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The Journal of the **INSTITUTE OF** **METALS**

and **METALLURGICAL ABSTRACTS**



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JULY 1946

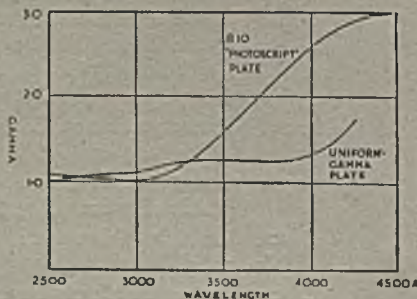
Spectrographers have asked for it!

- CONTRAST ALMOST UNIFORM OVER THE WAVELENGTH RANGE USED IN SPECTROGRAPHY
- CONTRAST AMPLE FOR SPECTROGRAPHY — UP TO GAMMA 1.6
- SPEED CONVENIENT FOR SPECTROGRAPHY — ABOUT HALF THAT OF THE 'KODAK' B.10 PLATE
- EXTREMELY RAPID PROCESSING
- ROBUST EMULSION COATING

THE KODAK UNIFORM-GAMMA PLATE

Most routine industrial spectrography is carried out in the ultra-violet between 2500Å and 4200Å. Over this region the photographic emulsion does not normally show uniform contrast — the gamma value rising typically from about 1.0 at 3200Å to the normal gamma value for white light, usually 3.0 or higher, as the visual is approached. For this reason it has been necessary in analytical practice to calibrate spectrographic exposures individually for the particular wavelength to be studied. It has long been recognised that spectrographic analysis could be simplified if a photographic material were available having a contrast characteristic uniform enough to permit comparisons at different wavelengths. Such a plate is now available for the first time in the 'Kodak' Uniform-Gamma Plate.

This new plate has an almost uniform contrast over the wavelength range specified, as shown by the comparison curves in the diagram. In addition, the new plate can be processed, washed and dried in an extremely short time, yet is of very robust type. Its speed in the ultra-violet (at 3000Å) is about half that of the B.10 'Photocrypt' plate and it gives a gamma of 1.0-1.6, according to the conditions of use. The 'Kodak' Uniform-Gamma Plate is marketed (in the usual spectrographic sizes) as an addition to the range of 'Kodak' Special Plates for Scientific Purposes — which already comprises 85 combinations of colour sensitiveness and speed.



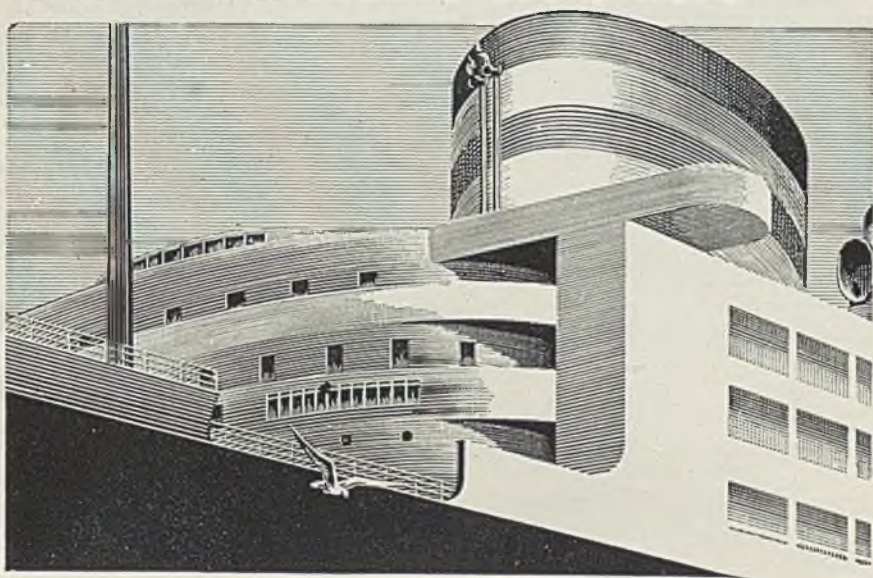
For further particulars see 'Spectrographic Plates of Substantially Uniform Contrast in the Ultra-Violet' by E. P. Davey and (Miss) D. M. Gauntlett — *Jnl. Soc. Chem. Ind.*, March, 1945. Vol. LXIV. pp. 70-72.

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The two curves above show the almost uniform contrast value (gamma) obtained with the 'Kodak' Uniform-Gamma plate over the wavelength range used in spectrography, by comparison with the steeply rising increase in contrast given by the B.10 'Photocrypt' plate — this latter is typical of normal photographic emulsions.

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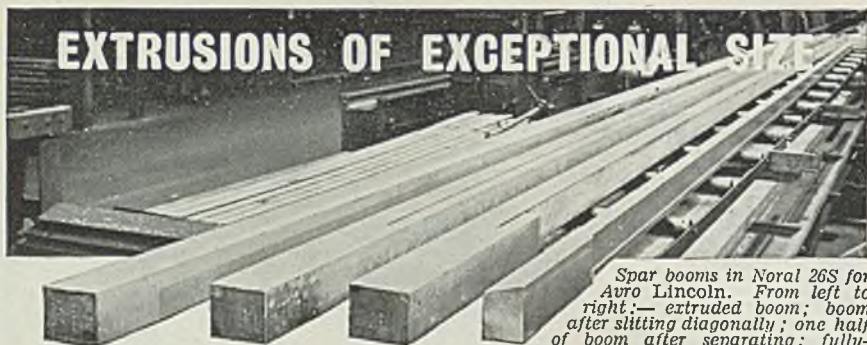
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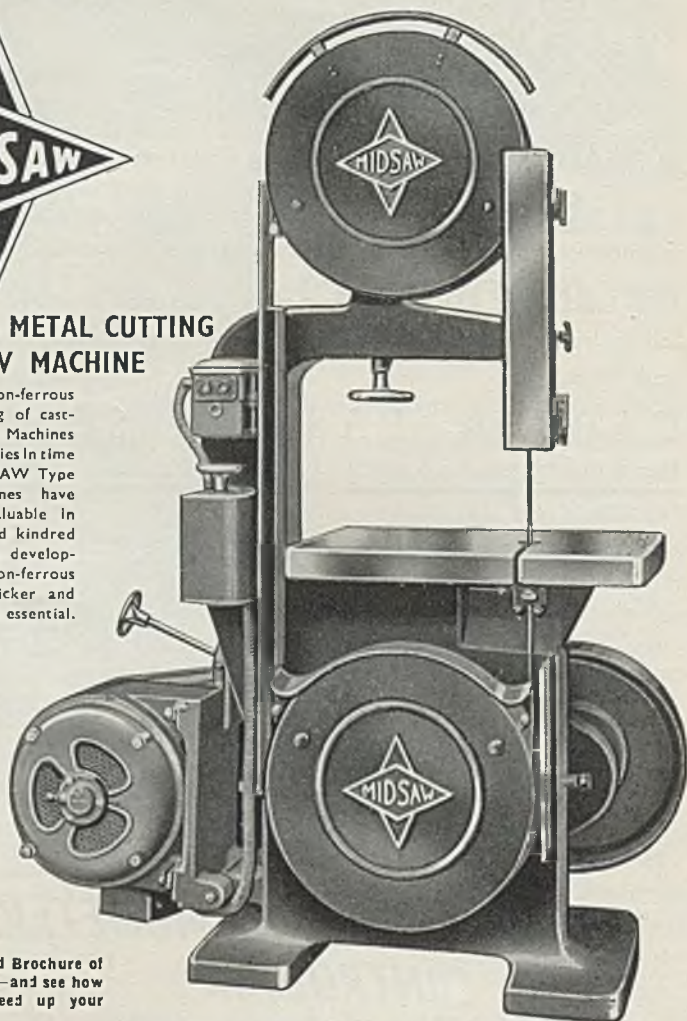
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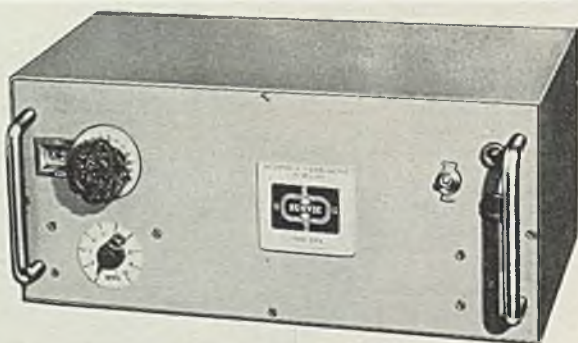
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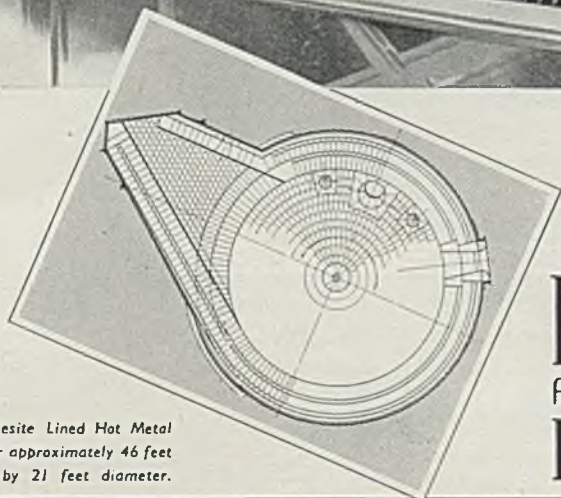
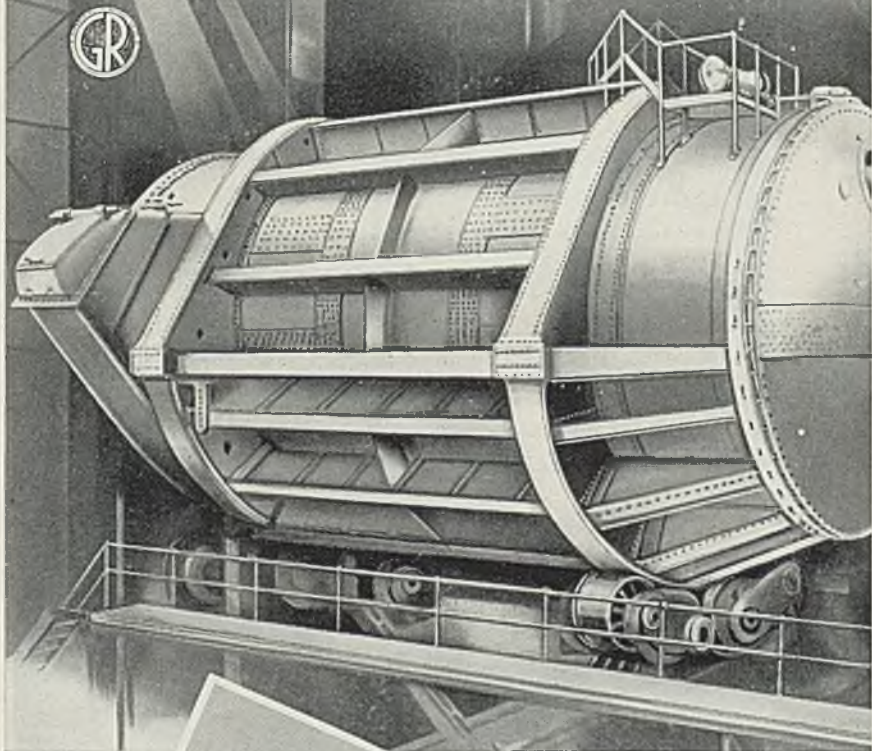
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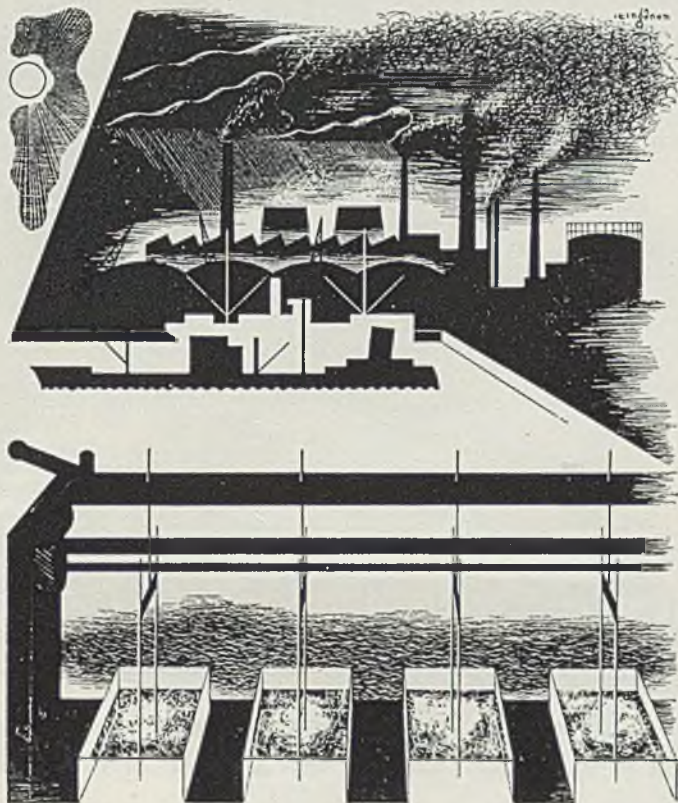
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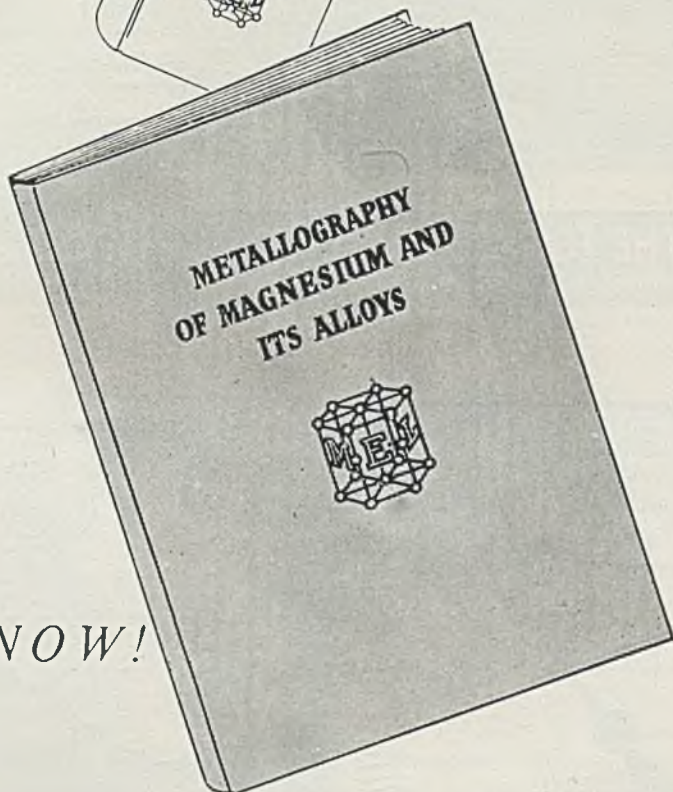
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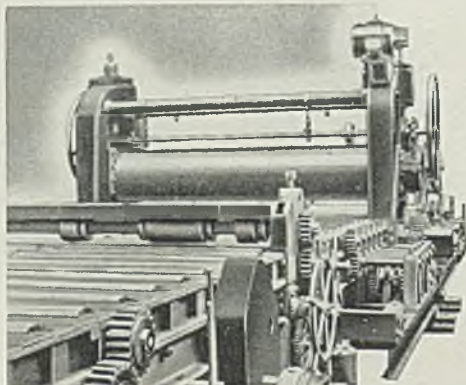
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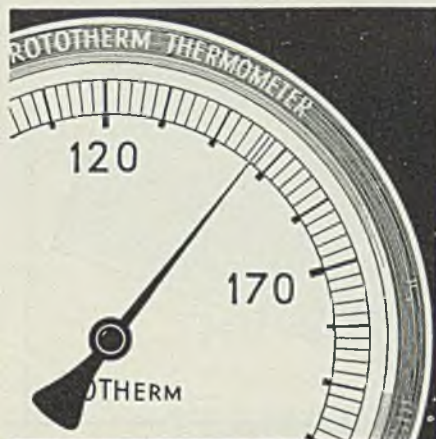
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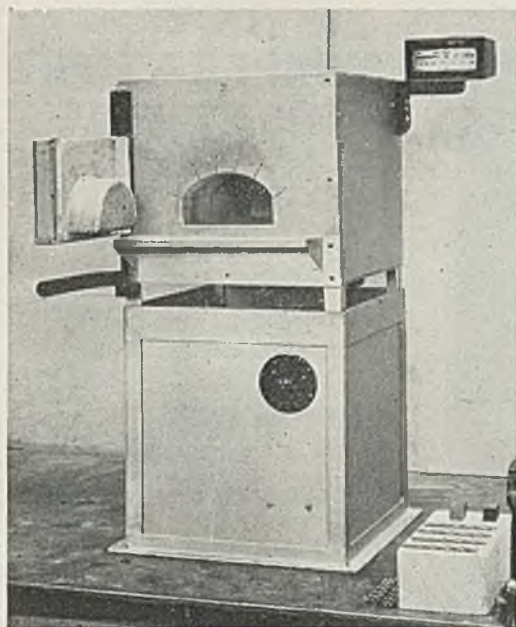
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JULY 1946

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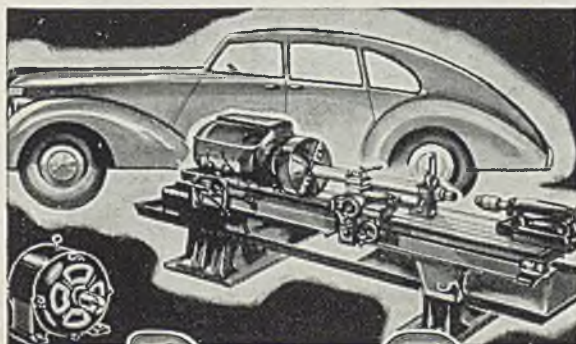
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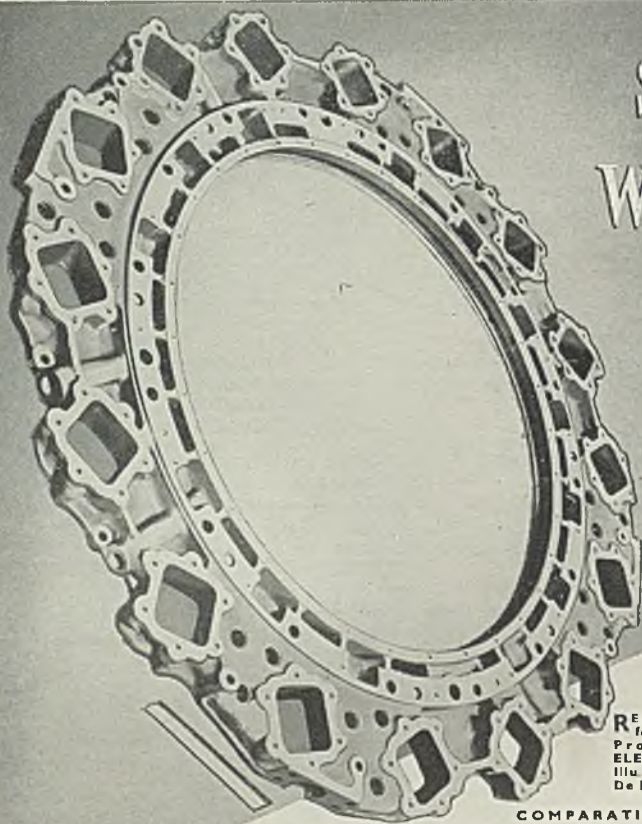
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July, 1946.

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Autumn Meeting, London.

September 10 and 11, 1946.

As already announced, the Thirtieth Eighth Annual Autumn Meeting of the Institute will be held on Tuesday and Wednesday, September 10 and 11, at the Institution of Civil Engineers, Gt. George St., London, S.W.1.

A luncheon for members will be held on September 11 at the Connaught Rooms, Great Queen Street, W.C.1.

Fuller details will be given in a circular which is being sent to all members.

Fuel Efficiency Conference.

October 8-10, 1946.

As a part of their drive for promoting economy in the consumption of fuel, the Fuel Efficiency Committee is arranging a Conference to be held in the Central Hall, Westminster, on October 8-10.

The Conference will be split up into Sections, each concerned with a group of industries having related fuel problems, and the Committee hopes that members of the Institute of Metals will take part in the session on the afternoon of Tuesday, October 8, from 2.15 to 5.0, in which leaders of the iron and steel, non-ferrous metals, and glass industries are collaborating. Dr. C. H. DESCH, F.R.S., will be in the Chair at this session, and the President of the Institute (Col. P. G. J. GUETERBOCK) will make an introductory statement. Papers of interest to members will be read by Professor L. AIRCHISON and Mr. FRANK HUDSON.

The provisional programme and invitations to the Conference will be circulated in the July issue of *Fuel Efficiency News*.

LETTERS TO THE EDITOR

Report of the Committee on Future Policy.

"I have read with interest the "Report to the Council of the Committee on Future Policy" and fully agree with the views expressed in the Conclusion. I should like to comment, however, on the method of election of Officers and Council, with particular reference to item (iii) on p. xxv of the *May Journal*.

The Committee has obviously given anxious thought to the nominations being made in the most democratic way, and has recommended that biographical notes on nominees appear only after they have been elected. I suggest that it would be more democratic to publish notes on all nominees before the election.

I think the Institute must contain many members like myself who are unable to take a very active part in it, but who do take an interest in its affairs through the *Journal*. The knowledge such members have of the active membership is limited, and voting becomes very difficult if no biographical notes are supplied. If the Council's nominees are indicated as such and no notes are available, it seems to me that the Council's nominees will have a distinct advantage, which is contrary to the best democratic principles. Alternatively, a large body of members will be voting blindly in a manner which cannot be in the best interests of the Institute.

I do hope this recommendation will be reconsidered from the point of view of members like myself.

Yours faithfully,

W. L. KENT (Member).

Warrington.

June 1946.

News and Announcements

Stress-Corrosion.

SIR,

I was interested to read Dr. Chaston's letter on "Stress-Corrosion" in the April issue of the *Journal*.

To my mind the intercrystalline attack on metals by certain specific reagents is one of the fundamental problems of physical metallurgy, and careful experiments will, I feel, yield valuable results. In this connection it appears to me that co-ordinated attack by several laboratories would be better than a number of isolated and unco-ordinated investigations. We are at present carrying out some preliminary experiments using a very pure lead which has been specially prepared for us. An advantage in using lead is that one can obtain the metal in commercial quantities of a high order of purity, and it has properties at ordinary temperatures which other metals possess at higher temperatures. The line of attack which we propose is to subject lead in a stressed and unstressed condition to the influence of solutions containing various ions and also of gases and metal vapours. Later we shall investigate the effects of solutes in the lead. I should be glad to hear of any similar work which is projected in England.

Yours faithfully.

J. NEILL GREENWOOD.

(Corresponding Member to the
Council for Australia).
Research School of Metallurgy,
University of Melbourne.
July 1, 1946.

PERSONAL NOTES

IN the recent Birthday Honours knighthoods were conferred on Dr. W. T. GRIFFITHS (Immediate Past-President), Chairman and Managing Director of The Mond Nickel Company, Ltd.; Mr. A. J. G. SMOUT, J.P. (Vice-President), lately Director-General of Ammunition Production Supply, Ministry of Supply; and Dr. C. C. PATERSON, O.B.E., F.R.S. (Member), Director of the Research Laboratories, General Electric Company, Ltd.

Dr. M. L. BECKER (Member) has been appointed Superintending

Metallurgist to the British Iron and Steel Research Association. For the last few years Dr. Becker has been Chief Metallurgist (Gear and Tool Division), Messrs. David Brown and Sons (Huddersfield), Ltd., and formerly he was at the National Physical Laboratory.

