influence of Friction and Die Geometry in Sheet Drawing. A. P. Green and R. Hill (*J. Mechanics Physics Solids*, 1952, 1, (1), 31-36).—A review is first given of the theory of sheet drawing through smooth dies. The results have been extended in some cases empirically, to determine the limits of reduction, and are summarized by empirical formulæ. The pressure distribution over the die is also discussed, and finally rough dies are considered, with empirical formulæ for drawing stress and die pressure.—E. O. H.

Springback: Problem in Metal [Sheet] Forming. Frederico Strasser (*Steel*, 1952, 131, (5), 90-91).—The factors are considered upon which the amount of springback depends during forming and bending of sheet. Various remedies such as overbending, restriking, and the use of special dies are given.—E. J.

Does New Process Challenge Foundries? Lorne Frame (*Canad. Metals*, 1952, 15, (3), 28-29).—A cored forging and pressing process is described. Several advantages are claimed over casting and forging: (1) no waste metal, (2) no rejects, (3) machining time reduced or eliminated, (4) parts can be made lighter and smaller, yet of higher tensile strength, and (5) complexity of design is only limited by the die.—W. A. M. P.

Saving Material by Cold Forming. J. R. Fawcett (*Mech. World*, 1952, 131, (3393), 168-170).—The advantages are discussed of cold heading, cold extrusion, and other cold-working operations for the prodn. of small metal parts.—R. W. R.

***Calculation of the Forces Operative in a Rolling Mill.** A. Geleji (*Acta Techn. Acad. Sci. Hungar.*, 1951, 2, (1), 123-142).—[In German]. In continuation of previous work (*ibid.*; 1950, 1, 78; *M.A.*, 19, 155) formulæ are derived for calculating the resistance to change of shape, the operative pressure, and the power requirements of a rolling mill. A comparatively simple method for determining the distribution of the resistance to deformation is developed, and it is shown how roll-turning moment, together with other characteristics of the rolling process, can be derived from the diagram representing the distribution of the resistance to deformation.—J. S. G. T.

***Measurement of Strip Tension in Tandem Mills.** R. B. Sims (*Engineering*, 1952, 174, (4517), 232-233; (4518), 262-264).—*Cf. M.A.*, 19, 156, 323. A relationship between the tension in a strip passing inelastically over a roller, and the resulting thrust on the roller, is deduced, and shown to be in reasonable agreement with experimental results. The theory is used in the design and construction of a deflection roller-type tensiometer, which has been calibrated against a standard type instrument for strip thicknesses varying from 0.015 to 0.110 in. An accuracy of $\pm 5\%$ is obtained over the complete range. An indust. form of the tensiometer for dealing with strip up to 56 in. wide, is described.—D. K. W.

***Study on the Back-Tension Drawing Method. II.—The N.N.S.-Type Back-Tension Drawing Machine.** Kenichi Nakamura and Osamu Nishimura (*J. Mech. Lab. (Tokyo)*, 1950, 4, (3), 118-125).—[In Japanese]. The power necessary for drawing, the angular velocity of the drawing drum and the drum giving back tension, and the relation between the drawing force and the back tension force in a N.N.S.-type back-tension drawing machine have been calculated. Results show that: (i) the relation of the angular velocities varies with the reduction ratio, (ii) the back tension/drawing force ratio remains const., and (iii) less power is required in this type of machine than in a machine in which back tension is supplied by a brake or dead weight.—AUTHORS.

Machinability of Metals. Francis W. Boulger (*Canad. Metals*, 1952, 15, (2), 52).—A brief discussion of the properties of metals and alloys considered to be important in machining.—W. A. M. P.

***The Size-Effect in Metal Cuttings.** W. R. Backer, E. R. Marshall, and M. C. Shaw (*Trans. Amer. Soc. Mech. Eng.*, 1952, 74, (1), 61-71; discussion, 71-72).—A cutting process involving the formation of very small chips at high cutting speeds (micromilling) was investigated, and the results are applied to the study of the grinding operation. The shear energy involved in grinding is compared with that in turning, micromilling, and the tensile test, and a significant increase in shear energy is observed with decrease in specimen (chip) size. The shear stress involved in grinding metals under mild conditions is found to correspond to the theoretical strength, which is $\sim 1.8 \times 10^6$ lb./in.² for steel. The grit depth of cut is shown to be a more important variable in the interpretation of grinding data than the mere conventional wheel depth of cut.—H. Pl.