Mr. D. C. G. LEES, M.A. (Member), has joined the staff of Industrial Newspapers, Ltd., as associate editor of *Metal Treatment*. For the last six years Mr. Lees has been an investigator with the British Non-Ferrous Metals Research Association, and the results of some of his work there are contained in a paper published in the May issue of the *Journal*, entitled "The Hot-Tearing Tendencies of Aluminium Casting Alloys."

Mr. A. R. E. SINGER, B.Sc. (Member), and Dr. V. KONDIC, B.Sc. (Member), have been appointed lecturers in Industrial Metallurgy in the University of Birmingham. Mr. Singer will deal particularly with wrought metals and their production, whilst Dr. Kondic will specialize in the melting and casting of metals. Dr. Kondic has been part-author (with Dr. W. T. Pell-Walpole) of several papers on the melting and casting of bronzes that have been published in the *Journal* in the last few years, the latest of them appearing in the May, 1946, issue. Mr. Singer has recently been engaged as principal investigator in a research team dealing with the welding of light alloys; he is the co-author (with Mr. S. A. Cottrell) of a paper on aluminium-silicon alloys which will be published in the *Journal* shortly.

SIR EWART SMITH (Member) has now left the Ministry of Supply and returned to Imperial Chemical Industries, Ltd.

Mr. H. J. SMITH (Member) has resigned his position as Chief Engineer and Technical Director of Ether, Ltd., Birmingham, and has formed the Industrial Pyrometer Company, 29 Vittoria Street, Birmingham 1, to manufacture indicating pyrometers and thermocouples.

Dr. W. H. J. VERNON (Member), of the Chemical Research Laboratory (D.S.I.R.), Teddington, has been awarded the O.B.E.

SOME ANOMALIES AND SOME REFINEMENTS 1028 IN THE DIAMOND PYRAMID HARDNESS TESTING OF HEAVILY COLD-ROLLED STRIP.*

By THOMAS B. CROW,† Ph.D., MEMBER, and JOHN F. HINSLEY,‡
MEMBER.

SYNOPSIS.

The work described is primarily concerned with diamond pyramid hardness determinations on heavily cold-rolled strip, though part of it has general application. The conditions under which it may be not inaccurate to report a diamond pyramid hardness number from the measurement of one diagonal only have been studied, and the use of the geometric mean of the diagonals has been considered. The difference in length of the diagonals in any one indentation has been correlated with the load and with the directional properties of the strip.

Attention has been directed to the serious errors in diamond pyramid hardness which may result from neglecting to take convexity into account. The geometric form of the bulge curve has been examined, and the results applied to calculations of area. The geometry of the diamond indentation has been studied in detail, and a technique of refined measurement and calculation developed.

A comprehensive table of "corrected" hardness numbers, based on the authors' findings, has been compiled, and the desirability of introducing certain modifications and amplifications into British Standard Specifications Nos. 427 and 485 has been considered.

This investigation has been limited to practical issues; its extension along further lines (as, for example, to "concavity" and to the corresponding effects in Brinell hardness testing), has not been overlooked.

I.—PRELIMINARY.

THROUGHOUT this report, use will be made of the following descriptive expressions, which are based upon the assumption that the observer is seated, facing north, behind the Vickers machine :

N-S diagonal.

W-E diagonal.

D/R = N-S or W-E (square lie).

D/R = NW-SE or NE-SW (oblique lie).

The N-S and W-E diagonals are those which are formed in a north-south and a west-east direction, respectively. D/R = N-S means that the rolled strip under test was placed upon the anvil so that its direction of rolling was north and south. D/R = NW-SE similarly indicates

* Manuscript received December 10, 1945.

† Emery Brothers, Ltd., Birmingham 6.

‡ Edgar Allen and Company, Ltd., Sheffield.

a north-west to south-east setting. The two other settings are likewise described. Alternative descriptions of the orientation of the test-piece in relation to diagonal direction, are "square lie" and "oblique lie." The rolling direction was permanently marked on each test-piece by scribing a straight scratch upon its prepared surface. In Figs. 2-5 (Plates XXXVII-XL) this scratch separates two indentations, that on the left being made with a square lie, whilst that on the right was made with an oblique lie.

II.—INTRODUCTION.

The circumstances which led to the present investigation were as follows:

(1) The observation, during routine diamond pyramid hardness tests upon heavily cold-rolled phosphor-bronze strip, that when the test-pieces were placed upon the anvil so that $D/R =$ (say) $W-E$, the $W-E$ diagonal was frequently appreciably longer than the $N-S$ diagonal.

(2) A report,¹ which reached one of the authors, that a certain firm was in the habit of positioning their test-pieces so that $D/R = W-E$ and of measuring the $W-E$ diagonal only. Further, A.I.D. Inspection Instruction M 406 (Issue No. 3), para. No. 7, may be intended to apply to diamond hardness tests as well as to ball tests. If this be so, the implication is that the measurement of one diagonal only may be sufficient.

(3) The observation that when a specimen of hard-rolled phosphor-bronze was placed upon the anvil in the oblique lie, both diagonals were found to have substantially the same length² and the hardness number was then very little different from that determined with the orientation as described under (1) above, the arithmetic mean of the diagonals being used in both cases. It was further noticed that the convexity sometimes associated with diamond indentations in heavily cold-worked metals was of considerable size, but only obviously present upon one pair of opposite sides of the impression, giving it a rectangular appearance, with the "long" sides straight and parallel to D/R and the short sides bulged. These features are well brought out in Fig. 2(a) (Plate XXXVII). Figs. 2(b) and 2(c) (Plate XXXVII) respectively show a bulged "end" and an unbulged "side" of the right-hand indentation of Fig. 2(a) at 500 magnifications.

(4) The absence, in any relevant British Standard Specifications, of guidance as to (i) the manner of setting up a heavily cold-rolled specimen upon the anvil, and (ii) the extent to which bulge need be considered.

Experimental work was therefore undertaken to ascertain whether

the facts recorded above would apply generally to heavily cold-rolled metals, and, if so, whether an improved testing technique for this class of material could be suggested.

III.—EXPERIMENTAL.

The general scheme of experiment is described below. Short lengths of annealed strip about 0.1 in. thick were obtained from a number of the common industrial cold-rolled metals (see Table III). These were then cold rolled down to a thickness of 0.020 in. without any annealing. At this gauge, test-pieces $\frac{3}{8}$ in. square were guillotined from the parent strip and carefully prepared. Precautions were taken in rolling,

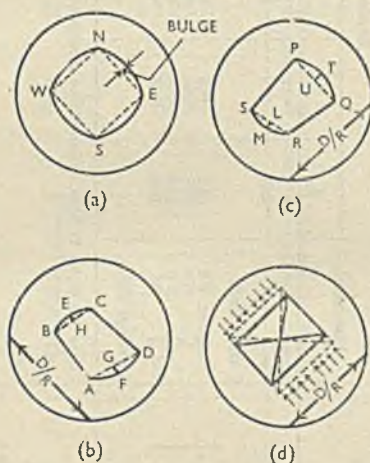


FIG. 1.—Types of Impression.

N.B.—(1) In (a) the N-S diagonal would be the longer if D/R were north to south; likewise the W-E diagonal if D/R were west to east.
(2) The lack of symmetry of impressions in (b) and (c) is exaggerated.

cutting, and preparing the specimens reasonably to ensure that such variations in hardness or in indentation shape as were observed in the subsequent tests were due entirely to the testing technique and/or to the highly directional properties of the material.

Some consideration had to be given to the most suitable load to use. The thickness and the percentage reduction having been fixed, it was decided to use such a load as would give an impression about 0.2 mm. square, whatever the metal under test. This size was very convenient (1) for manipulation on the stage, (2) in locating the image

TABLE I.—*Partial Reproduction of a Typical Test-Data Sheet for Phosphor-Bronze (10-kg. Load).*

Annealed at 0.116 in. Hard rolled to 0.020 in. Reduction = 83%.

		Dimension.	Replicate Tests.					Average.
			1.	2.	3.	4.	5.	
Series I.	D/R = North to South	NS	274	276	278	276	...	276
		WE	260	260	260	260	...	260
		Arith. Mean						268
		Bulge on WS	012	005	007	005	...	007.25
		" WN	008	006	003	004	...	005.25
		" NE	003	006	004	004	...	004.25
Series II.	D/R = East to West	" ES	008	006	007	012	...	008.25
		Average Bulge						006.25
			Data for Series II were obtained and recorded in the same manner as those of Series I, working in the same order.					

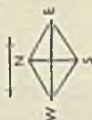




TABLE I—continued.

Series III.	D/R = NE to SW actual		AC	268	268	269	266	...	267.75
			BD	266	264	265	265	...	265.00
			Arith. Mean						266.375
			Bulge on AB	001	002	006	000	...	002.25
			" BC	014	015	015	015	...	014.75
			" CD	000	002	002	004	...	002.00
			" DA	014	015	013	014	...	014.00
			Average Bulge						008.25
			Side AB	188	188	190	189	...	188.75
			" BC	189	188	190	188	...	188.75
			" CD	190	189	189	187	...	188.75
			" DA	185	184	186	185	...	185.00
Series IV.	D/R = NW to SE actual		Data for Series IV were obtained and recorded in the same manner as for Series III, using the letters PQRS in place of CDAB, respectively, and working in the same order.						

N.B.—Dimensions are in "ocular units," i.e., mm./1000.

in the field of view, (3) in saving time in "knife-edge knob twiddling," and (4) for photographic reproduction.

Four series of impressions were made upon each specimen. In Series I and II, the D/R were N-S and W-E respectively; the resulting impressions were rhomboidal in shape, as shown in Fig. 1(a). In Series III, D/R was NE-SW (actual), appearing as NW-SE through the microscope, and in Series IV the D/R was NW-SE (actual). Figs. 1(b) and 1(c) show indentations of the types obtained in series III and IV respectively. These two figures are not mirror images, nor do they illustrate the same indentation before and after 90° rotation on the stage.

Table I is a partial reproduction of a data sheet (of which there were ten—one for each metal examined) and relates to the phosphor-bronze strip. The average values of four or five indentations in each series are shown in column 10, and these form the basis of the hardness calculations to be described later.

Although no serious difference was to be expected between the hardness values of Series I and II, or between those of III and IV (and each pair was finally averaged), the purpose of the apparent duplication of the work (e.g., N-S and W-E setting) was to ensure an automatic cancellation of equal and opposite errors due to what the authors have, for convenience, named *Diamondism*. This is fully defined in the Appendix. It was not considered necessary to check the actual value of θ , the angle between opposite faces of the diamond, since the same diamond was used throughout. Obliquity of application of the load was guarded against by the use of a specially made, parallel-ground, hardened steel anvil.

In this investigation three methods of calculating hardness numbers have been used, all of them based upon the accepted formula:

$$\text{Diamond Pyramid Hardness Number} = \frac{\text{Load}}{\text{Pyramidal Area of Indentation}}$$

though they differ in the method of calculating the pyramidal area.

(1) *Uncorrected Hardness*.—Applicable to Series I to IV, this is based on diagonal measurements only and assumes that the figure is a square or rhombus (4 equal sides with diagonals at right angles). It ignores bulge and asymmetry. If a and b are the lengths of the diagonals, then:

$$H_D = \frac{\text{Load} \times \sin \frac{\theta}{2}}{\frac{1}{2}(a+b)^2} \quad \text{or} \quad \frac{\text{Load} \times \sin \frac{\theta}{2}}{\frac{1}{2}(\sqrt{ab})^2},$$

depending upon whether the arithmetic mean (A.M.) or the geometric

mean (G.M.) of a and b is used. Applying the data of Table I (Series I) to the above formula, we have :

$$H_D = \frac{10 \times 0.9271839}{\frac{1}{2} \left(\frac{0.276 + 0.260}{2} \right)} \quad \text{or} \quad \frac{10 \times 0.9271839}{\frac{1}{2}(0.276 \times 0.260)}$$

$$= 258.2 \quad \text{or} \quad 258.4.$$

(2) *Hardness Corrected (Short Method).*—Also applicable to Series I to IV, this is based upon the calculation of the area of the rhombus or square by the first method (G.M. only) and the addition thereto of four times the area of one bulge (see Part IV). Using the same data from Table I, we have :

$$\text{Length of side of rhombus} = \sqrt{\left(\frac{0.276}{2}\right)^2 + \left(\frac{0.260}{2}\right)^2} = 0.189589 \text{ mm.}$$

$$\text{Area of 4 bulges ("} \frac{2}{3} \text{" basis)}^* = \frac{2}{3} \times 0.189589 \times 0.00625 \times 4 = 0.003160 \text{ sq. mm.}$$

$$\text{Area of the rhombus itself} = \frac{1}{2}(0.276) \times (0.260) = 0.035880 \text{ sq. mm.}$$

$$\text{Total projected area} = 0.039040 \text{ sq. mm.}$$

$$\text{Total pyramidal area} = \frac{0.039040}{\sin 68^\circ} = 0.042106 \text{ sq. mm.}$$

$$\text{Corrected hardness number} = \frac{10}{0.042106} = 237.5.$$

If the bulge area be calculated on the " $\frac{1}{2}$ " basis,* we have :

$$\text{Area of 4 bulges} = \frac{1}{2} \times 0.189589 \times 0.00625 \times 4 = 0.002370 \text{ sq. mm.}$$

which, proceeding in like manner, gives a

$$\text{corrected hardness number} = 242.4.$$

(3) *Hardness Corrected (Long Method).*—This method has been devised to suit impressions of the kind illustrated in Fig. 1(b), i.e., those in which the straight lines joining $ABCD$ do not necessarily form a parallelogram, rectangle, square, or rhombus; the method is therefore applicable to wholly unsymmetrical indentations. Since, of four-sided regular figures, only a square and a rhombus have diagonals intersecting at right angles, it is difficult to see how $ABCD$ can be a rectangle unless its formation results from directional elastic recovery of the material after removal of the load (see Fig. 1(d)). The determination of the area consists of six operations upon the data recorded in Series III or IV. The area of each bulge is determined separately, and that of the quadrilateral by dividing it into two triangles by joining opposite corners and applying the well-known trigonometrical formula :

$$\Delta = \sqrt{s(s-a)(s-b)(s-c)}.$$

* See pp. 468-469.

The six sub-areas are then added together, giving the total projected area. Illustrating this method by the figure and data of Series III (Table I) we have:

$$\begin{aligned} \text{Perimeter of } \triangle ABC &= 0.64525 \text{ mm.} & \text{Semi-perimeter} &= 0.322625 \text{ mm.} \end{aligned}$$

$$\begin{aligned} \text{Area of } \triangle ABC &= 0.017813 \text{ sq. mm.} & \text{Area of } \triangle ADC &= 0.017453 \text{ sq. mm.} \end{aligned}$$

$$\begin{aligned} \text{Total area of 4 bulges} &= 0.000283 + 0.001856 + 0.000252 \\ &\quad + 0.001727 \text{ sq. mm.} \end{aligned}$$

$$\begin{aligned} \text{Total projected area} &= 0.039384 \text{ sq. mm.} & \text{Total pyramidal} & \\ & & \text{area} &= 0.042477 \text{ sq. mm.} \end{aligned}$$

$$\text{Corrected hardness number} = \frac{10}{0.042477} = 235.4.$$

Similarly, calculating on the " $\frac{1}{2}$ " basis, we have a corrected hardness number = 241.7.

These methods were applied to the data of Series I to IV. Detailed results appear in Table V and bracketed results in Table VI. Full consideration of these is deferred.

IV.—CALCULATION OF BULGE AREAS.

A method of approximately correcting for the convexity of the impressions has been described by O'Neill.³ If Fig. 1(a) represents the projected image and b the height of the bulge (mean of four) shown in Fig. 1(a), then, by O'Neill's correction, the projected area becomes approximately $\left(\frac{d}{\sqrt{2}} + b\right)^2$, where d is a diagonal.

Now

$$\left(\frac{d}{\sqrt{2}} + b\right)^2 = \frac{d^2}{2} + 4 \cdot \frac{1}{2} \cdot \frac{d}{\sqrt{2}} \cdot b + b^2$$

and, neglecting b^2 (which is the square of a small quantity), we are left with projected area,

$$= \frac{d^2}{2} + 4 \times (\text{an expression giving the area of one bulge}),$$

which means that the area of one bulge is that of a triangle of height b standing upon a base which is a side of an impression. That is

$$\text{Bulge area} = \frac{1}{2} \text{ base} \times \text{height}.$$

Although this is a useful approximate correction, it was thought desirable to attempt a more accurate evaluation of bulge area. This became a problem of finding an algebraic expression, which, when plotted by means of a convenient system of co-ordinates, would give

a curve which would closely approximate to the shape of the bulge as seen through the microscope. The expression sought should, moreover, be such that the area between the curve and the chord (the chord being the straight line joining two adjacent corners of an impression, *e.g.*, *NE* in Fig. 1(a)), could be easily calculated in terms of the chord length and the height of the bulge, both of which are available.

The first stage, therefore, was to obtain photographic reproductions of a number of impressions on a conveniently large scale. This was achieved by preparing a series of photomicrographs of representative bulges at approximately 500 linear magnifications (see, for example, Figs. 3(b) and 3(c), Plate XXXVIII). The areas between the chord and the curve were then measured very carefully with a planimeter; the chord lengths and the bulge heights were also measured. Since, in this instance, *relative* measurements only are required, the actual scale of magnification is unimportant.

The results of these measurements are set out in columns 1, 2, and 3 of Table II. In column 4, the area of the bulge has been calculated using O'Neill's correction (area = $\frac{1}{2} \times \text{chord} \times \text{height}$). This approximation—which evaluates the area as that of a triangle—is appreciably low and therefore leads to erroneously high values of hardness with the materials concerned.



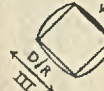
The bulge areas were therefore calculated on the assumption that the bulge contour conformed to various well-known curves such as the circle, parabola, conchoid, and sine curve, and it was found that for ease of calculation (and general close agreement with measured areas) the perimeter may be taken to be part of a parabola.

The area of the segment of a parabola cut off by a chord of length c which is parallel to the tangent at the vertex is $\frac{2}{3} \times c \times h$, where h is the height of the segment. Areas calculated on this basis are tabulated in column 5. The difference of the areas in columns 4 and 5 (respectively) from the corresponding measured areas are given (expressed as percentages of the latter) in columns 6 and 7, from which it will be seen that the parabolic basis is more nearly accurate than the "triangular" approximation, although no dogmatic claim that the curve is in fact a parabola is made. A comparison of the values in rows 2 and 3, 5 and 6, 7 and 8 of Table VI may now be made.

V.—RESULTS.

Table III gives particulars of the materials examined. Qualitative visual examination of indentations of Series I to IV enabled them to be classified into two distinct groups (*X* and *Y*), irrespective of series.

TABLE II.—Comparison of Measured and Calculated Bulge Areas.

Type of Bulge Examined.	Material.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Measured Area, sq. in.	Measured Height, in. (<i>h</i>).	Measured Chord, in. (<i>c</i>).	Calculated Area, sq. in. ($= \frac{1}{2}ch$).	Calculated Area, sq. in. ($= \frac{1}{2}ch$).	Difference, % (1)-(4).	Difference, % (1)-(5).
Series I or II. 	Bronze	0.391	0.155	3.79	0.294	0.392	24.8	0.26 (+)
	Steel	1.050	0.385	4.10	0.789	1.052	24.9	0.19 (+)
	Brass	0.655	0.225	4.41	0.496	0.661	24.3	0.92 (+)
	Copper	0.799	0.305	3.93	0.599	0.799	25.0	nil
	Monel	0.744	0.270	4.00	0.540	0.720	27.4	3.23 (-)
	Nickel	0.636	0.240	3.92	0.470	0.627	26.1	1.42 (-)
	80 : 20 Ni-Or	0.399	0.160	3.93	0.314	0.419	21.3	5.01 (+)
	Birmabright	0.790	0.290	4.08	0.592	0.789	25.1	0.13 (-)
	Gold	0.540	0.205	3.95	0.405	0.540	25.0	nil
	Easy-flo	0.339	0.130	3.73	0.242	0.323	28.6	4.72 (-)
Series III or IV, End Bulge 	Bronze	0.926	0.360	3.93	0.707	0.943	23.7	1.84 (+)
	Steel	1.220	0.470	3.97	0.933	1.244	23.5	1.97 (+)
	Brass	1.083	0.380	4.235	0.814	1.086	24.8	0.28 (+)
	Copper	1.353	0.560	3.80	1.064	1.419	21.4	4.88 (+)
	Monel	1.308	0.500	3.90	0.975	1.300	25.5	0.61 (-)
	Nickel	1.132	0.440	3.875	0.852	1.137	24.7	0.44 (+)
	80 : 20 Ni-Or	0.956	0.320	4.43	0.709	0.945	25.8	1.15 (-)
	Birmabright	1.279	0.490	3.945	0.967	1.289	24.4	0.78 (+)
	Gold	0.850	0.330	3.875	0.639	0.852	25.6	0.81 (-)
	Easy-flo	0.563	0.230	3.75	0.431	0.575	24.1	1.23 (+)
Series III or IV, Side Bulge 	Bronze	0.240	0.100	3.805	0.190	0.254	20.8	5.83 (+)
	Steel	1.019	0.385	3.940	0.758	1.011	25.6	0.79 (-)
	Brass	0.301	0.105	4.345	0.228	0.304	24.3	1.00 (+)
	Copper	0.940	0.365	3.80	0.694	0.925	26.2	1.60 (-)
	Monel	0.904	0.340	4.03	0.683	0.911	24.4	0.77 (+)
	Nickel	0.992	0.420	3.80	0.798	1.064	19.6	7.26 (+)
	80 : 20 Ni-Gr*	***	***	***	***	***	***	***
	Birmabright	0.971	0.375	3.945	0.740	0.986	23.8	1.54 (+)
	Gold	0.354	0.135	3.935	0.266	0.354	24.9	nil
	Easy-flo	0.362	0.160	3.690	0.277	0.369	23.5	1.93 (+)

* Bulge area not measurable.

Columns (1), (2), and (3) are actual measurements from high-magnification photographs of bulges of the types shown.

Columns (4) and (5) are, respectively, the bulge areas, calculated on the assumption that area = one-half \times height \times chord and two-thirds \times height \times chord.

Column (6) shows the difference between columns (1) and (4) expressed as a percentage of the measured area. The calculated area is invariably lower.

Column (7) shows the difference between columns (1) and (5) expressed as a percentage of the measured area. The calculated area is sometimes more than, and sometimes less than, the measured area.

The underlying physico-metallurgical foundation for this grouping requires investigation beyond the scope of this paper. The characteristic features of each group are given below and are illustrated in Figs. 2-6 (Plates XXXVII-XLI).

TABLE III.—*Schedule of Materials Examined.*

Material.	Annealed Gauge, in.	Final Cold-Rolled Gauge, in.	Reduction in Thickness, %.	Approximate Composition, %.
Phosphor-Bronze.	0.116	0.020	82.76	Sn = 6½, P = 0.25, Cu = diff.
Mild Steel	0.100	0.016	84.00	...
Brass	0.060	0.017	71.67	Cu = 63½, Zn = diff.
Copper	0.080	0.017	78.75	Cu = 99.9+.
Monel Metal	0.100	0.020	80.00	Ni = 67, Cu = 30.5, Fe = 1.5, Mn = 1.
Nickel	0.100	0.020	80.00	Ni = 99, Cu = 0.4, Fe = 0.25.
Nickel-Chromium	0.100	0.020	80.00	Ni = 80, Cr = 20.
Birmabright	0.120	0.020	83.33	Mg = 3½, Al = diff.
9-ct. Gold	0.100	0.020	80.00	Au = 9/24, Cu = 15/24.
Easy-flo Solder	0.100	0.020	80.00	Ag = 50, Cd = 18, Zn = 16½, Cu = 15½.

Group X (Bronze, Brass, 80 : 20 Nickel-Chromium alloy, 9-carat Gold, and Easy-flo Solder.)

- (1) The relatively small amount of "piling up" and the shallowness of the strain markings adjoining the sides.
- (2) The very clear and sharply defined edges and corners.
- (3) The ease of focusing, which enabled well-defined photographs to be made, with consequent accuracy of planimetric measurements.
- (4) A pronounced rectangular appearance in the case of Series III and IV, with the "long" sides parallel to D/R.
- (5) A minimum of bulge on the long sides and a maximum on the short sides.

Group Y (Steel, Copper, Monel, Nickel, and Birmabright.)

- (1) The relatively large amount of "piling up," with general roughness and deeply furrowed strain markings.
- (2) The somewhat blurred edges and corners.
- (3) The difficulty of focusing the whole impression at once, causing slight difficulty with the camera.
- (4) The absence of pronounced apparent rectangularity in indentations of Series III and IV.
- (5) No obvious difference in the height of the bulge on adjacent sides (*i.e.*, parallel and normal to D/R).

This qualitative grouping is strongly supported by quantitative evidence, as shown in Table IV. The persistence of low ratios in

TABLE IV.—*Ratio of Bulge Height to Side.*

Material.	1.	2.	3.	4.	5.
Phosphor-Bronze . . .	3½	7½	1½	X	0.9927
Mild Steel . . .	8½	11½	10	Y	0.9975
Brass . . .	4	8½	2½	X	0.9933
Copper . . .	7¾	11	9½	Y	1.0016
Monel Metal . . .	7½	10½	8	Y	0.9950
Nickel . . .	7½	11½	9	Y	0.9949
Nickel-Chromium Alloy .	3	6½	½	X	0.9944
Birmabright . . .	7½	12½	9½	Y	0.9974
9-ct. Gold . . .	4½	8½	2½	X	0.9949
Easy-flo Solder . . .	3½	6	2½	X	0.9935

Col. 1.	$\frac{\text{Height of bulge} \times 100}{\text{side}}$	(Mean of Series I and II).
Col. 2.	$\frac{\text{Height of end bulge} \times 100}{\text{appropriate end}}$	(Mean of Series III and IV).
Col. 3.	$\frac{\text{Height of side bulge} \times 100}{\text{appropriate side}}$	(Mean of Series III and IV).
Col. 4.	Classification Group	(See p. 471).
Col. 5.	Ratio Ends/Sides	(All data of Series III and IV).

Group X in all three types of bulges is noteworthy. Column 5 indicates that elastic recovery (see Fig. 2(a)) is more pronounced in Group X than in Group Y.

In Table V, comparison of uncorrected hardness numbers calculated by A.M. and G.M. methods shows a maximum difference of 0.2 in. units with square lie and practically no difference with oblique lie. This is to be expected from the approximately equal values of the diagonals of the latter. Comparison of rows 1 and 5, 2 and 6, 9 and 13, 10 and 14 indicates both positive and negative differences, thus ruling out diamondism and suggesting slight experimental error. Table VI averages and summarizes the data of Table V. In all the metals examined there is an appreciable bulge correction, the magnitude of which is shown by the ratios in rows 9–12. Comparison of rows 1 and 4, 2 and 5 shows that oblique positioning gives a higher uncorrected value but a lower corrected value than square positioning, thus increasing the bulge correction (compare rows 9 and 11). Comparison of the short and long methods of calculation is available by comparing the ratio:

$$\frac{\text{Row 5}}{\text{Row 4}} \bigg/ \frac{\text{Row 7}}{\text{Row 4}}, \text{ i.e., } \frac{\text{Row 5}}{\text{Row 7}}.$$

TABLE V.—Uncorrected and Corrected Hardness Values.

	Description.	Row Ref.	Bronze.	Steel.	Brass.	Copper.	Monel.	Nickel.	80 : 20 Ni-Cr.	Birma-bright.	Gold.	Easy-flo.
Series I	Uncorrected (A.M.)	1	258.2	224.8	197.7	125.4	285.9	246.3	374.6	114.0	241.9	199.7
	Uncorrected (G.M.)	2	258.4	224.9	197.8	125.5	286.1	246.5	374.8	114.1	242.0	199.8
	Corrected " $\frac{2}{3}$ "	3	237.5	183.7	178.3	104.2	242.5	204.5	342.5	95.9	215.3	184.6
	Corrected " $\frac{1}{2}$ "	4	242.4	192.6	182.8	108.8	252.1	213.6	350.1	99.9	221.4	188.2
Series II	Uncorrected (A.M.)	5	257.2	228.6	196.1	124.2	292.3	247.2	377.7	113.6	240.3	200.3
	Uncorrected (G.M.)	6	257.4	228.7	196.2	124.2	292.4	247.3	377.9	113.6	240.4	200.3
	Corrected " $\frac{2}{3}$ "	7	237.2	185.9	177.3	103.0	241.9	207.3	352.2	94.8	214.7	183.9
	Corrected " $\frac{1}{2}$ "	8	241.9	195.1	181.7	107.6	252.8	216.0	358.3	98.9	220.6	187.7
Series III (Short Method)	Uncorrected (A.M.)	9	261.3	232.8	200.2	128.6	292.3	254.8	388.4	118.6	243.0	202.0
	Uncorrected (G.M.)	10	261.3	232.8	200.2	128.6	292.3	254.8	388.4	118.6	243.0	202.0
	Corrected " $\frac{2}{3}$ "	11	234.0	183.3	173.0	100.7	236.1	201.1	355.5	91.8	210.5	181.8
	Corrected " $\frac{1}{2}$ "	12	240.3	193.6	179.1	106.5	248.0	212.3	363.2	97.3	217.8	186.5
Series IV (Short Method)	Uncorrected (A.M.)	13	261.1	237.6	201.7	128.4	296.4	250.2	384.4	118.3	243.2	202.2
	Uncorrected (G.M.)	14	261.1	237.6	201.6	128.4	296.5	250.2	384.4	118.3	243.2	202.2
	Corrected " $\frac{2}{3}$ "	15	232.7	182.1	177.5	101.1	236.6	194.9	354.3	90.6	212.5	181.9
	Corrected " $\frac{1}{2}$ "	16	230.2	193.4	183.0	106.8	249.2	206.3	361.4	96.3	219.5	186.6
Series III (Long Method)	Corrected " $\frac{2}{3}$ "	17	235.4	182.9	174.1	100.5	236.3	200.6	358.3	91.8	211.7	183.9
	Corrected " $\frac{1}{2}$ "	18	241.7	193.1	180.2	106.2	248.2	211.8	366.1	97.3	219.1	188.6
Series IV (Long Method)	Corrected " $\frac{2}{3}$ "	19	235.2	182.4	178.3	101.1	235.9	195.9	358.0	90.5	213.3	184.5
	Corrected " $\frac{1}{2}$ "	20	241.8	193.7	183.8	106.8	248.4	207.4	365.2	96.1	220.3	189.2

This is done in row 15, which shows that the two methods give results so near to unity that the long method has no especial advantage and may be abandoned. Another manifestation of the *X* and *Y* groups (Table IV) can be seen in row 9, metals of the *X* group having 8–11% correction and metals of the *Y* group 17–18%. In row 15 (or 16) the *Y* metals give values extremely near to unity, whereas *X* metals give values (relatively) appreciably short of it.

VI.—SUGGESTED TECHNIQUE OF HARDNESS TESTING.

Consider an indentation made either in the square or the oblique manner. Let d be the A.M. or the G.M. of the diagonals and let a be the mean length of a side, either measured or calculated from d . Let p, q, r, s be the measured heights of the bulges. Let $B = p + q + r + s$. Then the projected area of the figure is :

$$a^2 + \frac{2}{3}ap + \frac{2}{3}aq + \frac{2}{3}ar + \frac{2}{3}as = a[a + \frac{2}{3}B]$$

and the diamond pyramid hardness number (corrected) is given by :

$$\frac{P \sin \frac{\theta}{2}}{a[a + \frac{2}{3}B]}$$

The operation of determining the corrected hardness therefore becomes that of measuring the heights of four bulges and either both diagonals or (say) one pair of adjacent sides. This gives a and $\frac{2}{3}B$. Table X* (Plate XLII) has been compiled for a load of 10 kg., for a value of θ of 136° , for values of a from 0.180 to 0.265 mm., and for values of B from 0 to 0.1 mm., progressing by steps of 0.005 mm. Intermediate values of B can be obtained by the use of proportional parts, and the table is adaptable for a useful range of loads by taking proportionate values. It is probably sufficiently comprehensive for most requirements of the cold-rolled non-ferrous industry. Two examples of its use are appended :

(1) Steel: Load 10 kg., $a = 0.200$, $B = 0.081$. Hardness number = 182.5.

(2) Easy-flo: Load $7\frac{1}{2}$ kg., $a = 0.184$, $B = 0.031$. Hardness number = $246.2 \times \frac{7\frac{1}{2}}{10} = 184.6$.

* Separate copies of this table are available and may be obtained gratis on application to the Institute. The question of the re-issue of the table in booklet form, with explanatory notes, is under consideration.

TABLE VI.—*Summary and Comparisons of Results in Table V.*

	Description.	Row Ref.	Bronze.	Steel.	Brass.	Copper.	Monel.	Nickel.	80 : 20 Ni-Cr.	Birma-bright.	Gold.	Easy-flo.
Mean of Series I and II (Short Method)	Uncorrected (G.M.)	1	257.9	226.8	197.0	124.85	289.25	246.9	376.35	113.85	241.2	200.05
	Corrected " $\frac{1}{2}$ "	2	237.35	184.8	177.8	103.6	242.2	205.9	347.35	95.35	215.0	184.25
	Corrected " $\frac{1}{2}$ "	3	242.15	193.85	182.25	108.2	252.45	214.8	354.2	99.4	221.0	187.95
Mean of Series III and IV (Short Method)	Uncorrected (G.M.)	4	261.2	235.2	200.9	128.5	294.4	252.2	386.4	118.45	243.1	202.1
	Corrected " $\frac{1}{2}$ "	5	233.35	182.7	175.25	100.9	236.35	198.0	354.9	91.2	211.5	181.85
	Corrected " $\frac{1}{2}$ "	6	239.75	193.5	181.05	106.65	248.6	209.3	362.3	96.8	218.65	186.55
Mean of Series III and IV (Long Method)	Corrected " $\frac{1}{2}$ "	7	235.3	182.65	176.2	100.8	236.1	198.25	358.15	91.15	212.5	184.2
	Corrected " $\frac{1}{2}$ "	8	241.75	193.4	182.0	106.5	248.3	209.6	365.65	96.7	219.7	188.9
Ratios	Row 2/Row 1	9	0.920	0.815	0.903	0.830	0.837	0.834	0.923	0.838	0.891	0.921
	Row 3/Row 1	10	0.939	0.855	0.925	0.867	0.873	0.870	0.941	0.873	0.916	0.940
	Row 5/Row 4	11	0.893	0.777	0.872	0.785	0.803	0.784	0.918	0.770	0.870	0.900
	Row 6/Row 4	12	0.918	0.823	0.902	0.830	0.844	0.829	0.938	0.817	0.899	0.923
	Row 7/Row 4	13	0.901	0.777	0.877	0.784	0.802	0.785	0.927	0.770	0.874	0.911
	Row 8/Row 4	14	0.926	0.822	0.906	0.829	0.843	0.830	0.946	0.816	0.904	0.935
	Row 5/Row 7	15	0.992	1.000	0.995	1.001	1.001	0.999	0.991	1.001	0.995	0.987
	Row 6/Row 8	16	0.992	1.000	0.995	1.001	1.001	0.999	0.991	1.001	0.995	0.988

VII.—DIAGONAL ANOMALY.

Diagonal anomaly—or simply “anomaly”—may be defined as the difference in length of the diagonals of a squarely positioned test-piece due to the directional properties of the metal and excluding such directional defects as elongated cavities or inclusions. It has been shown that when anomaly exists, hardness calculations based respectively upon the arithmetic and geometric means of the diagonals give different values, owing to the slight inaccuracy in area associated with the use of the A.M. Although this difference is of no practical consequence, its mathematical aspects are of interest. In addition, evidence already to hand indicated the possibility of interesting experimental results.

Since the hardness number is derived from an area, it is necessary to evaluate the effect of anomaly upon that area. Let x be the arithmetic mean of the two diagonals of a rhomboid impression whose anomaly is $2a$. Then the lengths of the diagonals are $(x + a)$ and $(x - a)$, and :

$$\begin{array}{ll} \text{Area based on G.M. (= true area)} & = \frac{1}{2}x^2 - \frac{1}{2}a^2 \\ \text{Area based on A.M.} & = \frac{1}{2}x^2 \\ \text{Discrepancy} & = \frac{1}{2}a^2 \end{array}$$

Thus, the area calculated by using the A.M. is greater than the true area by $\frac{1}{2}a^2$.

Certain corollaries follow from the above :

(1) “A.M.” area will always be greater than “G.M.” area, and therefore the “A.M.” hardness will be less than the “G.M.” hardness. (See Table VII, rows 5, 6, 7, and 9.)

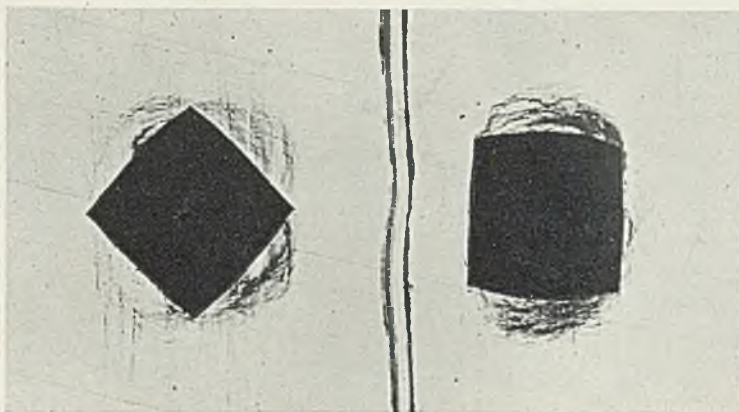
(2) The above relationship between discrepancy in area and anomaly is entirely independent of the area, x having disappeared. But it will be clear that, the bigger the “A.M.” area the smaller will be the relative effect of subtracting from it a constant amount of discrepancy, $\frac{1}{2}a^2$. This is important and arises again later.

(3) The above relationship has nothing whatever to do with the causes of anomaly, since the relationship is derived only from mathematical facts.

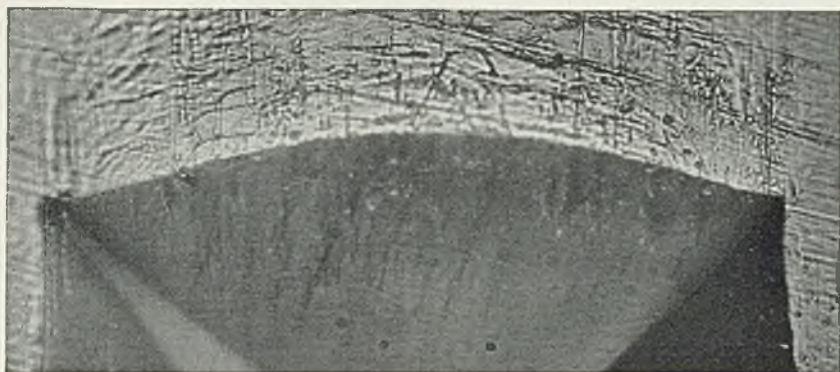
(4) Discrepancy of surface (or pyramidal) area is given by :

$$\frac{a^2}{2} \times \frac{1}{\sin \frac{\theta}{2}}$$

(5) If the anomaly be denoted by u , and u be given values of 1, 2, 3 . . . n (in ocular units) then the discrepancy is given by :



(a) $\times 100$.

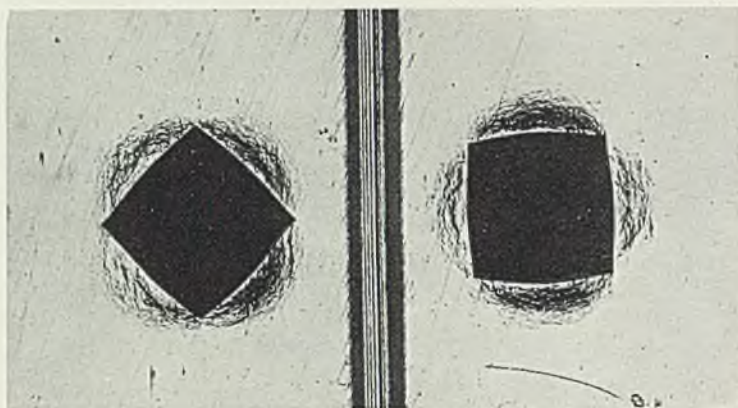


(b) Bulged end. $\times 500$.

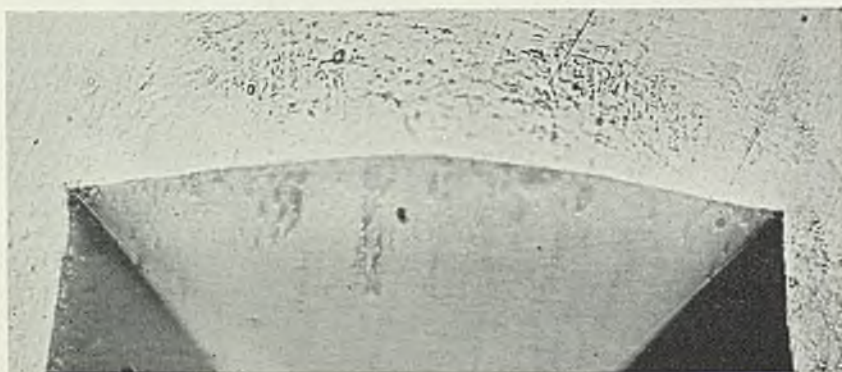


(c) Unbulged side. $\times 500$.

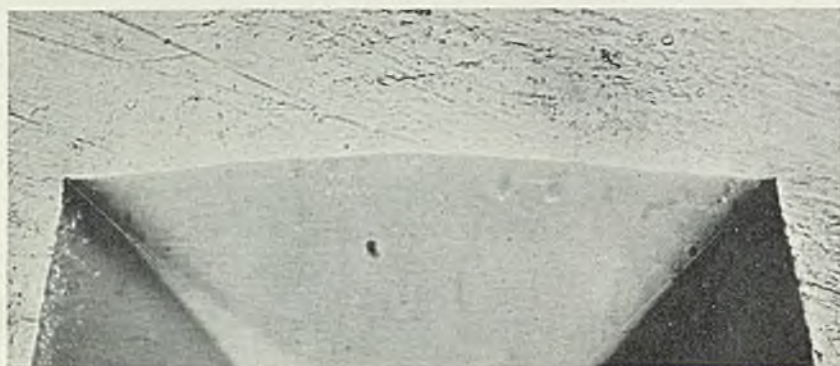
FIG. 2.—Diamond Pyramid Impressions in Bronze.



(a) $\times 100$.

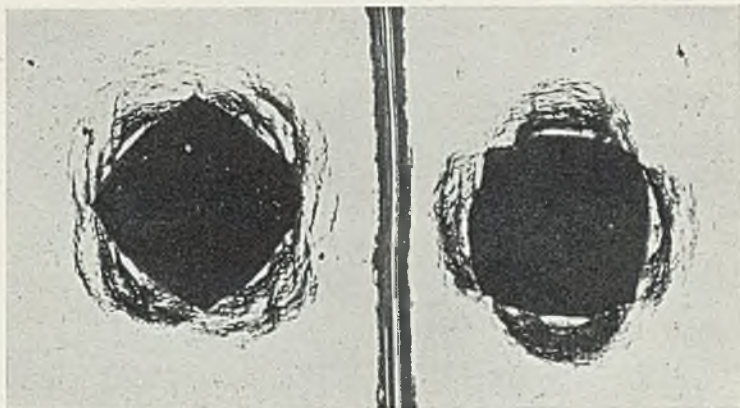


(b) Bulged end. $\times 500$.



(c) Slightly bulged side. $\times 500$.

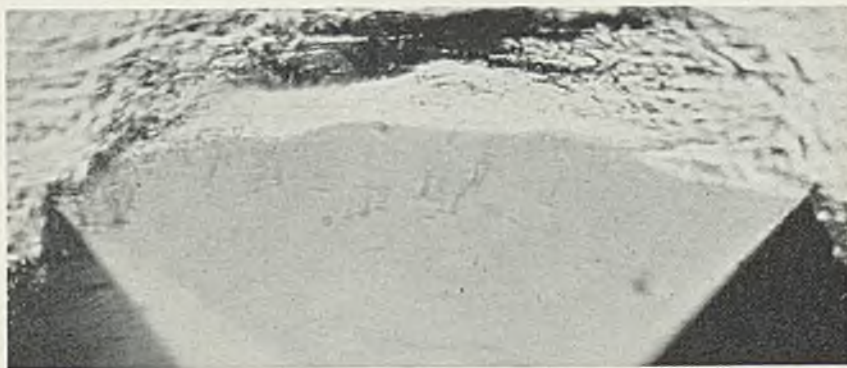
FIG. 3.—Diamond Pyramid Impressions in Easy-flo Solder.



(a) $\times 100$.

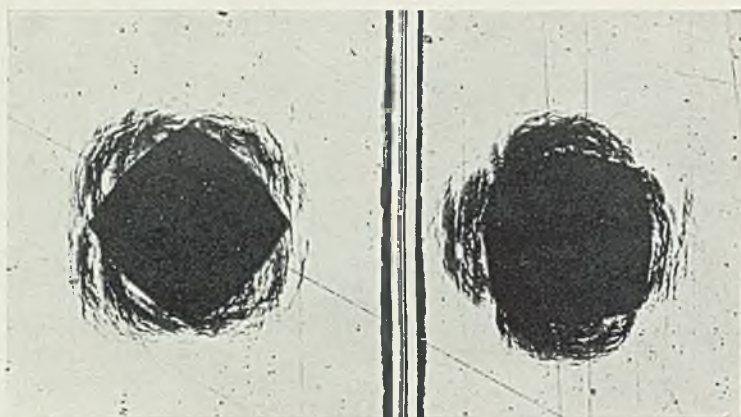


(b) Bulged end. $\times 500$.

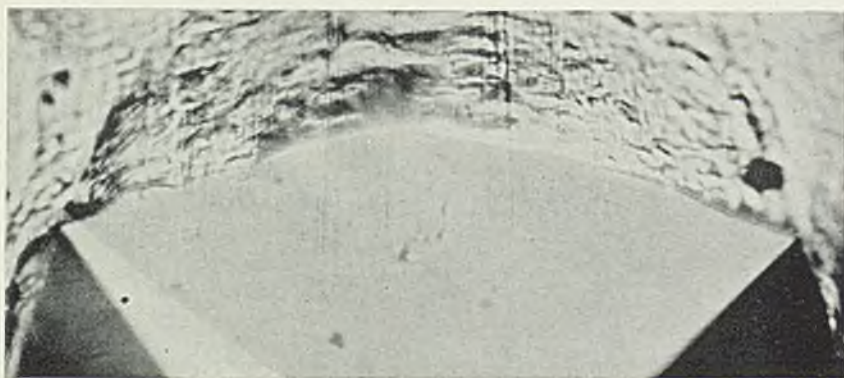


(c) Bulged side. $\times 500$.