***Cutting Temperature and Metal-Cutting Phenomena.** B. T. Chao and K. J. Trigger (*Trans. Amer. Soc. Mech. Eng.*, 1951, 73, (8), 777-787; discussion, 787-793).—Many changes during the cutting of metals are due to the change in tool/chip interface temp. through its influence on the tool/chip friction. Cutting forces and cutting temp. were observed during conventional turning and orthogonal cutting under identical conditions, and the higher heat-dissipating capacity of the tool in orthogonal cutting operations was found to be fundamentally responsible for the observed differences. The tool/chip contact area is an important factor influencing interface temp. A decrease in contact area is associated with an increase in the interface temp. This area is larger in orthogonal cutting than in conventional turning at const. cutting speed. When used for cutting steel, WC tools cause higher cutting forces, higher coeff. of friction, larger tool/chip contact area, and lower interface temp. than triple carbide tools under otherwise const. cutting conditions.—H. Pl.

***An Analytical Evaluation of Metal-Cutting Temperatures.** K. J. Trigger and B. T. Chao (*Trans. Amer. Soc. Mech. Eng.*, 1951, 73, (1), 57-66; discussion, 66-68).—The average tool/chip interface temp. is calculated by considering the mechanism of heat generated during metal-cutting operations in which a type 2 chip is formed. The analytical results agree well with those obtained by test methods, and the theoretical analysis has yielded some important phys. quantities and measurements which affect cutting temp. 18 ref.—H. Pl.

***Basic Factors in Hot Machining of Metals.** E. J. Krabacher and M. E. Merchant (*Trans. Amer. Soc. Mech. Eng.*, 1951, 73, (8), 761-768; discussion, 768-776).—Two main factors oppose each other in their effect on tool life in hot machining. These are the increased ease with which the heat-softened tool material can be abraded away and the decreased ability of the heat-softened chip and the work-piece to produce such abrasion. It was found that these two factors can be evaluated roughly from tool-temp. data taken in combination with data on the mechanics of cutting. In the discussion some criticism is made of the use of Trigger and Chao's (*ibid.*, (1), 57; preceding abstract) equation for calculating the chip/tool interface temp., as it is argued that the carbide tool is submerged only for short intervals of time.—H. Pl.

25 — BOOK REVIEWS

Studies in Large Plastic Flow and Fracture, with Special Emphasis on the Effects of Hydrostatic Pressure. By P. W. Bridgman. (Metallurgy and Metallurgical Engineering Series). 9 × 6 in. Pp. x + 362, with 169 illustrations. 1952. New York: McGraw-Hill Book Co., Inc. (\$8.00); London: McGraw-Hill Publishing Co., Ltd. (76s. 6d.)

In this volume is collected the work of Professor Bridgman on plastic deformation and fracture of many kinds of materials under a wide range of complex stress conditions. It is very natural that much of the work involved a superimposed hydrostatic pressure, since Bridgman's name has become automatically associated in most scientists' minds with the investigation of high-pressure phenomena.

Much of the work has been reported elsewhere, but has not been readily available to the general public. This book, which collects the results of Bridgman's experiments over at least the last twelve years and presents them in a coordinated whole, is welcome for this reason alone. The value of the book, however, goes much further than this. For in submitting materials to various stress combinations and superimposing hydrostatic compressive stresses of such magnitude as only he is capable of, Bridgman has opened a new field of investigation. While his results are not such that they can be used to confirm or contradict the fundamental theory of plasticity, they suggest a very great range of profitable experimental investigations.

Bridgman has confined himself to reporting the results of his own work, and the reader must not look for a critical survey of the work of others in the field of plastic deformation.

The early chapters describe a very great number of tensile tests, both simple tension and two-dimensional, under hydrostatic pressure, and the now-famous work on necking under pressure is dealt with in detail.

A great range of compression tests are reported also, and such processes as ball hardness testing, punching, wire drawing, and extrusion, all under high pressure, form a fascinating study.