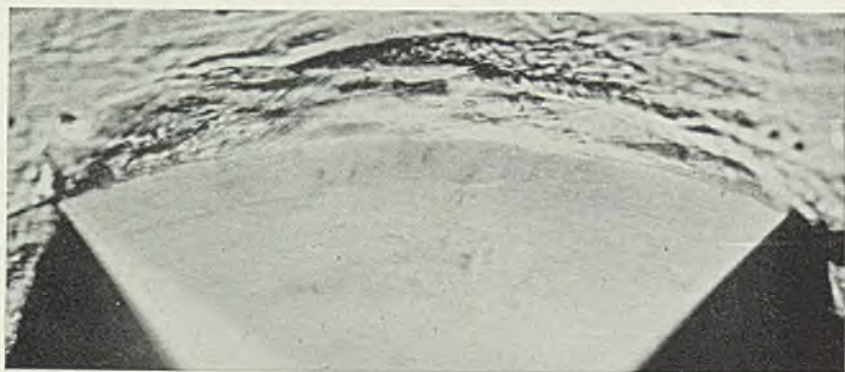
FIG. 4.—Diamond Pyramid Impressions in Mild Steel.



(a) $\times 100$.

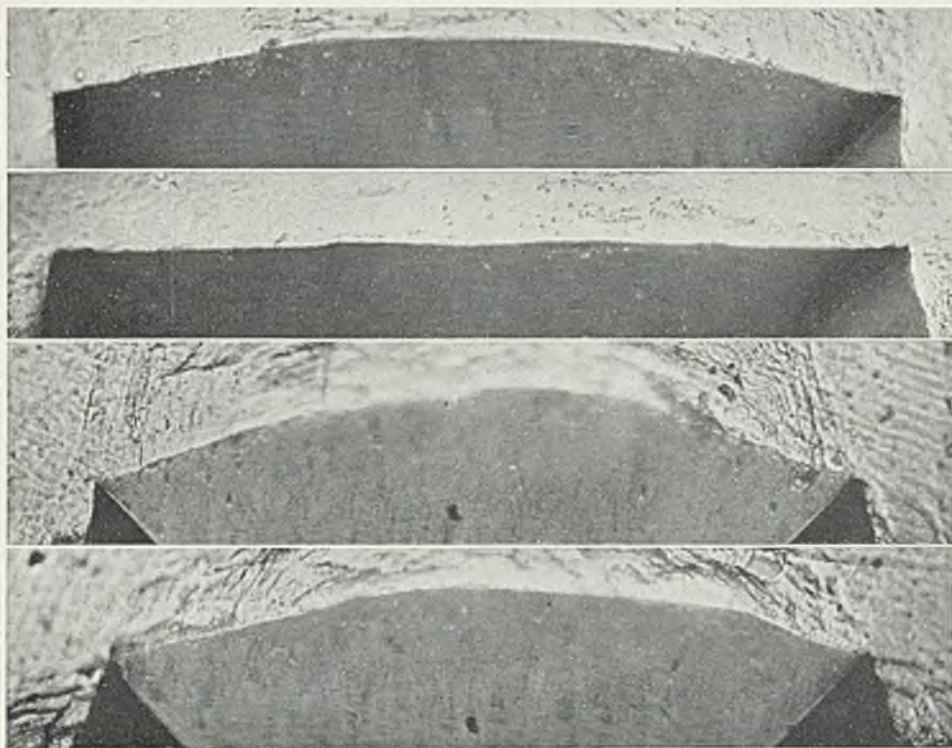


(b) Bulged end. $\times 500$.



(c) Bulged side. $\times 500$.

FIG. 5.—Diamond Pyramid Impressions in Copper.



(a) 80 : 20 Ni-Cr.
Bulged end.

(b) 80 : 20 Ni-Cr.
Unbulged side.

(c) Birmabright.
Bulged end.

(d) Birmabright.
Bulged side.

FIG. 6.—Diamond Pyramid Impressions in 80 : 20 Nickel-Chromium Alloy and Birmabright. $\times 500$.

$$\frac{\left(\frac{u}{2}\right)^2}{2} = \frac{u^2}{8} = \frac{1^2}{8}, \frac{2^2}{8}, \frac{3^2}{8} \dots \frac{n^2}{8}.$$

Thus, in Table VII we have discrepancies of

$$\frac{(0.0051)^2}{8}, \frac{(0.0077)^2}{8}, \frac{(0.0103)^2}{8} \dots \&c.,$$

which are respectively equal to :

$$\frac{3.25125}{10^6}, \frac{7.41125}{10^6} \dots \&c. \text{ (sq. mm.)},$$

as shown in row 7 (Table VII).

The above findings may now be applied to a comparison of "A.M." and "G.M." hardness. As before, let x be the A.M. of two diagonals differing in length by $2a$, and let P be the load which produced the impression. Then :

$$\text{Surface area based on A.M.} = \frac{x^2}{2 \sin \frac{\theta}{2}}$$

$$,, \quad ,, \quad \text{G.M.} = \frac{(x+a)(x-a)}{2 \sin \frac{\theta}{2}}$$

$$\begin{aligned} \frac{\text{Hardness A.M.}}{\text{Hardness G.M.}} &= \frac{P \left/ \frac{x^2}{2 \sin \frac{\theta}{2}} \right.}{P \left/ \frac{(x+a)(x-a)}{2 \sin \frac{\theta}{2}} \right.} \\ &= \frac{x^2 - a^2}{x^2}, \end{aligned}$$

which is a relationship in terms which can be easily measured experimentally. P has disappeared, but its influence is retained in that it has fixed the value of x . (See Series V.) An example of this relationship may be taken from the data in Table I. Substituting the values given therein, we have :

$$\frac{\text{Hardness A.M.}}{\text{Hardness G.M.}} = \frac{x^2 - a^2}{x^2} = \frac{0.268^2 - 0.008^2}{0.268^2} = \frac{0.99911}{1}$$

$$\therefore \text{Hardness G.M.} = \frac{\text{Hardness A.M.}}{0.99911}$$

But Hardness A.M. = 258.2 (calculated, as Table V)

$$\therefore \text{Hardness G.M.} = \frac{258.2}{0.99911} = 258.4,$$

which agrees with the value calculated directly by the G.M. method.

The ordinary formula for hardness may now be modified so as to take diagonal anomaly into account, as follows :

$$\text{Pyramid hardness} = \frac{\text{Load} \times \sin \frac{\theta}{2}}{(\text{area given by A.M.}) - \frac{(\text{half the anomaly})^2}{2}}$$

In this equation a change in value of any one variable will result in an automatic change in the others so as to preserve its validity. For example, with constant hardness and increasing load, the mean diagonal length will increase and the anomaly will automatically relate itself to this increase in a manner yet to be determined. Again, with constant load and increasing hardness and directionality, the diagonal length will decrease and so will the anomaly; but this decrease of the anomaly is masking an increase due to the greater directionality. This increase can be revealed (and measured) only by arranging the magnitude of the load upon test-pieces of different hardness in such a way that impressions of constant mean diagonal length are obtained.

Three series of experiments were therefore devised to clarify these issues, namely :

Series V.—For this series a piece of bronze was rolled from 0.250 to 0.050 in. equivalent to 80% reduction. The specimen for testing was about $\frac{3}{4}$ in. square and was cut from strip in such a way as to avoid heterogeneity arising from roll camber, &c. Loads ranging from 1 to 50 kg. were used, and at least five impressions were made, each with D/R — N-S and W-E. Table VII shows the results, together with the relevant calculations.

Series VI.—For this series a strip of annealed bronze at 0.144 in. thick was rolled down to 0.116, 0.087, 0.058, and 0.028 in., suitable pieces (not ends) being cut off at each gauge to provide separate test-pieces at approximately 0, 20, 40, 60, 80% reduction. Each piece was impressed with a 10-, 20-, and 30-kg. load, giving three parallel sets of data, in any one of which the load was constant and the hardness varied. Precautions against diamondism were taken. The results are set out in Table VIII.

Series VII.—For these experiments duplicate test-pieces identical with those used in Series VI were impressed with suitable loads (as shown in column 9 of Table VIII) to give impressions of constant size (A.M.) upon the pieces of increasing hardness. Table VIII shows these results also.

Attention should be drawn to an unavoidable and possibly misleading cause of experimental inaccuracy in dealing with the anomaly.

TABLE VII.—*Examination of "Diagonal Anomaly" Due to Various Loads on One Specimen.*

All lengths in millimetres; all areas in square millimetres.

		1 kg.	2½ kg.	5 kg.	10 kg.	15 kg.	20 kg.	30 kg.	40 kg.	50 kg.
1	Mean of long diagonals	0.0960	0.1448	0.2016	0.2849	0.34475	0.39925	0.48925	0.562625	0.63040
2	Mean of short diagonals	0.0909	0.1371	0.1913	0.2686	0.32560	0.37840	0.46190	0.532125	0.59855
3	Difference between diagonals	0.0051	0.0077	0.0103	0.0163	0.01915	0.02085	0.02735	0.0305	0.03185
4	Half sum of diagonals	0.09345	0.14095	0.19645	0.27675	0.335175	0.388825	0.475575	0.547375	0.614475
5	Square of row 4 divided by 2 = area based on A.M.†	0.004366	0.009933	0.019296	0.038295	0.05617	0.07559	0.11308	0.14980	0.18878
6	Half product of diagonals = area based on G.M.†	0.004363	0.009926	0.019283	0.038262	0.05612	0.07553	0.11299	0.14969	0.18866
7	Discrepancy in projected area between (5) and (6)	$\frac{3.25125}{10^6}$	$\frac{7.41125}{10^6}$	$\frac{13.26125}{10^6}$	$\frac{33.21125}{10^6}$	$\frac{45.8403125}{10^6}$	$\frac{54.3403125}{10^6}$	$\frac{93.5028125}{10^6}$	$\frac{116.28125}{10^6}$	$\frac{126.8028125}{10^6}$
8	Ratio: $\frac{\text{Row 3}}{\text{Row 4}} \times 100$	5.45	5.46	5.24	5.89	5.71	5.36	5.75	5.57	5.18
9	Ratio: * "A.M." hardness "G.M." hardness	0.99926	0.99925	0.99931	0.99913	0.99918	0.99928	0.99917	0.99922	0.99933

* Based on $(x^2 - a^2)/x^2$, where x = arithmetic mean of diagonals (Row 4), and a = half of the anomaly, i.e., half of the values in Row 3 (see Part VI).

† Some decimal places in rows 5 and 6 have been omitted, but the values in Row 7 (Row 5 minus Row 6) were obtained before the omissions were made.

It arises from the fact that the means available for measuring differences in diagonal length are crude in relation to the magnitude of the difference being measured. For example, suppose the diagonals are 0.330 and 0.336 mm. in length. An error of 0.001 mm. is only $\frac{1}{333}$ of the mean diagonal length, *i.e.*, about 0.3%, but it is 16.7% of the anomaly. All experiments of Series V, VI, and VII were carried out upon phosphor-bronze strip. This was because (1) the anomaly exists to a marked degree, (2) a high degree of polish and surface perfection could readily be obtained, (3) the alloy was available in any "temper," and (4) phosphor-bronze was the material which led to the initiation of this research.

Reference to row 8 of Table VII shows that, when "square lie" impressions are made with any load upon one piece of metal of given uniform hardness and high directionality, the ratio of the anomaly to the mean diagonal length is practically constant, being about 5.5%. Further data on other pieces of bronze of the same temper (from the same ingot) confirm this (see Table VIII, columns 7 and 12). It is therefore convenient at this stage to introduce a definition:

The anomaly constant is the ratio, expressed as a percentage, of the anomaly to the arithmetic mean of the diagonal lengths (A.M.D.L.) of an impression produced by any load, when D/R is parallel to one diagonal;

$$\text{i.e., anomaly constant} = \frac{a}{\text{A.M.D.L.}} \times 100.$$

If now the results of Series VI be studied from Table VIII, it will be seen that (1) the ratio $\frac{a \times 100}{\text{A.M.D.L.}}$ is constant for any particular degree of cold work, whether the load be 10, 20, or 30 kg., and (2) it increases from about 0.3% (for the particular sample of bronze examined) in the annealed condition to about 5½% in the 80% cold-worked condition. The slight but definite anomaly constant of the annealed metal probably indicates a not quite complete annealing, as it is too consistent to be due to experimental error. The purpose of Series VII has already been achieved by the results of Series V and VI, since they have enabled a simple relationship to be established which will enable the "hidden" anomaly for any hardness and any load to be derived, provided the anomaly constant appropriate to any percentage of cold work is known. Thus the work embodied in Series VII is redundant so far as its original purpose is concerned, but affords confirmatory evidence of the principle of anomaly constant. The method of working whereby the load is varied and the size of indentation is kept constant would be very

TABLE VIII.—Results of Series VI and VII.

Cold Work, %.	Series VI.							Series VII.			
	10 kg.			20 kg.	30 kg.	Col. (7) Average of (4), (5), (6) (%).	Col. (8) Ordinary V.P.N.	Col. (9) (kg.).	Col. (10) (mm.).	Col. (11) Anomaly, mm.	Col. (12) (%).
	A.M., mm.	Anomaly, mm.	Col. (4) (%).	Col. (5) (%).	Col. (6) (%).						
0 (annealed)	0.457	0.0017	0.37	0.28	0.34	0.33	88— 89	5.960	0.349 $\frac{1}{2}$	0.0014	0.4
20	0.347	0.0081	2.33	2.35	2.25	2.31	154-155	10.164	0.350 $\frac{3}{8}$	0.008 $\frac{1}{8}$	2.37
40	0.311	0.011	3.55	4.01	3.89	3.82	192-196	12.936	0.350 $\frac{5}{8}$	0.012 $\frac{3}{8}$	3.65
60	0.293	0.014	4.75	4.81	4.54	4.70	216-219	14.220	0.349 $\frac{3}{4}$	0.017 $\frac{1}{4}$	4.93
80	0.275	0.0157	5.7	5.07	5.05	5.27	245-245	16.262	0.350 $\frac{7}{8}$	0.019 $\frac{1}{2}$	5.56

Cols. (4), (5), and (6) show $\frac{\text{Anomaly}}{\text{A.M.}} \times 100$ for 10, 20, and 30 kg.-load, respectively.

Col. (8) gives the lowest and highest of the three ordinary diamond pyramid hardness values obtained with the three loads, using A.M. [such as Col. (2)] and the published tables.

Col. (9) gives the load required to produce an impression of constant size (diagonal = 0.350 mm.) upon any of the five tempers.

Col. (10) gives the mean diagonal of at least 10 impressions with the load given in column (9) (0.350 mm. was aimed at).

Col. (11) gives actual anomaly resulting from (9) and (10).

Col. (12) gives $\frac{\text{Col. (11)}}{\text{Col. (10)}} \times 100$. Compare Col. (7).

suitable for a detailed plan of investigation of the relation of cold work and/or hardness to the anomaly constant.

Some tentative comparisons of the anomaly constant for the various alloys surveyed in this work (all being cold worked to about 80%) are given in Table IX. It will be noted that phosphor-bronze heads the list at 5.59%. The values given, though only approximate, are sufficiently different, as between one alloy and another, to suggest further enquiry (carried out with better means of anomaly measurement), correlated with the alloy structure and with certain other physical properties.

VIII.—CONCLUSIONS.

(1) When indentations are made upon heavily cold-rolled strip so positioned under the diamond that one diagonal is parallel to the direction of rolling, the appreciable difference in diagonal length makes it inadvisable to rely upon measurement of one diagonal only.

(2) If the test-piece has its direction of rolling at 45° to the diagonals, they are then practically equal in length, so that measurement of one diagonal only involves much less risk of inaccuracy than in the case of (1).

(3) A comparison of the areas of a rhomboid impression, as calculated from the arithmetic mean and from the geometric mean of its diagonals, has been made. Although the "A.M." area is slightly erroneous (positive) it is not sufficient (even in severe cases) to justify any departure from its accepted use in favour of the "G.M." area.

(4) A series of tests upon one piece of phosphor-bronze with loads between 1 and 50 kg. (80% cold work "square" positioning) showed that the ratio :

$$\frac{\text{Difference in diagonal length}}{\text{A.M. length of diagonals}} \times 100$$

was constant. With different specimens of bronze having increasing percentages of cold work, this ratio became greater, thus increasing the rhombus-like shape of the indentation.

(5) The above ratio (4) appeared to be a property of the material in conjunction with the percentage cold work, *e.g.*, bronze = 5.59%; Easy-flo solder = 2.7%, both at 80% reduction.

(6) The camber of the bulge (height/base) appeared to be a property of the metal, irrespective of its orientation with respect to direction of rolling. With any one particular metal, the camber of the bulge depended upon the orientation.

(7) The equation of the bulge curve very closely approximated to that of a parabola, thus enabling the bulge area to be calculated. The

TABLE IX.—*Diagonal Anomaly.*

1	2	3	4	5	6	7	8		9
Material.	Cold Work, %.	Load, kg.	Long Diagonal.	Short Diagonal.	Difference.	Anomaly Constant.	V.P.N. (High).	V.P.N. (Low).	V.P.N. Difference.
Bronze	83	10	275.75	260.75	15.0	5.59	272	243	29
Steel	82	10	291.30	280.70	10.6	3.70	235	219	16
Brass	71	10	314.25	299.50	14.75	4.81	207	188	19
Copper	78	5	276.875	268.25	8.625	3.16	129	121	8
Monel	80	12½	289.50	276.875	12.625	4.46	302	276	26
Nickel	80	10	279.875	268.375	11.50	4.20	258	236	22
80 : 20 Ni-Cr	80	15	278.125	265.75	12.375	4.55	393	360	33
Birmabright	83	5	291.875	279	12.875	4.51	119	109	10
Gold	80	10	283.70	271	12.70	4.58	253	230	23
Easy-flo	80	7½	267.25	260.125	7.125	2.70	205	195	10

$$\text{Col. 7} = \frac{\text{Col. 6}}{\text{Mean of Cols. 4 and 5}} \times 100.$$

Col. 8 = Diamond pyramid hardness number corresponding to Cols. 5 and 4 respectively; to nearest integer.

Col. 9 = Difference between values in Col. 8.

N.B.—Values in Col. 8 are those of the published tables, where available.

calculated value ($\frac{2}{3} \times h \times c$) agreed very closely indeed with the value measured with a planimeter upon a high-magnification photograph.

(8) The difference between hardness numbers corrected for bulge area and those not so corrected was of the order of 10–20%.

(9) Based upon (7), a new formula for the diamond pyramid hardness has been evolved. A comprehensive table (Table X) has been compiled, having a range probably suited to the requirements of most manufacturers of cold-rolled strip.

The authors are of the opinion that a case has been made out for :

(i) A universal adoption of oblique (45°) positioning of cold-rolled strip upon the platform of the Vickers machine, coupled with a very guarded and restricted recourse to measurement of one diagonal in certain classes of inspection work under certain conditions.

(ii) A much greater appreciation amongst metallurgists—particularly those charged with the drawing up of specifications—of the inaccuracies resulting from neglect to consider bulge.

(iii) A specific ruling as to procedure in dealing with bulge in the determination of the diamond pyramid hardness of cold-rolled strip generally, but especially in those cases where a stated hardness number is to be met, as in many B.S. Specifications.

There are several directions in which this work may be continued, namely :

(a) Correlation of the effects observed with micro- and lattice structures of the alloys under review; and co-ordination of bulge and anomaly with physical properties of the alloys themselves.

(b) Study of concavity effects on similar lines.

(c) Systematic application to alloy systems generally.

(d) Studies at smaller percentages of cold work.

(e) Development of a laboratory technique for accurate anomaly measurements and also for the preparation of an ideal test-piece.

IX.—ACKNOWLEDGEMENTS.

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TABLE X.—Corrected Hardness Table (10-kg. Load).

$$\text{Corrected diamond pyramid hardness} = \frac{P \sin \frac{\theta}{2}}{a \left(a + \frac{2}{3} B \right)},$$

where a = side of indentation and B = sum of the four bulge heights.

$$a = \frac{d_1 + d_2}{2\sqrt{2}},$$

where d_1 and d_2 are the measured diagonals of an indentation.

The hardness values given by this table should be halved if the load (P) is 5 kg.; quartered if 2½ kg.; doubled if 20 kg.; and so on, proportionately. For intermediate values of B , the use of proportional parts will be sufficiently accurate.

a (side of indentation), mm.	B (sum of heights of four bulges), mm.																				a (side of indentation), mm.	
	0-000.	0-005.	0-010.	0-015.	0-020.	0-025.	0-030.	0-035.	0-040.	0-045.	0-050.	0-055.	0-060.	0-065.	0-070.	0-075.	0-080.	0-085.	0-090.	0-095.		0-100.
0-180	286.2	281.0	276.0	271.1	266.4	261.9	257.6	253.3	249.2	245.3	241.5	237.7	234.1	230.6	227.3	224.0	220.8	217.7	214.6	211.7	208.8	0-180
0-181	283.0	277.9	273.0	268.2	263.6	259.2	254.9	250.7	246.7	242.8	239.0	235.3	231.8	228.3	225.0	221.8	218.6	215.5	212.6	209.7	206.8	0-181
0-182	279.9	274.9	270.0	265.3	260.8	256.4	252.2	248.1	244.1	240.3	236.6	233.0	229.5	226.1	222.8	219.6	216.5	213.5	210.5	207.7	204.9	0-182
0-183	276.9	271.9	267.1	262.5	258.1	253.7	249.6	245.5	241.6	237.9	234.2	230.6	227.2	223.8	220.6	217.4	214.4	211.4	208.5	205.7	202.9	0-183
0-184	273.9	269.0	264.3	259.7	255.4	251.1	247.0	243.0	239.2	235.5	231.8	228.4	224.9	221.7	218.5	215.3	212.3	209.4	206.5	203.7	201.0	0-184
0-185	270.9	266.1	261.5	257.0	252.7	248.5	244.5	240.6	236.8	233.1	229.5	226.1	222.7	219.5	216.3	213.3	210.3	207.4	204.6	201.8	199.1	0-185
0-186	268.0	263.3	258.7	254.3	250.1	246.0	242.0	238.1	234.4	230.8	227.3	223.9	220.6	217.4	214.2	211.2	208.3	205.4	202.6	199.9	197.3	0-186
0-187	265.1	260.5	256.0	251.7	247.5	243.4	239.5	235.7	232.0	228.5	225.0	221.7	218.4	215.3	212.2	209.2	206.3	203.5	200.7	198.1	195.5	0-187
0-188	262.3	257.8	253.3	249.1	245.0	241.0	237.1	233.4	229.7	226.2	222.8	219.5	216.3	213.2	210.2	207.2	204.4	201.6	198.9	196.2	193.7	0-188
0-189	259.6	255.1	250.7	246.5	242.5	238.5	234.7	231.0	227.5	224.0	220.6	217.4	214.2	211.1	208.2	205.3	202.4	199.7	197.0	194.4	191.9	0-189
0-190	256.8	252.4	248.1	244.0	240.0	236.1	232.4	228.7	225.2	221.8	218.5	215.3	212.2	209.1	206.2	203.3	200.6	197.8	195.2	192.6	190.1	0-190
0-191	254.2	249.8	245.6	241.5	237.6	233.8	230.1	226.5	223.0	219.6	216.4	213.2	210.1	207.2	204.2	201.4	198.7	196.0	193.4	190.9	188.4	0-191
0-192	251.5	247.2	243.1	239.1	235.2	231.4	227.8	224.3	220.8	217.5	214.3	211.2	208.1	205.2	202.3	199.5	196.8	194.2	191.6	189.1	186.7	0-192
0-193	248.9	244.7	240.6	236.6	232.8	229.1	225.5	222.1	218.7	215.4	212.2	209.2	206.2	203.3	200.4	197.7	195.0	192.4	189.9	187.4	185.0	0-193
0-194	246.4	242.2	238.2	234.3	230.5	226.9	223.3	219.9	216.6	213.4	210.2	207.2	204.2	201.4	198.6	195.9	193.2	190.7	188.2	185.7	183.4	0-194
0-195	243.8	239.7	235.8	231.9	228.2	224.6	221.1	217.8	214.5	211.3	208.2	205.2	202.3	199.5	196.7	194.1	191.5	188.9	186.5	184.1	181.7	0-195
0-196	241.4	237.3	233.4	229.6	226.0	222.4	219.0	215.7	212.4	209.3	206.3	203.3	200.4	197.7	194.9	192.3	189.7	187.2	184.8	182.4	180.1	0-196
0-197	238.9	234.9	231.1	227.4	223.8	220.3	216.9	213.6	210.4	207.3	204.3	201.4	198.6	195.8	193.1	190.5	188.0	185.5	183.1	180.8	178.5	0-197
0-198	236.5	232.6	228.8	225.1	221.6	218.1	214.8	211.6	208.4	205.4	202.4	199.5	196.7	194.0	191.4	188.8	186.3	183.9	181.5	179.2	176.9	0-198
0-199	234.1	230.3	226.5	222.9	219.4	216.0	212.8	209.6	206.5	203.5	200.5	197.7	194.9	192.3	189.7	187.1	184.6	182.2	179.9	177.6	175.4	0-199
0-200	231.8	228.0	224.3	220.8	217.3	214.0	210.7	207.6	204.5	201.6	198.7	195.9	193.2	190.5	187.9	185.4	183.0	180.6	178.3	176.1	173.9	0-200
0-201	229.5	225.8	222.1	218.6	215.2	211.9	208.7	205.6	202.6	199.7	196.8	194.1	191.4	188.8	186.2	183.8	181.4	179.0	176.7	174.5	172.3	0-201
0-202	227.2	223.5	220.0	216.5	213.2	209.9	206.8	203.7	200.7	197.8	195.0	192.3	189.7	187.1	184.6	182.1	179.8	177.4	175.2	173.0	170.8	0-202
0-203	225.0	221.4	217.8	214.4	211.1	207.9	204.8	201.8	198.9	196.0	193.3	190.6	188.0	185.4	182.9	180.5	178.2	175.9	173.7	171.5	169.4	0-203
0-204	222.8	219.2	215.7	212.4	209.1	206.0	202.9	199.9	197.0	194.2	191.5	188.8	186.3	183.8	181.3	178.9	176.6	174.4	172.2	170.0	167.9	0-204
0-205	220.6	217.1	213.7	210.4	207.2	204.0	201.0	198.1	195.2	192.5	189.8	187.2	184.6	182.1	179.7	177.4	175.1	172.8	170.7	168.6	166.5	0-205
0-206	218.5	215.0	211.6	208.4	205.2	202.1	199.2	196.3	193.5	190.7	188.1	185.5	183.0	180.5	178.1	175.8	173.6	171.3	169.2	167.1	165.1	0-206
0-207	216.4	213.0	209.6	206.4	203.3	200.3	197.3	194.5	191.7	189.0	186.4	183.8	181.3	178.9	176.6	174.3	172.1	169.9	167.8	165.7	163.7	0-207
0-208	214.3	210.9	207.7	204.5	201.4	198.4	195.5	192.7	190.0	187.3	184.7	182.2	179.7	177.4	175.0	172.8	170.6	168.4	166.3	164.3	162.3	0-208
0-209	212.3	208.9	205.7	202.6	199.5	196.6	193.7	191.0	188.2	185.6	183.1	180.6	178.2	175.8	173.5	171.3	169.1	167.0	164.9	162.9	160.9	0-209
0-210	210.3	207.0	203.8	200.7	197.7	194.8	192.0	189.2	186.6	184.0	181.5	179.0	176.6	174.3	172.0	169.8	167.7	165.6	163.5	161.5	159.6	0-210
0-211	208.3	205.0	201.9	198.8	195.9	193.0	190.2	187.5	184.9	182.3	179.9	177.4	175.1	172.8	170.5	168.4	166.2	164.2	162.1	160.2	158.3	0-211
0-212	206.3	203.1	200.0	197.0	194.1	191.3	188															

Iron Research Association for the preparation of some forty photomicrographs upon which much of this work has depended, and they (the authors) thank the Director and Council of that Association for permission to publish a number of them.

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APPENDIX.—*Definition of Diamondism.*

The perfect and ideal indentation projection is a true square in the strict geometrical sense. The nearest approximation to this, for our purpose, is a figure which would be a square except for bulges or concavities. Next there is the figure which is a true rhombus. Then there is the rhombus with bulges or concavities. All these types are symmetrical about each diagonal. Again, there are impressions which are symmetrical about one diagonal only, *e.g.*, kite-shaped. Then there are rectangular or parallelogram impressions. Lastly, there are irregularly-shaped impressions, with or without bulges.

An analysis of the causes of these various malformed indentations suggests the following :

- (1) Asymmetry in the diamond pyramid itself.
- (2) Asymmetry in the mounting of the diamond, in relation to the direction of the applied load.
- (3) Lack of normal application of the load owing to faults in the machine.
- (4) Carelessness in the preparation or setting up of the specimen.
- (5) Faulty location or overcrowding of impressions.
- (6) Directionality of the metal under test.
- (7) Directional abnormality (*e.g.*, elongated pin-holes) of the test-piece.
- (8) Combinations of (1) to (7).

These may be resolved into causes due to (1) the diamond or the machine, (2) the preparation of the test-piece, and (3) the properties of the test-piece. Diamondism may therefore be defined as any cause, associated with lack of perfection in preparing or mounting the diamond or in applying the load, which would give an "un-square" impression upon a properly prepared and mounted specimen of homogeneous, isotropic, non-directional material.

INTERCRYSTALLINE CORROSION OF ALUMINIUM-MAGNESIUM ALLOY RIVETS.*

1029

By G. J. METCALFE,† B.Sc.Tech., MEMBER.

SYNOPSIS.

A number of service failures in aluminium alloy rivets containing 7% and 5% of magnesium which are described are attributed to intercrystalline corrosion, probably accentuated by stress. Normally aluminium alloy rivets containing 5% of magnesium are not susceptible to intercrystalline corrosion, but it is shown that when they are subjected to tropical temperatures for long periods precipitation of the β -phase occurs, which renders them susceptible to intercrystalline attack. Cold working the rivets before heating at tropical temperatures is found to cause grain-boundary precipitation of the β -phase to take place more readily. Low-temperature stabilizing treatments are shown to be unsuccessful in preventing grain-boundary precipitation. Corrosion tests on riveted lap joints show that in rivets that have been previously heated at 70° C. for 14 days intercrystalline corrosion occurs at the junction of the shank and the head.

INTRODUCTION.

THE possibility of developing aluminium alloys with age-hardening characteristics and of producing a reasonably strong alloy that is lighter than those of the Duralumin type has engaged the attention of metallurgists for several years. It is not surprising, therefore, that considerable interest has been shown in essentially binary aluminium-magnesium alloys, particularly in Germany, where they have been used to a larger extent than in this country. The susceptibility of the higher-magnesium alloys to intercrystalline corrosion has, however, prevented their more rapid development, and research work during recent years has been concentrated mainly on resistance to corrosion.

From the point of view of corrosion-resistance the low-magnesium alloys are reasonably satisfactory, but as the magnesium content is raised the risk of intercrystalline corrosion increases. Susceptibility to intercrystalline corrosion may also develop when the alloys are heated for long periods at temperatures such as are likely to be encountered in the tropics and appears to be associated with precipitation of the β -phase at the grain boundaries.

Fig. 1 is part of the equilibrium diagram of the system aluminium-magnesium as given by Raynor.¹ It shows that at 400° C., the approximate temperature to which the 7% and 5% magnesium alloys are heated during manufacture, all the magnesium should be in solid solution in aluminium. At room temperature, however, the solubility

* Manuscript received December 17, 1945.

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of magnesium in aluminium has fallen to approximately 1.5%, and a considerable proportion of the magnesium is precipitated as β -phase.

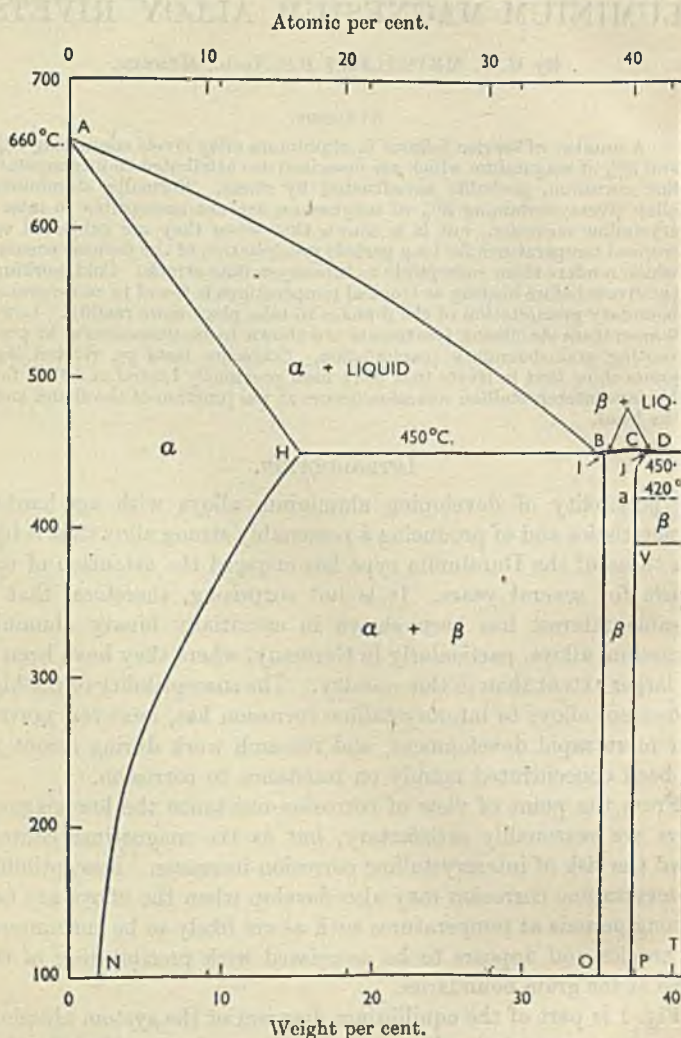


FIG. 1.—The Aluminium End of the Aluminium-Magnesium System.
(Raynor.¹)

The β -phase is frequently precipitated at the grain boundaries, and when this occurs the material is rendered susceptible to intercrystalline corrosion. Möckel² found that in an aluminium alloy containing 7%

of magnesium, ageing at 100° and 75° C. for prolonged periods caused a continuous grain-boundary network of β -phase to form and that this rendered the material susceptible to intercrystalline corrosion; whereas annealing at 300° C. and above produced a "string of pearls" structure which resulted in the alloy being resistant to intercrystalline attack. Similar work by Bollenrath³ and Vosskühler⁴ confirmed Möckel's findings.

According to Söhnchen,⁵ the susceptibility to intercrystalline corrosion of aluminium-magnesium alloys is dependent on the nature and distribution of the precipitated phase. Measurements have shown that almost all intermetallic compounds occurring in aluminium alloys are more or less cathodic to aluminium, with the exception of Mg_2Si and Mg_2Al_3 , which are anodic. In the aluminium-magnesium alloys the distribution of the β -phase is therefore important and decides the nature of the corrosion, grain-boundary precipitation in the form of a continuous network resulting in intercrystalline attack.

Many attempts to prevent the formation of a grain-boundary film of the β -phase have been made both by heat-treatment and by adding small amounts of other elements. Bollenrath³ and Siebel and Vosskühler⁶ have had encouraging results with alloys to which small amounts of chromium and zinc were added. The work of Siebel⁷ on Hydroalium sheet has shown that alloy Hy 18 is superior to Hy 9 as regards resistance to intercrystalline corrosion and stress-corrosion.* Further work by Siebel and Vosskühler⁸ on this type of alloy containing 7-8% of magnesium and 0.2% of manganese, with or without 1% of zinc, shows, however, that the tendency for stress-corrosion to develop when the alloys are annealed between 60° and 160° C. can be prevented by subjecting the alloys to a suitable "heterogenizing treatment," the details of which are not published. About the same date (1942), Menzen⁹ published the results of similar work in which the heterogenizing treatment consisted of heavily cold rolling an aluminium-9% magnesium alloy and then causing precipitation along the slip planes by annealing. This resulted in a very fine and uniform distribution of the β -phase, accompanied by an improvement in resistance to stress-corrosion. No change in microstructure was detected after subsequent annealing at 100° C. for 24 hr. Particularly satisfactory results were obtained when a small quantity of zinc was added.

In experiments on aluminium-9% magnesium alloys made from very high-purity aluminium and magnesium, Beerwald and Grober¹⁰

* Alloy Hy 18 is an aluminium alloy containing 8% of magnesium, 1% of zinc, and less than 1% of total impurities; Hy 9 is essentially a binary aluminium-9% magnesium alloy.

found that the resistance to corrosion was considerably improved by raising the purity of the alloy. When β -phase had precipitated along the grain boundaries, however, intercrystalline corrosion occurred irrespective of the purity of the aluminium and magnesium.

Sterner-Rainer,¹¹ on the other hand, has investigated the effects of small amounts of copper, iron, silicon, manganese, and nickel on the corrosion-resistance of very pure aluminium alloys containing 2.3% of magnesium. He found that 0.03% of copper or nickel accelerated corrosion appreciably. Up to 0.1% of iron weakened the corrosion-resistance of the pure alloy, but above 0.1% iron had little further effect. As much as 0.3% of silicon had little effect provided that the Mg_2Si was retained in solid solution. The presence of manganese increased the corrosion-resistance considerably, the maximum effect being reached at 0.8% of manganese.

The effect of the addition of small quantities of a large number of elements on the resistance to intercrystalline corrosion of an aluminium-base alloy containing 7% of magnesium has been investigated by Mulfinger.¹² He concluded that the addition of 0.5% of silicon prevented the precipitation of an envelope of β -phase around the grains, and that the addition of 2% of zinc was necessary in order to produce similar results.

A new light has been cast on the corrosion of these alloys by the work of Lacombe¹³ and Chaudron.¹⁴ They found that aluminium-9% magnesium alloys heated at temperatures below 280° C. showed a maximum rate of corrosion as a function of the duration of heating at the ageing temperature. As the temperature of ageing increased, the amplitude of this maximum diminished until at 280° C. no maximum was observed. It was found that below 280° C. an unstable β_1 -phase was precipitated which was more electronegative than the stable β -phase. The occurrence of a maximum rate of corrosion, the amplitude of which varied with the ageing temperature, was attributed to the presence of appreciable amounts of β_1 -phase, which was rapidly transformed to β -phase as the temperature approached 280° C.

In general, aluminium-magnesium alloys are fairly easy to work, and those containing less than about 6% of magnesium have been extensively used in wrought form by the Germans. In the British aircraft industry the alloys, although not as popular as in Germany, are used in the form of rivets to Specifications D.T.D. 404 and D.T.D. 303, which cover aluminium alloys containing 7% and 5% magnesium, respectively.

Rivets to Specification D.T.D. 404 are not used very much, as difficulty is experienced in riveting with certain varieties of rivets in

this material. The 5% magnesium alloy rivets, on the other hand, are extensively used in British aircraft.

The present paper deals with the metallurgical examination of rivets that have failed in service and the effect of tropical temperatures on the microstructure and corrosion-resistance of rivets to Specification D.T.D. 303.

EXAMPLES OF FAILURES OF RIVETS IN SERVICE.

(a) *Aluminium-7% Magnesium Alloy Rivets.*

Failure of 7% magnesium alloy rivets was discovered on certain aircraft that had been operating in coastal areas of the British Isles for about two years. The countersunk heads of $\frac{1}{8}$ -in. dia. rivets used on the engine cowling for joining sheets conforming to B.S. Specifications L3 and L46 had parted from the shanks. The ranges of chemical composition called for in these specifications are given in Table I, and

TABLE I.—*Specified Chemical Compositions of Aluminium Alloys.*

	D.T.D. 404.	D.T.D. 390.	D.T.D. 303.	B.S.S. L46.	B.S.S. L3.
Magnesium, %	{ $\nless 6.5$ $\nless 10.0$	$\nless 0.6$ $\nless 1.8$	$\nless 4.5$ $\nless 5.5$	$\nless 1.0$ $\nless 6.0$	$\nless 0.4$ $\nless 0.9$
Iron, %	$\nless 0.5$	$\nless 0.7$	$\nless 0.5$	$\nless 1.5$ *	$\nless 0.7$
Manganese, %	$\nless 0.6$	{ $\nless 0.3$ $\nless 1.2$	$\nless 0.6$	$\nless 1.5$	{ $\nless 0.4$ $\nless 0.7$
Silicon, %	$\nless 0.5$	$\nless 0.7$	$\nless 0.5$	$\nless 0.7$	$\nless 0.7$
Copper, %	...	{ $\nless 3.5$ $\nless 5.0$	...	$\nless 1.0$ *	{ $\nless 3.5$ $\nless 4.5$
Nickel, %	...	...	...	$\nless 1.5$ *	...
Chromium, %	...	...	...	$\nless 0.5$ *	...
Titanium, %	...	...	...	...	$\nless 0.3$

* Present at option of manufacturer.

the results of chemical analysis of the rivets concerned are given in Table II.

Examination of several rivets revealed that cracking had occurred at the junction of the countersunk head and the shank, as shown in Fig. 2 (Plate XLIII). A photomicrograph of a section etched in 9% orthophosphoric acid for 30 min. is shown in Fig. 9 (Plate XLVI), in which it can be seen that the cracking is intercrystalline and that appreciable grain-boundary precipitation of the β -phase has occurred. Failure was attributed to stress-corrosion.

(b) *Aluminium-5% Magnesium Alloy Rivets.*

Rivets to Specification D.T.D. 303, the range of chemical composition of which is given in Table I, are made in a binary aluminium-

5% magnesium alloy which normally contains not more than 0.5% of other elements. It was found that the heads of $\frac{1}{8}$ -in. dia. mushroom-head rivets used for joining the skin to the stringers on the top surface of the main planes of certain aircraft operating in the tropics were severely corroded. The sheet material which the rivets joined together was aluminium-coated Duralumin to Specification D.T.D. 390 (see Table I for range of chemical composition of the basic alloy). The broken rivet heads were severely corroded and material readily flaked off from under the heads, but the tops of the heads were usually sound.

TABLE II.—*Chemical Composition of Aluminium-Magnesium Alloy Rivets.*

	Defective Mg 7 Rivets.	Defective Mg 5 Rivets.	As-received Mg 5 Rivets.	As-received Mg 5 Rivets.
Size:	$\frac{1}{8}$ -in. dia. countersunk head.	$\frac{1}{8}$ -in. dia. mushroom head.	$\frac{3}{16}$ -in. dia. flat head.	$\frac{1}{8}$ -in. dia. snaphead.
Magnesium, % . . .	7.04	4.62	4.65	4.90
Iron, % . . .	0.50	0.35	0.23	0.33
Manganese, % . . .	0.18	0.15	0.10	0.04
Silicon, % . . .	0.13	0.11	0.12	0.08
Copper, % . . .	Nil	Nil	Nil	Nil
Nickel, % . . .	Nil	Nil	Nil	Trace
Zinc, % . . .	Nil	Nil	Nil	Nil
Titanium, % . . .	Nil	Nil	Nil	Trace
Chromium, % . . .	Nil	Nil	0.08	Nil

The chemical composition of the rivets is given in Table II. Microscopical examination revealed that severe foliation had occurred at the underside of the rivet head, as shown in Fig. 3 (Plate XLIII). Cracks were present in some of the heads (Fig. 10, Plate XLVI). These cracks were intercrystalline and followed the grain flow in the rivet. Corrosion was most severe in the heavily cold-worked regions at the junction of the head and the shank. The rivets were abnormal in that grain-boundary precipitation is not usually present in aluminium-5% magnesium alloy rivets in the condition as supplied by the manufacturer, and they are not normally susceptible to intercrystalline attack. Failure of the rivets occurred as a result of weakness caused by intercrystalline corrosion of the head, particularly at the junction of the head and the shank, and was probably accelerated by stress. Subsequent investigations which are described later in this paper show that the susceptibility to intercrystalline corrosion developed as a result of prolonged exposure to tropical temperatures.

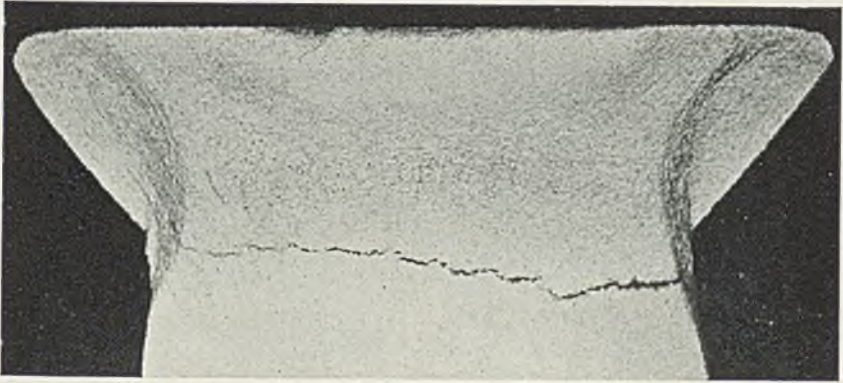


FIG. 2.—7% Magnesium Alloy Rivet Head, showing stress-corrosion crack.
Etched. × 25.



FIG. 3.—Foliation of 7% Magnesium Alloy Rivet Head. × 15.



FIG. 4.— $\frac{3}{8}$ -in. dia. 5% Magnesium Alloy Rivet, as received. Etched. × 10.



FIG. 5.— $\frac{3}{16}$ -in. dia. 5% Magnesium Alloy Rivet after Accelerated Corrosion Test. $\times 40$.



FIG. 6.—5% Magnesium Alloy Rivet As Received. Etched. $\times 40$.

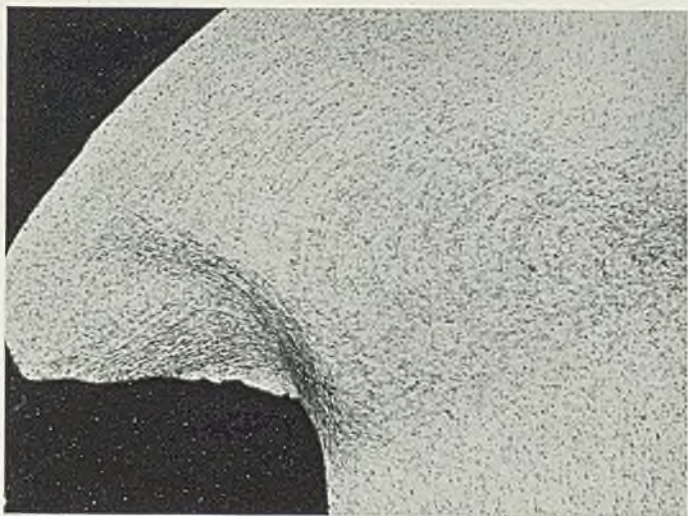


FIG. 7.—5% Magnesium Alloy Rivet after 14 days at 70° C. Etched. $\times 40$.