The later chapters give an account of experiments in which materials were subjected to various stress combinations after some measure of prestraining had been previously carried out. A final chapter called "Gathering up the Threads" makes remarkably good reading and shows deep insight into the problems and the fundamentals of plastic flow.

HUGH FORD.

Metallurgical Engineering. Volume I.—Engineering Principles. By Reinhardt Schuhmann, Jr. (Addison-Wesley Metallurgical Series). 9½ × 7½ in. Pp. ix + 390, illustrated. 1952. Cambridge (42), Mass.: Addison-Wesley Press, Inc. (\$7.50.)

In these days of international standardization one can almost envisage a conference called to discuss the various definitions of Metallurgical Engineering. The present book, based on lectures to students at the Massachusetts Institute of Technology, is the result of a recognition of the need to reorganize instruction in extractive metallurgy. This change of outlook is apparently partly due to the tendency of chemical engineers to be more useful than metallurgists even in the extractive metallurgical industry, owing to their better grasp of basic principles and their ability to apply these principles quantitatively to practical problems. The three objectives of the book are to present the subject according to principle rather than metal treated, to integrate the underlying science of physical chemistry with metallurgical engineering, and to place greater emphasis on analysis and quantitative solution of problems.

With regard to the subject matter of the book, a general discussion of the unit processes of chemical metallurgy is followed by a consideration of the application of some of the elementary physical and chemical laws to various processes

to obtain a materials balance and a heat balance. Further chapters are devoted to the properties of various fuels, combustion conditions, heat utilization, and recuperator design, as well as problems of heat flow under steady and fluctuating conditions. The inclusion of a chapter on fluid flow indicates a proper appreciation of the importance of this subject in view of the number of processes where tremendous quantities of gases are involved. The properties of phases encountered in pyrometallurgical operations are discussed, including questions of gas solubility in metals and the nature and the behaviour of slags. The final chapter gives a useful account of refractory materials and the factors which influence their selection under different conditions.

On the whole, the author successfully avoids the inherent danger in a book of this kind of introducing difficult scientific ideas to explain technical matters, but it is felt that there is a certain inconsistency in the amount of knowledge which the student is expected to possess. For example, concepts such as kinetic and potential energy are explained, whereas a knowledge of the phase rule and the principles of equilibrium diagrams are assumed. The book is intended for students, and there are numerous worked examples illustrating the various principles with plenty of problems to be solved at the end of each chapter and adequate references for further reading. The topics which are included are in general well presented, and the outlook of the author is to be commended, but the scope of the book is almost inevitably not as comprehensive as the title might suggest.

N. SWINDELLS.

Corrosion: Causes and Prevention. By Frank N. Speller. Third edition, revised. 9 × 6 in. Pp. xiii + 686, with 181 illustrations. 1951. New York: McGraw-Hill Book Co., Inc. (\$10.00); London: McGraw-Hill Publishing Co., Ltd. (85s.)

Those familiar with the earlier editions of this book will have no difficulty in recognizing their successor. The same general treatment has been used, although chapters on biological influences and on cathodic protection have been added and an attempt has been made to bring the information up to date, or at least up to 1948. Strangers to the earlier editions need to know that the book is concerned almost wholly with ferrous metals, non-ferrous metals appearing only as coating materials for steel; that it is divided into an outline of general principles and a description of the application of knowledge to some practical problems; and also that it is well written in terms easily understood by those without specialized knowledge.

By the clear presentation, in previous editions, of material not then collected elsewhere, Dr. Speller did much to promote the vigorous growth of the subject which has made his own task in preparing a new account an extremely difficult one. The revision has not been sufficiently drastic to produce a well-balanced picture of our present knowledge of corrosion. This is partly due to an excessive reliance on American sources, though some matters commercially important on both sides of the Atlantic receive only slight attention. For instance, tinplate is mentioned only as a possible roofing material. Again, the author's evident desire to show historical developments has led to the retention of too much detail about early work to permit the clear presentation of recent findings, and sometimes the more recent ideas are not adequately related to some of the older observations. Thus, although biological influences are dealt with in a separate chapter, their probable contribution to many of the results quoted in the chapter on corrosion by soil is not mentioned.

Even if the picture is incomplete and not too well balanced, however, the general outline is good, and some of the detail is very clear, as in the sections dealing with steam-raising plant and heating systems. Although the specialist corrosion



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