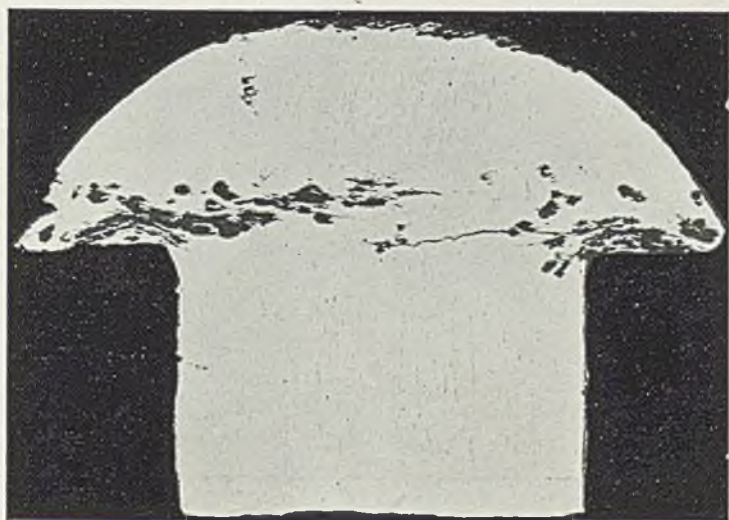
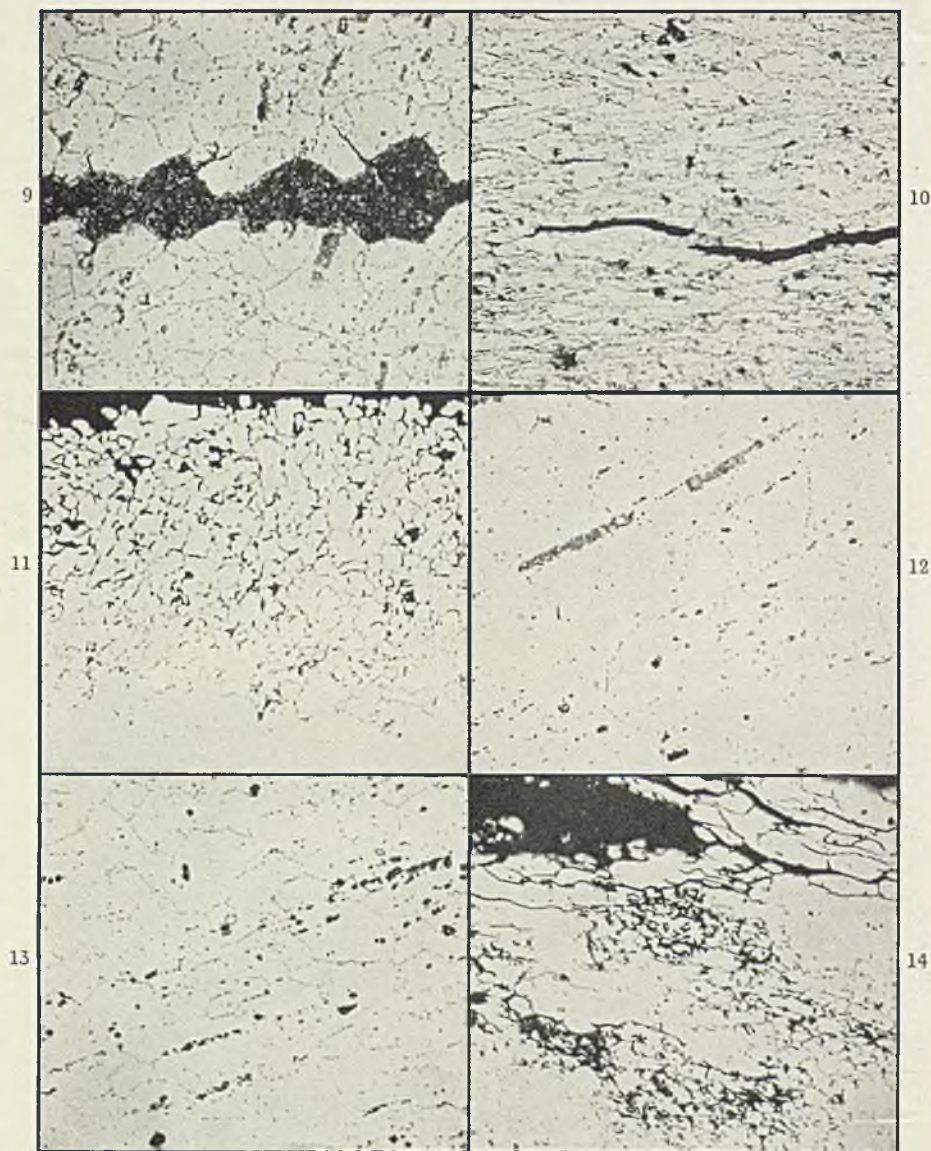


FIG. 8.—5% Magnesium Alloy Rivet after 12 months' exposure to stress-corrosion test. Unetched. $\times 15$.



ALUMINIUM-MAGNESIUM ALLOY RIVETS.

- FIG. 9.—7% Mg. Showing intercrystalline nature of crack. Etched. $\times 500$.
 FIG. 10.—5% Mg. Intercrystalline cracks. Etched. $\times 500$.
 FIG. 11.—5% Mg. Intercrystalline attack in accelerated test. Unetched. $\times 250$.
 FIG. 12.—5% Mg. As received. Etched. $\times 500$.
 FIG. 13.—5% Mg. Heated 14 days at 70° C. Etched. $\times 500$.
 FIG. 14.—5% Mg. Intercrystalline corrosion. Unetched. $\times 250$.

EXAMINATION OF RIVETS AS RECEIVED FROM THE MANUFACTURER.

Microscopical examination of aluminium-5% magnesium alloy rivets from several different batches of $\frac{1}{8}$ -in. dia. rivets in the condition as received from the manufacturer usually revealed a fairly uniform distribution of finely divided β -phase particles and only a very slight and local indication of grain-boundary segregation. Grain boundaries were not usually revealed even after etching specimens for 30 min. in 9% orthophosphoric acid solution.

Examination of one set of rather large flat-head rivets, $\frac{3}{16}$ in. dia. and 4 in. long, revealed a very different structure, however. Heavy precipitation of β -phase had occurred and the grain boundaries were readily revealed by etching sections of the rivets in 9% orthophosphoric acid. The darkly etched areas shown in Fig. 4 (Plate XLIII) indicate regions that have been severely cold worked during heading. Heavy precipitation has occurred in these regions and pronounced grain-boundary precipitation has occurred elsewhere in the rivet. Some of the rivets were immersed for 24 hr. in a normal solution of sodium chloride containing 1% of hydrogen chloride by weight. Severe attack occurred, as shown in Fig. 5 (Plate XLIV), and was rather more severe in the heads than in the shanks. Fig. 11 (Plate XLVI) shows the intercrystalline nature of the attack. The chemical composition of the rivets is given in Table II, from which it may be seen that the alloy contained 0.08% of chromium. Whether or not the chromium was intentionally added to prevent grain-boundary precipitation of the β -phase as suggested by Siebel and Vosskühler,⁶ is not known, but the amount present was apparently insufficient to have any beneficial effect.

LABORATORY INVESTIGATION OF THE EFFECTS OF TROPICAL TEMPERATURES ON D.T.D. 303 ALLOY RIVETS.

In view of the extensive use of rivets in this material and the apparent susceptibility to stress-corrosion failure under tropical conditions, it was decided to investigate the following features, using $\frac{1}{8}$ -in. dia. rivets to Specification D.T.D. 303:

A. The effect of prolonged heating at tropical temperatures on rivets in various heat-treated conditions.

B. The possibility of heat-treating rivets so as to prevent the formation of a continuous grain-boundary network of β -phase.

C. The resistance to stress-corrosion failure of sets of lap joints, each set riveted with rivets in a particular state of heat-treatment.

The results of chemical analysis of the batch of rivets used are given

in Table II. The chemical composition of the rivets complies with the requirements of Specification D.T.D. 303, the total impurities present amounting to 0.45%.

A. Effect of Prolonged Heating at Tropical Temperatures on Rivets in Various Conditions.

Several batches of rivets in the condition as supplied by the manufacturers were heat-treated. Most of the batches were given a preliminary anneal at 350–360° C. for 30 min. and air-cooled before being given a stabilizing treatment at a lower temperature. In order to reproduce the effects of exposure to tropical heat, rivets in various conditions were maintained at 70° C. for 14 days. This temperature was selected because metal surfaces exposed to the direct rays of tropical sunlight attain temperatures of this order. The heat-treatments of the various batches of rivets are given in Table III.

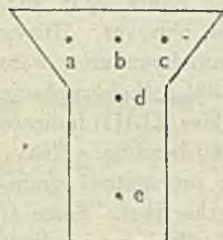


FIG. 15.

Diamond pyramid hardness tests were made on two or three rivets from each of several heat-treated batches, five impressions being made on each rivet in positions shown in Fig. 15.

TABLE III.—*Heat-Treatment of Various Batches of Rivets.*

Batch.	Heat-Treatment.
A	As supplied by manufacturer.
B	Annealed 30 min. at 350–360° C. and cooled in air.
C	As A, heated 14 days at 70° C.
E	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> 30 min. at 350–360° C. </div> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> 14 days at 70° C. </div> <div style="border-left: 1px solid black; padding-left: 10px;"> <div style="display: flex; flex-direction: column; align-items: center;"> <div>1 hr. at 120° C.</div> <div>1 hr. at 150° C.</div> <div>1 hr. at 180° C.</div> <div>1 hr. at 210° C.</div> <div>1 hr. at 100° C.</div> <div>2 hr. at 100° C.</div> <div>2 hr. at 120° C.</div> <div>4 hr. at 120° C.</div> <div>2 hr. at 150° C.</div> </div> </div> </div> </div>
F	
G	
H	
J	
K	
L	
M	
N	
O	

The results of the tests are given in Table IV. The hardness values obtained show that rivets in the as-received condition are appreciably harder than those heated at 350–360° C. for 30 min. and air-cooled. This is doubtless due to the rivets' having been made by cold heading from wire that has had a light drawing pass after annealing. Heating

rivets in the as-received condition at 70° C. for 14 days resulted in a slight decrease in hardness, indicating that some softening had occurred during this low-temperature heat-treatment. Rivets annealed at

TABLE IV.—*Diamond Pyramid Hardness of Sectioned Rivets after Heat-Treatment.*

Tests carried out in duplicate or triplicate.

Batch.	Condition.		Hardness ($H_D/24$) at Positions Shown in Fig. 15.				
			a.	b.	c.	d.	e.
A	As-received.		126	109	126	90	92
			123	109	126	95	103
			131	140	128	95	94
		Mean	127	119	127	94	96
B	30 min. at 350–360° C.		79	83	76	84	86
			79	75	76	67	78
			70	74	75	71	81
		Mean	76	78	76	74	82
C	As-received and heated 14 days at 70° C.		116	97	123	89	94
			119	97	119	89	86
		Mean	118	97	121	89	90
E	30 min. at 350–360° C. and heated 14 days at 70° C.		81	76	78	84	83
			83	80	76	75	83
			87	83	82	86	86
		Mean	84	80	79	82	84
F	30 min. at 350–360° C., 1 hr. at 120° C., and 14 days at 70° C.		80	74	73	75	75
			74	74	75	75	78
			80	75	71	75	74
		Mean	78	75	73	75	76
G	30 min. at 350–360° C., 1 hr. at 150° C., and 14 days at 70° C.		76	70	70	67	71
			72	70	71	66	71
			78	79	78	70	70
		Mean	76	73	73	68	71
H	30 min. at 350–360° C., 1 hr. at 180° C., and 14 days at 70° C.		76	76	75	81	79
			78	83	76	83	80
			76	78	76	...	80
		Mean	77	79	76	82	80
J	30 min. at 350–360° C., 1 hr. at 210° C., and 14 days at 70° C.		74	78	73	73	71
			79	75	75	73	79
			81	74	76	75	80
		Mean	78	76	75	74	77

350–360° C. air-cooled, and then given a stabilizing treatment followed by heating for 14 days at 70° C., gave hardness values similar to those of rivets that had been annealed only. As would be expected, the

tests also show that the heavily cold-worked regions of the heads of rivets that have not been annealed are appreciably harder than the shanks.

Longitudinal sections of rivets from each batch (see Table III) were etched in 9% orthophosphoric acid at 20° C. for 30 min. and examined microscopically. The microstructures of rivets from batches *A* and *B* were almost identical, the amount of grain-boundary segregation of the β -phase being very slight. Fig. 6 (Plate XLIV) and Fig. 12 (Plate XLVI) are typical of the microstructures of these two batches of rivets.

Rivets in the conditions as supplied and as annealed at 350–360° C. (batches *C* and *E*) showed appreciable grain-boundary precipitation in the form of a continuous network of β -phase after heating for 14 days at 70° C., as shown in Fig. 13 (Plate XLVI). Precipitation was heaviest in the severely cold-worked regions of the head, as shown by the darkly etched regions in Fig. 7 (Plate XLV).

In order to establish whether precipitation occurred gradually or after a period of heating at 70° C., rivets were examined at intervals of one day over a period of a fortnight. The evidence obtained was somewhat conflicting, as some rivets showed precipitation after a few days, whereas others showed no precipitation until about the tenth day. Generally, however, all specimens examined after 12 days at 70° C. showed appreciable precipitation in the form of a continuous grain-boundary network.

B. Prevention of Grain-Boundary Precipitation of β -Phase.

In an attempt to prevent grain-boundary precipitation at tropical temperatures, rivets that had been annealed at 350–360° C. were given various stabilizing treatments, as shown in Table III, batches *F* to *O*.

Stabilizing treatments at temperatures of 150° C. and above and for less than 2 hr. at 100° or 120° C. did not completely prevent the formation of a grain-boundary network in rivets subsequently heated for 14 days at 70° C. Formation of a grain-boundary network of β -phase was prevented by heating at 100–120° C. for 2 hr. or more. The formation of a continuous grain-boundary network appeared to have been prevented as a result of the spheroidization and coalescence of grain-boundary particles.

In order to determine the effect of cold work on the precipitation of the β -phase, lap joints were made using rivets in the following conditions: (a) as received, batch *A*; (b) as annealed, batch *B*; (c) annealed and then heated for 2 hr. at 100° C., *i.e.* stabilized.

The lap joints were then heated at 70° C. for 14 days, after which

the rivets were removed from the joints, sectioned longitudinally and examined microscopically. The results of the examination showed that grain-boundary precipitation in the form of a continuous network had occurred in all the rivets, particularly in heavily worked portions, and even in those rivets that had been given a stabilizing treatment. Although the precipitation was not quite so severe in the stabilized rivets as in rivets from series (a) and (b), it was considered that the stabilized rivets would be rendered susceptible to intercrystalline attack if they were driven and then subjected to tropical conditions for an appreciable period. It was also evident that in rivets in the conditions as received and as annealed, grain-boundary precipitation after heating at tropical temperatures was greater in driven than in undriven rivets.

C. Stress-Corrosion Tests.

Three series of test-pieces were made using rivets in the following conditions :

- A. As received from the manufacturer.
- B. As annealed for 30 min. at 350–360° C. and cooled in air.
- C. As-received rivets heated for 14 days at 70° C.

Each series consisted of ten test-pieces and the programme of tests carried out was as follows :

TEST-PIECE No.	CONDITION OF TEST.
1 and 2	Tested in tension immediately after riveting.
3 and 4	Subjected to continuous stress (without sea-water spray) for 12 months and then tested in tension.
5 and 6	Subjected to continuous stress while exposed to sea-water spray and, if unbroken after 3 months, tested in tension.
7 and 8	As 5 and 6, but tested in tension after 6 months.
9 and 10	As 5 and 6, but tested in tension after 12 months.

Single-riveted lap-joint test-pieces were made from 14G Duralumin sheet to B.S. Specification L3. The test-pieces, which were about 12 in. long by 1½ in. wide, were riveted at mid-length with a half-inch overlap and were stressed in bending by three-point loading. The test-pieces were fitted in frames with the centre line of the rivet midway between end supports under which the ends of the test-piece were free to slip. Load was applied by raising a support, situated at a distance of half an inch from the centre line of the rivet and bending the test-piece until an estimated axial tensile load of 100 lb. was induced in the rivet shank. This is equivalent to a tensile stress of approximately 3.6 tons/sq. in. The specimens that were sprayed with sea-water were coated with lanolin, except in the immediate vicinity of the rivet,

and were sprayed at room temperature (20° C. approx.) three times a day. One of the specimens (C10) broke in the frame after about 9 months' exposure; failure was due to parting of the rivet at the junction of the head and the shank.

After appropriate periods of exposure, the remaining specimens were subjected to tensile tests, the rivets being tested in shear. The results of these tests are given in Table V. All the test-pieces failed

TABLE V.—*Stress-Corrosion Tests on Riveted Joints.*

Test-pieces bent in frames, so as to induce a load of 100 lb. tension in rivet shank.

Test-Piece No.	Time Exposed to Stress (100 lb. tension), months.	Time Exposed to Sea-water Spray, months.	Failing Load of Joint, lb.		
			Series A.	Series B.	Series C.
			Rivets as received.	Rivets annealed 30 min. at 350-360° C.	Rivets heated 14 days at 70° C.
1	Nil	Nil	390	363	380
2	Nil	Nil	387	363	384
3	12	Nil	392	343	351
4	12	Nil	380	348	375
5	3	3	379	352	351
6	3	3	381	353	358
7	6	6	377	336	363
8	6	6	379	359	373
9	12	12	351	356	336
10	12	12	321	358	... *

* Broken under test after 9 months' exposure.

as a result of shear of the rivets. The test results show that even after 12 months' exposure to stress and corrosion the reduction in shear strength of the rivets is negligible. It will be noted that specimen C9, which is the corresponding specimen to C10 from the same series and which was tested in tension after 12 months' exposure, failed by shear of the rivet at a load of 336 lb. This value is only slightly lower than that obtained on specimens tested immediately after riveting.

MICROSCOPICAL EXAMINATION OF STRESS-CORROSION TEST-PIECES.

All the fractured rivets from the stress-corrosion test-pieces were sectioned longitudinally and microscopically examined. The results of the examination were as follows.

Series A and B.—Rivets from test-pieces 1 and 2 (Series A and B) showed that at the commencement of the tests the microstructures of rivets from both batches were almost identical. There was evidence of very slight grain-boundary precipitation at isolated places, but this

was not considered to be serious. Rivets from specimens 3 and 4 showed microstructures similar to those of specimens 1 and 2. There was no indication of any increase in the amount of grain-boundary precipitation having occurred over a period of 12 months at room temperature. The corrosion of rivets from specimens 5 to 10 was not severe and was chiefly of the pitting type. There was, however, a very slight tendency for intercrystalline attack to occur, presumably where there had originally been grain-boundary precipitation of the β -phase. As would be expected, specimens that had been given the longest exposure had corroded to the greatest extent, and the corrosion of individual rivets was most severe in regions that had been heavily cold worked.

No evidence of stress-corrosion cracking at the junction of the preformed head and the shank of the rivets was detected.

Series C.—Microscopical examination of rivets from test-pieces 1 and 2 (Series C) revealed that as a result of heating the rivets at 70° C. for 14 days pronounced grain-boundary precipitation of the β -phase in the form of a continuous network had occurred.

Rivets that had been subjected to the stress-corrosion test had suffered appreciable intercrystalline attack after only 3 months' exposure, and as the period of exposure became more prolonged the severity of the attack increased. The attack was chiefly confined to the heavily cold-worked regions at the junction of the head and the shank, a typical example of which is shown in Fig. 8 (Plate XLV). In many of the rivets, corrosion cracking had penetrated almost completely through the head. It had been so severe in specimen 10 that the rivet head broke away after only 9 months' exposure. Typical intercrystalline attack was observed at the fracture, as shown in Fig. 14 (Plate XLVI). Specimen 9 withstood the stress-corrosion test for 12 months and failed at a load of 336 lb. when the joint was tested in shear. This failing load is only 50 lb. lower than that of joints tested immediately after riveting. A section through this rivet is shown in Fig. 8 (Plate XLV), from which it may be seen that intercrystalline cracking has penetrated almost completely through the head.

DISCUSSION OF RESULTS.

The work described in this paper shows that prolonged heating at tropical temperatures of aluminium-5% magnesium alloy rivets results in grain-boundary precipitation of the β -phase in the form of a continuous network, the presence of which renders the material susceptible to intercrystalline corrosion. The formation of this network occurs more readily when the material is cold worked before heating at

tropical temperatures. The results obtained are in agreement with the results of work on alloys of somewhat higher magnesium content by other investigators, to which reference has already been made. In weathering tests on rivets made in an aluminium-6% magnesium alloy used for joining aluminium-coated Duralumin sheet, Mutchler¹⁵ found that severe intercrystalline attack of the rivets occurred after about 2 years' exposure to marine atmospheres in temperate and tropical climates.

The results of mechanical tests described earlier in this paper have shown that even in specimens in which intercrystalline corrosion has penetrated almost completely through the rivet head, the shear strength of riveted lap joints is not seriously affected after 12 months' exposure to sea-water spray. Under service conditions, however, although rivets are usually stressed in shear, tensile stresses such as those resulting from internal stress or from panting of a panel are developed in the rivet shank. Since the rate of chemical attack at tropical temperatures will be greater than at the laboratory temperature at which the corrosion tests described were made, it is to be expected that under tropical conditions there will be very severe corrosion of the rivets and the heads will be liable to flake off.

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CONTROL OF INTERNAL STRESSES IN HEAT-TREATED ALUMINIUM ALLOY PARTS.*

By L. E. BENSON,† M.Sc., MEMBER.

SYNOPSIS.

Serious internal stresses may develop in aluminium alloy parts on quenching after solution-treatment. It is shown that for the alloy D.T.D. 410 such stresses are unaffected by subsequent precipitation-hardening. Two methods of minimizing the final stresses are compared, and data are given regarding the physical properties of the alloy. It is believed that the principles involved are applicable to other heat-treated aluminium alloys.

RISK OF QUENCHING STRESSES IN ALUMINIUM ALLOY PARTS.

THE normal heat-treatment applied to many aluminium alloys and called for in many specifications involves quenching from a temperature in the region of 500° C. and subsequent precipitation-hardening. What is not so well known, although it has been referred to in the published literature by a number of workers, including Grogan and Clayton,¹ Sachs,² von Zeerleder,^{3, 4} Mortimer and Paige,⁵ and Murphy,^{6, 9} is that this treatment may set up internal stresses of dangerous magnitude. These stresses arise from the differential cooling and contraction on quenching, the magnitude of the stress increasing with the mass of the part and the speed of quenching.

With parts of even moderate size, very high stresses can be generated; Fig. 1 (Plate XLVII) shows a quenched and hardened cylinder in Duralumin S, 8 in. in dia., which ruptured spontaneously on machining the ends. This example illustrates also the characteristic distribution of quenching stresses, namely, tensile stress in the interior balanced by compressive stress towards the outside, as would be expected and as has been demonstrated already by Sachs² and von Zeerleder.^{3, 4}

Clearly, the presence of such high stresses is of great importance on account of the risk, not only of internal rupture, but of distortion on machining or in service or of failure in service through unsuspected stress effects in addition to the calculated service stresses.

Experience during the war has shown that these risks are not sufficiently appreciated by suppliers of aluminium castings and forgings, by machine-shop executives, or by engineers responsible for design and ultimate serviceability. The author has come across numerous cases

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of the distortion of aluminium alloy parts resulting from quenching stresses introduced by the makers, and the forging shown in Fig. 1 was actually supplied to make a high-speed centrifuge. Furthermore, the wording of the heat-treatment clause in some specifications which permit or demand quenching without qualification is misleading in suggesting that such a treatment is normal and safe, and the author's firm have had to issue their own specifications for large and medium-sized forgings and castings because it was found unsafe to use existing standard specifications.

It is the object of this paper, therefore, to draw attention again to the risk of dangerously high stresses in quenched aluminium alloy parts and to compare two methods of minimizing the quenching stresses.

EXPERIMENTAL.

The experiments described below were made on wrought metal to D.T.D. 410, *i.e.*, R.R. 56, having the following specification analysis: copper 1.8-2.5, nickel 0.6-1.4, magnesium 0.65-1.2, iron 0.6-1.2, silicon 0.55-1.25, and titanium 0.05-0.15%.

The experiments, which were carried out several years ago in connection with service contracts, concerned the effects of:

- (1) Dimensional changes during precipitation-hardening on quenching stresses.
- (2) Stress relief accompanying, or subsequent to, precipitation-hardening on quenching stresses.
- (3) Solution-quenching-water temperature on internal stresses.
- (4) Stress-relieving treatment and of increasing quenching water temperature on mechanical properties.

Effect of Dimensional Changes During Precipitation-Hardening on Quenching Stresses.

Precipitation-hardening of aluminium alloys is not normally accompanied by volume changes of such magnitude as will have a significant effect on the distribution or magnitude of stresses due to the previous quenching operation. This can be demonstrated with small quenched specimens, which will contain only low quenching stresses, by carrying out the precipitation-hardening treatment in a dilatometer.

Fig. 2 refers to one such test in which a $\frac{1}{2}$ -in. dia. specimen was first solution-treated and then placed in a dilatometer and given the normal precipitation-hardening treatment at 200° C. followed by heating to 350° C., at which temperature the material became considerably over-

tempered and softened. As will be seen, there is no significant dimensional change beyond normal expansion and contraction. The final dimensions are the same, of course, if the specimen is left in the hard state by cooling from 200° C. without being given the over-tempering treatment at 350° C.

Stress-Relief Effects During Precipitation-Hardening.

To investigate the possibility of quenching stresses being relieved by plastic flow during the precipitation-hardening treatment, stress-

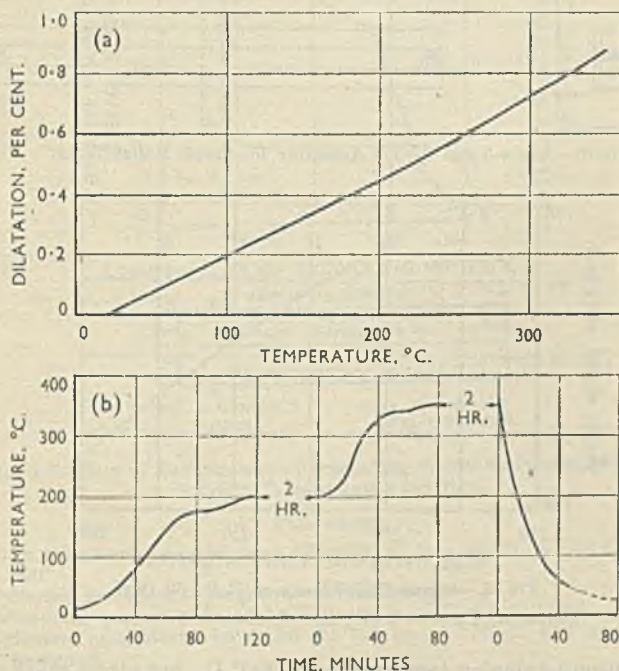


FIG. 2.—Dimensional Changes in Aluminium Alloy on Precipitation-Hardening.

relief tests were made over a range of temperatures including the normal precipitation-hardening temperature.

The test-bars used were $\frac{3}{4} \times \frac{1}{2}$ in. rolled section, solution-treated at 530° C. and hardened at 200° C. in the normal way. The procedure was to strain the bars in pairs in a frame (see Fig. 3) substantially the same as that described previously.^{7,8} The initial fibre stress at the surface was 5 tons/sq. in., and the annealing was carried out for 3 hr.

at the chosen temperature; the percentage stress-relief after annealing is shown in Fig. 4.

As will be seen, very little relief of initial stress occurs at the normal

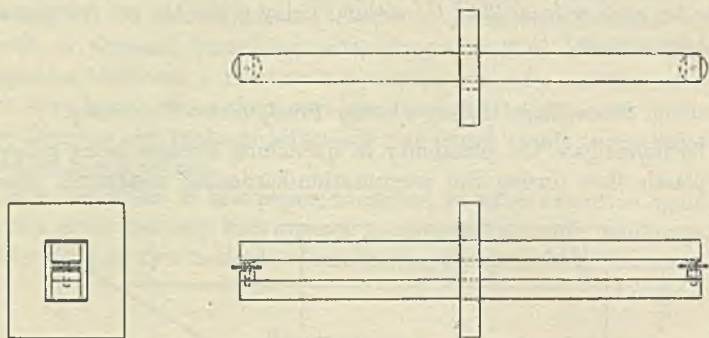


FIG. 3.—Screw-Type Wedge Assembly for Stress Relief Tests.

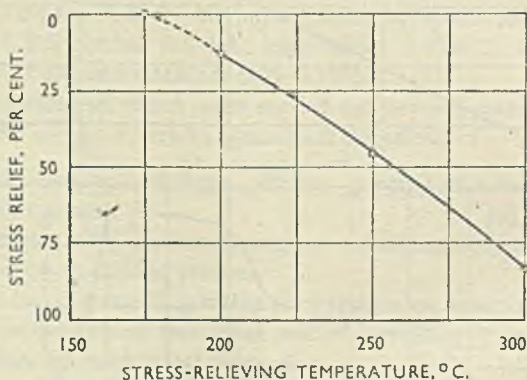


FIG. 4.—Stress-Relief Tests on R.R. 56 Bars.

Duration of test = 3 hr.; initial stress = 5 tons/sq. in.

precipitation-hardening temperature of 200° C., but stress relief occurs progressively as the temperature is increased, a substantially stress-free condition being reached only after treatment at temperatures in the region of 300° C.

Severity of Solution-Quenching Treatment and Magnitude of Internal Stresses.

A method of modifying quenching stresses sometimes practised is to reduce the severity of the quench. This may be done by quenching in oil instead of in water or by quenching in warm instead of cold water.

The following experiments were made to show the influence of the temperature of the quenching water on the magnitude of the internal stress. Test cylinders were machined from a D.T.D. 410 forging and put through the normal heat-treatment (2 hr. at 530° C., water-quenched, followed by 7-8 hr. at 175° C.), except that for different bars the quenching water was at 15°, 70°, 85°, or 100° C. After treatment, the cylinders were machined and measured so that a relative estimate of

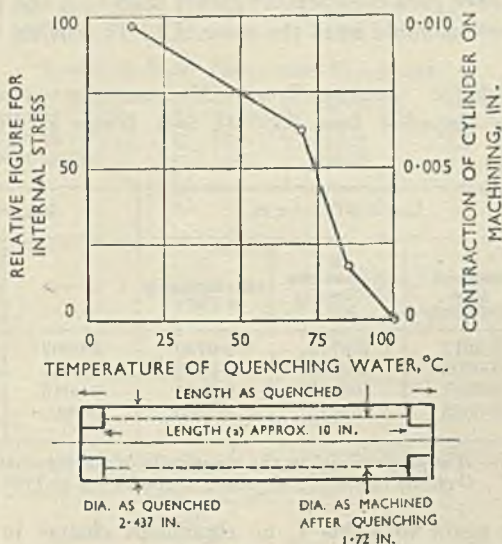


FIG. 5.—Effect of Temperature of Quenching Water on Internal Stress in Solution-Treated and Aged Bars.

PROCEDURE.

- (i) Four cylinders quenched from 525-530° C. into water at 15°, 70°, 85°, or 100° C.
- (ii) Cylinders machined to length (a) and measured.
- (iii) Cross-sectional area reduced by 50% and length (a) remeasured.
- (iv) Cylinders precipitation-hardened for 7-8 hr. at 175° C. and length (a) re-measured.
- (v) Cylinders used for extensometer tensile tests.

the magnitude of the internal stress could be made. This was done by machining away the outside layers in such a way that the cross-sectional area was reduced by 50% and measuring the accompanying change in length of the remainder.

Fig. 5 shows the dimensions of the test cylinders, with details of the machining and measuring procedure, and indicates graphically the influence of the temperature of the quenching water on the internal stress as shown by the change in length on machining.

Table I gives the results of the measurements of length, and it will be seen that the core of the cylinder contracted in length on machining, so that the stress system must have been tension at the centre balanced by compression towards the surface, as expected. Incidentally, taking the modulus of elasticity as 4500 tons/sq. in., the mean stress in the bar quenched in cold water is seen to be approximately 4.5 tons/sq. in., so that the maximum stresses at the surface and at the centre must have been considerably higher than this, and for a normal stress distribution would be of the order of 10-12 tons/sq. in.

TABLE I.—*Relative Internal-Stress Measurements on R.R. 56 Cylinders Quenched from 530° C. into Water at Various Temperatures.*

Temp. of Quenching Water, ° C.	Length of Cylinder, in.			Differences, in.	
	A Machined after Quenching.	B Cross-Section Reduced by 50%.	C After Hardening at 175° C.	A - B	B - C.
15	9.9812	9.9715	9.9720	0.0097	-0.0005
70	10.0008	9.9945	9.9945	0.0063	-0.0000
85	9.9447	9.9429	9.9435	0.0018	-0.0006
100	9.9835	9.9835	9.9840	0.0000	-0.0005

N.B.—A - B is proportional to the magnitude of the internal stress.

B - C shows the negligible effect of treatment at 175° C.

Referring again to Table I, no significant change in dimensions occurred on precipitation-hardening, thus confirming the results of the dilatometric experiments referred to above.

Effect on Mechanical Properties of Increasing Solution-Quenching-Water Temperature, or the Precipitation-Hardening Temperature, so as to Reduce Internal Stresses.

Whilst the above experiments showed that internal stresses could be reduced by increasing the precipitation-hardening temperature or the quenching-water temperature, it seemed likely that either method would involve some sacrifice of mechanical properties. In view of this, specimens which were used for the stress-relief tests and for the quenching tests were now machined for extensometer tensile tests.

The test figures obtained are given in Table II, the shape of the load-extension curves being shown in Figs. 6 and 7. In comparing these figures, it should be noted that the material for the stress-relief tests was rolled and heat-treated bar of only $\frac{1}{2} \times \frac{3}{4}$ in. section, whilst

TABLE II.—Tensile Test Results on R.R. 56 Alloy.

Treatment.	0.1% Proof Stress, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, %.	Redn. of Area, %.
<i>Stress-Relief Annealing Experiments on $\frac{1}{4} \times \frac{1}{2}$ in. Heat-Treated Bar.</i>				
As treated	22.8	26.2	14	17.8
After 3 hr. at 200° C.	22.1	25.0	15	15.1
After 3 hr. at 250° C.	16.0	20.4	14	22.5
After 3 hr. at 300° C.	8.9	16.0	15	25.3
<i>Quenching-Water Temperature Experiments.</i>				
Quenching water at 15° C.	23.0	26.0	1.3	2.5
Quenching water at 70° C.	21.8	25.7	1.5	2.5
Quenching water at 85° C.	20.5	24.0	1.5	2.5
Quenching water at 100° C.	16.3	21.8	3.2	3.5

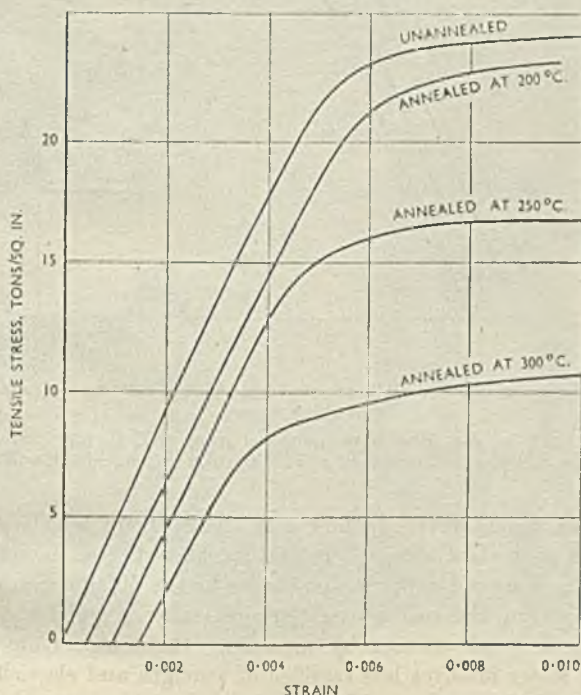


FIG. 6.—Extensometer Tensile Tests, showing effect of final stress-relief annealing.

Treatment: Bars solution-treated and precipitation-hardened, then annealed for 3 hr. at temperatures indicated, machined, and tested.

the quenching test-pieces were approximately $2\frac{1}{8}$ in. in dia. and had been machined from a $2\frac{3}{4}$ -in. thick forging. There is naturally, therefore, considerable discrepancy between the two sets of ductility figures.

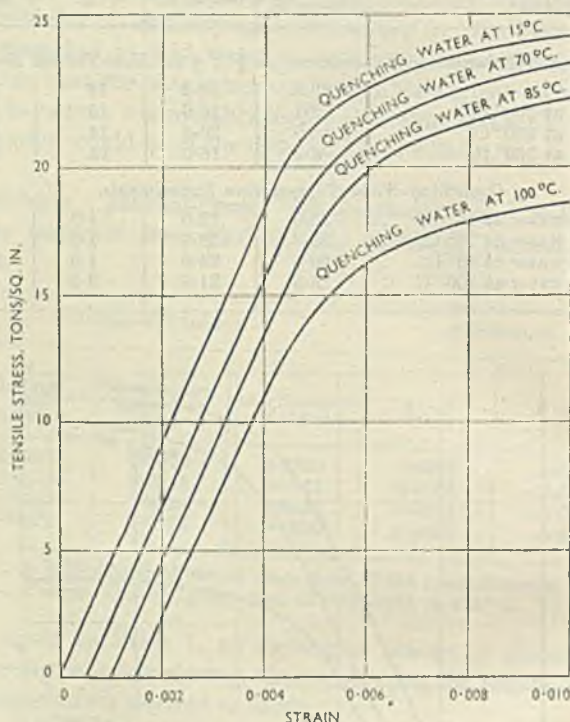


FIG. 7.—Extensometer Tensile Tests, showing effect of varying temperature of quenching water.

Treatment: $2\frac{7}{8}$ -in. dia. bars were quenched from 530° C. into water at the temperatures shown, then tempered at 175° C. for 8 hr., machined, and tested.

It is interesting, however, to find that the ultimate tensile strength and elastic properties obtained in the initial tests are in very good agreement and are not appreciably affected by the difference in mass.

On comparing the two sets of tests generally, it will be seen that minimizing internal stresses by increasing the temperature of the quenching water involves less sacrifice of strength and elasticity than final stress-relief annealing. The comparison can be seen more clearly by reference to Fig. 8, in which the tensile strength and 0.1% proof stress are plotted against the remanent internal stress. From the general shape of the two upper curves in the diagram, it also appears

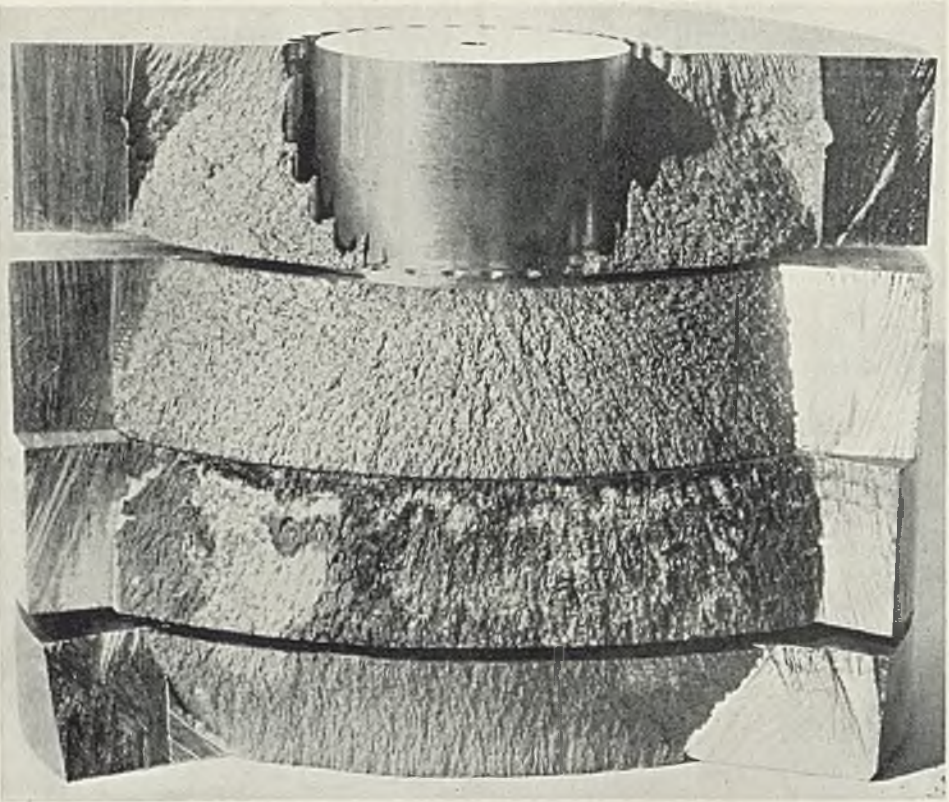


FIG. 1.—Quenched and Hardened Duralumin Cylinder (8 in. dia.) which ruptured spontaneously on machining the ends.

that for many purposes the best combination of physical properties with low internal stress is obtained by quenching in water at about 85° C., though to obtain minimum internal stresses water at 100° C. is required.

CONSIDERATION OF RESULTS.

It has been shown that the stress system developed on water-quenching aluminium alloy parts in D.T.D. 410 alloy is substantially unaffected by the subsequent precipitation-hardening treatment, since the temperature is ordinarily too low for stress relief to occur and since

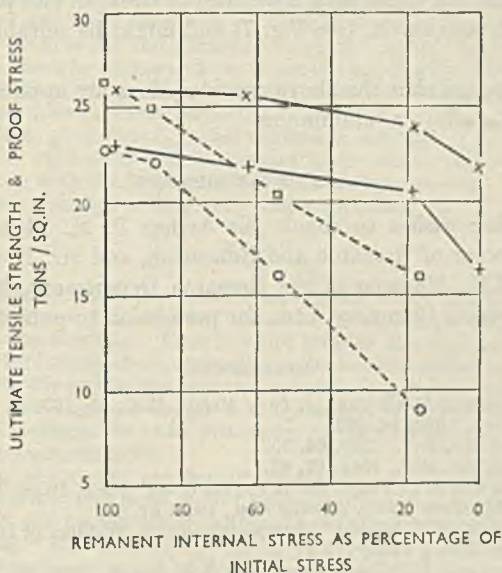


FIG. 8.

X — X } Quenching-water experiments.
 + — + }
 □ — □ } Stress-relief annealing experiments.
 ○ — ○ }

precipitation-hardening is not accompanied by appreciable volume change.

There are two possible methods of reducing quenching stresses by modifying the heat-treatment procedure: (1) The treated part may be given a final stress-relieving treatment, or (2) the quenching may be made less drastic as, for instance, by increasing the temperature of the quenching water. The former procedure would probably be carried

out most conveniently in practice by increasing the precipitation-hardening temperature. The former method is used by at least one manufacturer⁹ of Diesel-engine pistons, but the latter method appears to be preferable for general engineering applications, since it involves the least sacrifice of tensile strength and elastic properties.

Under the conditions of the experiments described, freedom from internal stress was obtained by quenching in water substantially at 100° C.; the tensile strength and 0.1% proof stress were then reduced by 4-5 tons/sq. in., and this treatment has been successfully used with very large forgings. Quenching in water at 85° C. produced a very useful reduction of stress with a sacrifice of strength and proof stress of only about 2 tons/sq. in. (see Fig. 7) and might be suitable for certain work.

It is suggested that the above considerations are applicable to other heat-treatable alloys of aluminium.

ACKNOWLEDGEMENTS.

The author wishes to thank Sir Arthur P. M. Fleming, C.B.E., D.Eng., Director of Research and Education, and Mr. B. G. Churcher, M.Sc., M.I.E.E., Manager of the Research Department, Metropolitan-Vickers Electrical Company, Ltd., for permission to publish this paper.

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DISCUSSION ON DR. R. F. HANSTOCK AND MR. A. MURRAY'S PAPER: "DAMPING CAPACITY AND THE FATIGUE OF METALS." *

(*J. Inst. Metals*, this vol., p. 97.)

PROFESSOR F. C. THOMPSON,† M.Sc., D.Met. (Member of Council): My first words must be ones of whole-hearted admiration for the paper, congratulations on the work itself—it is a classic—and congratulations and thanks to the authors for the detailed description of the apparatus, which enables anyone else who wishes to do so to use it; and finally, but by no means least, congratulations on the extraordinarily clear way in which a very complicated piece of work has been presented.

The paper is so good that it makes discussion difficult. One point which I should like the authors to look into again is concerned with equation (16) on p. 110, dealing with the heating effect of the exciting current. It seems to me that the rate of change of frequency with temperature is :

$$\frac{\delta f}{\delta t} = f \left(\frac{\alpha}{2} + \frac{\beta}{2} \right).$$

That does slightly increase the possible temperature rise, if I am right, but the difference is not very significant. There is an additional point, however, which I should like to make. Here it is not perhaps the average rise of temperature which is of significance, so much as some local maximum temperature. As the heat from the end in the exciter coil is conducted downwards into the specimen, one would expect to get a temperature variation, and it is the maximum local temperature at or just under the skin of the specimen which may be of greatest significance.

Passing on to the results, the first impression with which the paper leaves me is that there is not, and there is no likelihood of being, any single form of apparatus which will be universally applicable to all aspects of the measurement of damping. The authors' apparatus seems to me to be ideal for non-magnetic non-ferrous materials of high electrical conductivity. From their own curves it is clear that for steels the method is less satisfactory, despite the very ingenious manner in which the authors have tackled that problem; and it would be of interest in the non-ferrous field if they would publish the results given by their apparatus on non-ferrous materials of high resistivity.

In extending what I may call (for want of a better term) the physical methods of measurement to stresses of the order of 10 tons/sq. in., the authors have done a really remarkable piece of work.

In connection with the authors' remarks on fatigue, the results again are of extreme interest. It appears from the paper that the only materials which showed the very curious change in damping characteristics as a result of the continued vibration before test were aluminium and its alloys. I am not altogether satisfied that all the effects which have been described so well are necessarily due to the formation of fatigue cracks. If that had been the case I should have expected the same sort of effect to be observed with copper

* Discussion at the Annual General Meeting on March 13.

† Professor of Metallurgy, The University, Manchester.

as with aluminium; and that, as far as I can see from the paper, has not been found.

I throw it out as a suggestion that in aluminium alloys there is the possibility that some of the effects observed may be due either to recrystallization or at any rate to some stress- or strain-relief. Aluminium does sometimes behave in a rather curious way, and that is at any rate not an impossibility.

MR. H. G. WARRINGTON * (Member): When, more than ten years ago, the late Dr. Frommer started this investigation at the instigation of Colonel W. C. Devereux on the first Förster apparatus to be installed in this country, he was soon satisfied that the property of energy absorption by damping was one of the least understood properties of metals, and one for the measurement of which no satisfactory technique existed. It is this development of suitable apparatus for the study of damping which has resulted in the present paper.

I would raise one question on the temperature of the specimen, arising from the remarks made on p. 110 of the paper, where the authors estimate that the average temperature of the specimen increased by 15° C. in 5 hr., that estimate being obtained by calculation. I cannot find any authoritative information on the temperature coefficient of the rigidity modulus, which may vary for different aluminium alloys. In addition to heating by the exciter, there must be a slight temperature increase due to the actual energy change, and while the effect on damping measurements may not be serious, temperature is of more importance, I feel, on the fatigue work, and particularly so with the aluminium alloys containing 6–15% of magnesium, where precipitation of β may be accelerated at temperatures which are quite moderate, or, in the case of the age-hardening of solution-treated commercial aluminium alloys, where the rate and perhaps the mode of age-hardening may be altered even by such temperature changes as those of the order quoted. I feel, therefore, that the results of some temperature measurements might with advantage be given, and that the authors might give not only the actual rise in temperature but also the temperature gradients within the specimen.

DR. C. H. DESCH, F.R.S. (Past-President): This is a first-class piece of work. I have always felt, with regard to previous publications of research work on damping, that most people were measuring the damping of the machine which they used, and it was only when Dr. Frommer introduced his methods of suspension that we got entirely unexceptionable results. This continuation of that work with a further development of the apparatus is most interesting. I think that we can, as previous speakers have said, accept these results as representing the real damping capacity and not some combination of factors.

CORRESPONDENCE. *

DR. G. L. J. BAILEY,† A.R.C.S.: The many-fold increase in damping capacity at high strains which arises from the presence of incipient fatigue failure and which is presumably due to sub-microscopic cracks, is interesting. Can the authors say if any estimate is possible of the fractions of the increased energy absorption which are dissipated in friction on the faces of a fracture and which go to increase the depth of the crack? It does seem that the damping capacity under these conditions might be to a large extent a measure of

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the surface-frictional properties of the material. In this connection, experience with the Föppl-Pertz machine may be relevant. This machine clearly distinguishes between materials, yet, as is now evident, only a small fraction of the vibrational energy can be absorbed in the volume of the specimen. Apparently a large loss, which is characteristic of the specimen, occurs elsewhere. The most likely place appears to be at the grips, where areas of high local strain and small relative motion are probably present, and where the high "fatigue-crack" type of loss demonstrated by the authors might well be present. With any particular set of grips the observed damping capacity would then appear to be sensitively dependent on the material of the specimen in a reproducible way.

DR. U. R. EVANS,* M.A. (Member): Great importance may be attached to the authors' statement that "for aluminium alloys . . . fatigue does not occur until a critical vibrational strain is reached which is indicated by a sharp increase in damping capacity. . . . The hypothesis that a high rate of increase in damping implies rapid failure by fatigue, will, if substantiated . . . provide a quick method for assessing the fatigue properties of materials."

It should, of course, be recollected that in a corrosive environment there is no fatigue limit—a matter emphasized by Gough.† It is hoped that, in the further investigations which are promised, careful attention will be devoted to the atmosphere, some tests being carried out in pure dried air (or dry inert gas), and others in air containing corrosive constituents. (Sulphur dioxide and moisture would probably serve in the case of steel, and hydrogen chloride and moisture in the case of aluminium alloys.) If experiments were conducted on, say, steel specimens wetted with a suitable chloride-chromate solution, and the electrode potential measured during the vibration,‡ it would be interesting to ascertain whether a sudden rise in damping capacity occurred at the moment when the potential "tumbled"—indicating the breakdown of the protective film.

MR. L. ROTHERHAM,§ M.Sc.: In discussing the paper presented by Frommer and Murray to the Institute in 1944,|| I was able to show one curve of results we had obtained at low stresses, of the order of those used by the authors, in which we had recorded very low values of damping capacity. Since that time it has been impossible to continue our work, so that detailed comparison with the results reported in the present paper cannot be made, but it is to be noted that the values now reported at higher stresses are comparable with the results we have published. For instance, at a surface shear strain of 5×10^{-4} , a 0.6% carbon steel is stated to give a damping capacity of 0.2%, while in our work a 0.5% carbon steel at a surface stress of 2 tons/sq. in. gave a value of 0.41%. Whereas the material we used was normalized, the present authors have dealt with quenched and tempered materials, so that further comment on these results is difficult.

It is clear, however, that some of the discrepancies between the results of the present authors and our own lie in the wide differences in the conditions of test, and further experiments on the lines of those described in the present paper may resolve the discrepancies further. It is hoped that the authors may be able to test the stainless iron which in our work gave very high values of damping capacity and which between stresses of 112 lb./sq. in. and 2

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† H. J. Gough, *J. Inst. Metals*, 1932, 49, 17.

‡ A. J. Gould and U. R. Evans, *Iron Steel Inst. Special Rep. No. 24*, 1939, p. 325.

§ The Brown-Firth Research Laboratories, Sheffield 4.

|| *J. Inst. Metals*, 1944, 70, 217.

tons/sq. in. shows a parabolic rise in damping capacity with stress and then remains virtually constant up to 5 tons/sq. in.

The importance of the present paper lies, of course, more particularly in the investigation of the phenomenon of fatigue. Some fairly elaborate theories of the fatigue failure of metals have been devised, and from these theories it might be assumed that in the earlier reversals of stress work would be done on the material in causing local work-hardening. The amount of work-hardening would decrease with the number of cycles, until some defect appeared in the material, at which point the work done on the sample would begin to increase again. This final increase in the work done is reflected in the damping capacity, as shown in curve *A* of Fig. 14, but the earlier part of the curve would not fall in with any of the theories of fatigue failure. It will be interesting to know if the authors have any views on this aspect of the work.

It is possible that the results obtained are to some extent dependent on the material used, and here again it would seem desirable that the authors should carry out tests at stresses near the fatigue limit on a material such as mild steel which has a well-defined fatigue limit, although this would be difficult owing to the high stresses involved and the high damping capacity likely to be encountered.

A further point on which I should welcome comment from the authors is the nature of the effect on the material of exceeding the critical value of strain. It is suggested that the corresponding stress gives an indication of the elastic limit of the material. In this case we can assume that measurements of damping capacity below this stress are measurements of an effect such as that suggested by Zener, *viz.*, energy dissipation mainly due to thermo-elastic coupling. Above the critical stress, presumably the measurements show an increment due to plasticity, and at the same time the material will show some change in other properties such as hardness. One would also expect changes of damping capacity with time to take place in this range of stress, as indeed are reported, but below the critical value of strain no variation with time would be expected.

Finally, it may be appropriate to comment on the section of the paper dealing with the apparatus and methods of test. It would be desirable to develop the apparatus further so that the value of stress can be maintained constant at high values of damping capacity. It would be of interest to know if the authors contemplate this step, since it would undoubtedly add to the value of their future work, but for the present we must express our thanks to the authors for the detailed description they give of their equipment. This will be of very considerable value to anyone wishing to adopt this method of measuring damping capacity.

The AUTHORS (in reply): We are indebted to Professor Thompson for noticing the error in equation (16), which should be of the form he suggests. Consequently, the estimated mean rise in temperature under conditions of maximum continuous output of the amplifier should be 17° C. instead of 15° C., as quoted for an aluminium alloy. We have to admit that the more important matter of temperature distribution presents a problem that has not yet been solved to our satisfaction, and in recent work we have endeavoured to prevent large rises in temperature by using air cooling in such a way as not to disturb the vibration of the specimen. We feel that the temperature which it is most important to determine and control fairly accurately is that at and near the surface of the central section of the specimen. We have ideas for doing this, but have not yet been able to develop them experimentally. The main cause of heat generation is, of course, the resistance offered to the eddy currents by the material of the specimen boss at the exciter end.

The excitation efficiency with specimens of high electrical resistivity will be

comparatively low unless highly conducting sleeves are fitted or deposited on the bosses, as was done in the case of the steel specimens mentioned in the paper.

We agree that an increase in the damping capacity during vibration does not necessarily indicate fatigue, but if an increase occurs cracks should be suspected and sought after.

Our examination of materials other than the aluminium alloys mentioned was little more than a determination of the damping capacity *versus* strain relationship, and since, in most cases, stresses higher than 2-3 tons/sq. in. were not developed, the fact that we did not observe changes in these materials during vibration is not, in our opinion, evidence that such changes will not be observed during more prolonged examination, especially if higher stresses can be developed.

In answer to Mr. Warrington, we can state that the value of the temperature coefficient of rigidity quoted in the paper was determined in a subsidiary experiment; no great accuracy is claimed for it. The desirability of temperature control during fatigue studies is acknowledged.

In due course, it is hoped to control surface conditions of the specimen more effectively, as suggested by Dr. Evans.

With regard to Dr. Bailey's remarks, it does not seem possible to distinguish, experimentally, between energy absorption at the faces of a fracture and crack-propagation energy, since we cannot be certain that, in the absence of a process of propagation, the characteristics of an established crack remain constant.

Although our equipment enables us to deduce the amount of work done on a specimen in maintaining vibrations and in observing any changes brought about by cracks, we can set only an upper limit to the amount of energy involved in the production of a specific crack, supposing this to be isolated. There then remains the difficulty of describing the crack in a way which enables comparisons to be made with specimens of different material similarly cracked.

In connection with the Föppl-Pertz apparatus, the authors have also felt that the published results might be dependent on the nature of the surfaces in contact at the grips, with the result that, given sufficient care, reproducible results characteristic of various materials might be obtained.

In reply to Mr. Rotherham, it is hoped at a later date to publish further information concerning the relations between damping capacity, strain-hardening, and fatigue. Damping capacity at stresses above the critical strain is believed to arise mainly from plasticity of the metal; consequently, changes in the properties (including the initial critical strain) are to be expected and have in fact been observed during vibration at strains above the initial critical strain. The formation of cracks may, of course, affect the value of the damping capacity at strains below the initial critical strain, but, apart from such an effect, the damping capacity below the critical strain may be expected to remain unchanged during vibration and to include any contributions predicted by Zener for a particular condition of the vibrating system.

DISCUSSION ON MR. G. FORREST'S PAPER: "SOME EXPERIMENTS ON THE EFFECTS OF RESIDUAL STRESSES ON THE FATIGUE OF ALUMINIUM ALLOYS."*

(*J. Inst. Metals*, this vol., p. 1.)

DR. H. SUTTON † (Member): To me this is a most interesting paper, because while for many engineering materials, and for steels in particular, there are known methods by which fatigue properties may be improved, I think that generally we are not so well off in relation to the light alloys. The author's work deals with aspects of the subject which are of considerable practical importance as well as scientific interest. He has made tests to determine the fatigue properties of Duralumin-type alloys and D.T.D. 298 castings, all of these materials being of the same class from the point of view of composition, broadly speaking, and he has considered them in relation to quenching stresses resulting from heat-treatments. The fact that heavy machining after heat-treatment is liable to lead to a very poor fatigue performance is one which should be more widely recognized by potential users of high-strength light alloys.

The author's samples notched after re-heat-treatment had fatigue properties not very far removed from those of his specimens notched before re-heat-treatment, and that suggests that the notches were perhaps not quite deep enough to reach to the regions carrying residual tensile stresses caused by the heat-treatment. I should like to ask him whether he has examined the effect of notches of different depths in any of his specimens. I feel that that would be of special interest in connection with the matter which he has been studying. I appreciate the difficulty of the investigator, in that to get one fatigue curve means breaking a large number of specimens, and a great deal of the time of the fatigue machine is taken up.

As regards the improvement of fatigue properties by cold pre-stretching, there seems to be a good deal of evidence to show that pre-stretching can be used to give some improvement, but it seems to me to be a matter for very cautious treatment, if I may put it in that way, especially when stress-raisers are present. In some recent work which has been done at the National Physical Laboratory for my Department on one of the modern Duralumin alloys known as D.T.D. 364A, it was found that the pre-stressing to about 32 tons/sq. in. of materials which had an ultimate stress of about 38 tons/sq. in. reduced quite appreciably the rotating bending fatigue properties of both plain and threaded specimens. I think that the reduction was about 30% of the stress at 20,000,000 cycles endurance. It is true that in that case the conditions were rather different. The work was carried out on commercial heat-treated and straightened bars. There was no cold drawing or working of the material in the nature of the sinking operation applied by the author to his tubes. All these results do seem to suggest, however, that when cold-deformation processes are used in the hope of improving fatigue performance, the effect of the various treatments should be subjected to close scrutiny in the interests of the user. In this connection it is very gratifying to know that

* Discussion at the Annual General Meeting on March 13.

† Ministry of Aircraft Production.

the author and his colleagues appreciate that aspect of fatigue studies. I hope they will pursue such studies further and will cover the newer higher-strength types of alloy.

With regard to spot welds, it seems to me that the author's very interesting experiments on the pre-loaded spot welds are concerned with producing a better condition of stress distribution about the weld, especially in the adjoining softened zone, with respect to the stresses applied in subsequent fatigue testing, which would presumably be of a moderate order compared with those which would occur in the pre-stressing. It seems quite conceivable to me—I do not know whether the author agrees—that a more favourable distribution of internal stresses might occur in the vicinity of the spot weld. The application of fatigue stresses to a spot weld must, I think, result in the combined effects of the pre-existing stress and the newly-applied stress at some stage reaching rather high magnitudes; and it is to considerations of that kind that we shall have to look for benefit to the properties of welds.

The results of the author's tests are very interesting, and one wonders whether spot-welded seams could be made so regularly that a mild degree of overloading might be given to them before they went into service.

Finally, I should like to ask the author whether he has ever tried to accentuate the beneficial internal-stress effect by the use of very cold quenching media after the solution heat-treatment of light alloys. It seems to me that it might be possible to produce still higher internal stresses in that way, with perhaps still further benefit to the fatigue properties.

DR. BRUCE CHALMERS * (Member): One would suppose that a possible interpretation of the author's results is that the fatigue curve is shifted bodily by the presence of a residual stress in the compressive direction if the fatigue properties are higher, or a tensile stress if the fatigue properties are lower. I should like to ask whether the author can in fact move each of his fatigue curves in such a way as to correspond to a single superimposed stress, *i.e.*, the residual stress. If that can be done consistently, the whole process is quite understandable and very useful, because it seems to afford a means of measuring residual stresses under conditions where the existing methods can hardly be applied. It is often very difficult to carry out either the destructive mechanical test or the non-destructive X-ray test at the root of a notch in such a way as to be sure of measuring it in the region where fatigue failure is going to occur. On the other hand, if a single superimposed stress resulting from pre-loading is not consistent with the results obtained—and that is what I suspect—I should like to ask the author what explanation he has to offer.

DR. J. W. JENKIN † (Member of Council): This paper is a welcome addition to the literature in that it draws attention (along with other work in this field) to the important effect of residual internal stress on the properties of engineering materials. After all, applied stresses are superimposed on whatever residual stresses are already present, and since stresses (whether internal or external) may be compressive or tensile, the net result may be detrimental or advantageous, according to circumstances. It is right, therefore, to emphasize Mr. Forrest's statements that compressive stresses may result in an increase in fatigue strength, and that there may be a reduction in fatigue strength when the internal stress is tensile. Probably the net effect of compressive or tensile internal stress may vary with the mean stress, plus or minus, of the range of externally applied alternating stress. At any rate, it would be highly dangerous to suppose that the influence of residual internal

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† Director of Research, Tube Investments, Ltd., Birmingham.

stress is necessarily beneficial; nor would I suggest that Mr. Forrest is other than quite careful to avoid giving a wrong impression.

The thought gives rise, however, to the hope that at some future time the author may be able to give more quantitative information on the internal-stress side of this investigation. He gives excellent references to the researches of others, but these are only by way of examples of the stress figures that can be obtained. It would be most instructive to know quantitatively the state of internal stress in specimens identical with those used for the fatigue tests Mr. Forrest describes. I make this plea without knowing just how practicable it would be to evaluate such stresses in aluminium alloys of this particular history, but at least I know that surprising variations in residual internal stress can occur with steel tubes, especially on reeling, and these variations can occur within one length of tube. Admittedly steel tubes are not straightened by stretching. Mr. Forrest says that he made no attempt to measure the residual stresses involved, but possibly that is not his last word. The very variations in the stresses he has not evaluated may have contributed towards the scatter of results to which he refers on p. 9. In steel tubes in the drawn or sunk condition there is some reason to believe that the magnitude and distribution of residual internal stress across the tube wall are influenced by the shape of the die through which the tube is drawn. So readers of Mr. Forrest's paper may be asking themselves whether his results represent the fatigue properties of these alloys or are highly specific to his own test-pieces. Thus, his paper stimulates further experiment, as it should do, and my question in no way shakes my view that this is an excellent piece of work.

DR. M. L. BECKER,* B.Met. (Member): I should like to thank the author for his remarks in connection with the work on residual stresses in spring steels carried out some years ago at the National Physical Laboratory by Mr. C. E. Phillips and myself. I always felt that that work was not completed, particularly with respect to further application, and I am glad that the author has found it possible to continue along similar lines with such marked success.

Dr. Jenkin has already dealt with the question of the importance of residual stress, and that is what underlies the whole of the results given in this paper—that and the notch effect. It is important, I think, to know just how the notches are made. In hardened steels we are obliged to produce the notch by a normal grinding operation, using a correctly formed wheel and possibly a diamond-impregnated wheel as a final lap. The author omits to say how he formed the notches mentioned in the paper, but I take it that they were produced by turning. I do not suggest that the method of notching has influenced the results given in the paper, because the curves show that the fatigue specimens which were notched after the stressing quench gave almost the same results as those which were notched and then heat-treated to produce the stress. On the other hand, it is well to bear in mind that the introduction of a notch, possibly by a rather blunted form tool, may completely upset the stress system. A local tensile stress may in fact be introduced just at the root of a notch turned in a layer of material initially stressed in compression, and this will have a marked influence upon the fatigue limit of the notched specimen.

The measurement of residual stress is always difficult, and in the present paper the author has carefully avoided this problem by quoting a number of references. This seems to be quite justifiable unless it were possible to put forward actual measurements which are truly representative of the conditions in the test-pieces used. It is to be hoped that the X-ray method of residual-

* Chief Metallurgist (Gear and Tool Divisions), David Brown and Sons (Huddersfield), Ltd.

stress measurement may prove applicable to this type of work, though unfortunately, that does not seem to be the case yet. Physicists and metallurgists should try to find a fairly simple and practical method of evaluating surface stress, as this is of such importance when considering the properties of cold-formed and drawn products, as described by the author, and also of case-hardened and surface-hardened steels, the application of which is likely to be much extended in the near future.

Possibly one of the best methods of comparing residual surface stresses—it will not provide a real measurement of the stress—would be to carry out fatigue tests on the stressed specimens which had been given a standard superficial notch. Provided that, as already mentioned, the standard notch can be produced without local deformation of the adjacent material, the fatigue limit would seem to provide a sensitive means of comparison of the magnitude of the residual stress.

MR. H. G. WARRINGTON * (Member): All metallurgists will be familiar with the troubles which are introduced into light alloy metallurgy by internal stresses, principally caused by the release of stresses on machining and by the partial heat-treatment of a service component such as a piston, and we are familiar even with complete failure where service loads are additive to the residual stresses. This paper is of importance in drawing attention to those cases where compressive surface-layer stresses may be of benefit, particularly by preventing or delaying the inception of fatigue under conditions of stress concentration at notches. Attempts have been made to benefit by this in practice by such means as the rolling of threaded air-screw shanks and the shot-blasting of steel springs, and in aluminium alloys a considerable amount of work has been done to evaluate this phenomenon, although not all of it has been published (as is the case with much work during the war). The results have always proved inconclusive, however.

It has been shown † that even machining alone will give a layer surface-stress system, and one must therefore be very careful in accepting one's standards. It is quite possible that the preparation of the specimens throughout all this type of work has been responsible for vitiating the standards of reference. In this investigation, for example, the author has relied on variations in machining and in heat-treatment to produce certain internal stresses. I see in the paper that the variations in quenching are variations of temperature from "near boiling" to "room temperature." Variations of temperature of quench of that order seem to have a marked effect on the mechanical properties of the material in any case, without any reference to the internal stress.

I have made one or two experimental determinations by quenching some of the material B.S.S. L45 after solution-treatment at 525° C. and ageing for 12 hr. at 165° C., and have obtained the following hardness figures, according to the quenching temperatures employed:

	HARDNESS.
0° C. (melting ice)	159
20° C.	148
70° C.	143
100° C. (boiling water)	117

There is a sudden drop in the hardness to 117 on quenching in boiling water. I find that those figures are strictly reproducible, so that I would expect material of this composition which was quenched in boiling water to be very

* Fulmer Research Institute, Stoke Poges, Bucks.

† L. Frommer, *J. Inst. Metals*, 1944, 70, 91.

much softer than material quenched in cooler water, and the tensile properties are in line with that. The 0.1% proof stress of material quenched in water not boiling is 24–25 tons/sq. in., but in clean boiling water one gets a figure of 17–18 tons/sq. in.

I find that when a certain amount of salt is carried over into the quenching water entirely different results are obtained. On quenching B.S.S. L45 in boiling water, or water not quite at 100° C., which contained 2% of sodium nitrate carried over from the salt bath, the hardness, reproducible in every case, came back to the figure of 159, exactly the same as if quenching had been carried out in ice-cold water. It seems to me, therefore, that two things emerge. One is that there is a change in the mechanical properties of the material other than a change in internal stress, which might equally well affect the fatigue properties of the material. Secondly, some rather surprising facts crop up in the course of the investigation, such as the effect of heat-treatment with a salt bath or air bath, which make it essential to do some check determinations of the actual internal stress which is developed before it is possible to build up even a hypothesis on a subject like this. As has been suggested, probably the back-reflection X-ray technique is the best to adopt in this type of investigation, because it is non-destructive and readings can be taken on actual specimens which are later used for the fatigue tests.

MR. A. J. MURPHY,* M.Sc. (Member): Some time ago, in connection with large pistons of Y alloy, we investigated the effect of different heat-treatments on the residual stress in rings about 10 in. in dia. Our procedure was to subject sand-cast rings of Y alloy to different heat-treatments—each ring to a different heat-treatment—and to split them after having placed gauge marks approximately 2 in. apart, as shown in Fig. A. After treatment, each

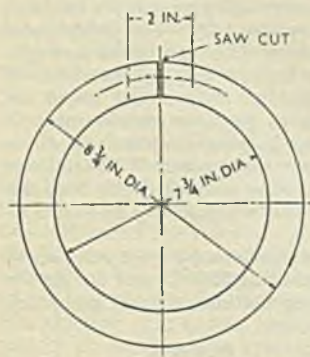


FIG. A.

ring was clamped down and then cut between the marks with a milling cutter, the clamps removed, and the ring allowed to spring in the direction in which the internal stresses would carry it. In the case of Y alloy (between which and D.T.D. 298 one may recognize some similarities), the ring as cast closed in to the extent of 0.002 in. on this 2-in. gauge length, and the Brinell hardness was 85. When the ring was split after being heat-treated for 5 hr. at 530° C., quenched in boiling water and aged for 11 days at room temperature, the points moved apart to the extent of 0.002 in., and the Brinell number was 88.4. If the heat-treatment was varied by quenching in cold oil instead of boiling water, the residual stress was of the opposite sign and the ring opened to a large amount (0.018 in.); the Brinell hardness was then 93.7. I think

that those figures are of the same order as the author has found. The greatest stress was found in the material quenched in cold oil, and also the numerical change in hardness was of approximately the same value.

It would have been interesting if the paper had contained the full mechanical properties of the D.T.D. 298 material in the two states. It is obvious that in the case of Y alloy there is an appreciable sacrifice of mechanical properties

* Chief Metallurgist, Messrs. J. Stone and Company, Ltd., Deptford, S.E.14.

with the treatment which gives the lower internal stress. The extent to which the stresses can be removed completely is shown by the fact that if the Y alloy ring was annealed at 450°C . for 2 hr. and cooled with the furnace, there was hardly any perceptible change in dimensions—a contraction of about 0.0002 in.—with a very low Brinell hardness number, 46. The relative freedom from internal stress of the material quenched in boiling water is retained even after a subsequent tempering operation has been applied to improve the mechanical properties.

The problem is very complex. The whole paper tends to emphasize the beneficial effects which can be obtained from controlled or at least predicted internal stresses, and I am sure that the author would agree with other speakers about the necessity of guarding against the misuse of this apparently valuable means of processing. In particular, I would mention the danger of the incalculable redistribution of stresses if internally stressed materials are machined in their subsequent application.

MR. H. L. COX,* M.A.: The discussion has been largely concerned with the heat-treated test-piece and has tended to ignore the test-piece in which the internal stress was produced by stretching. I can well believe that all sorts of effects may result from the quenching treatment and that the internal stress may be only one of several effects influencing behaviour. In the case of the pre-stretched test-pieces with notches in them, there is another effect which may be worrying some people, namely, whether the stretching can affect the stress concentration due to the shape of the notch. The integral of the curvature round the notch in Fig. B(a) is the change of angle as one goes round the notch. The stretching cannot alter the angle appreciably, so that the integral of the curvature from A to B remains practically the same. The only possible way to reduce the maximum curvature is to spread out the whole distribution of curvature, as shown in Fig. B(b), and it can be confirmed that that does not happen. What does probably happen is that a new distribution of curvature is set up, of the type shown in Fig. B(c). It would be interesting if some measurements could be made on stretched notches to show how this kind of effect does take place.

Assuming for a moment that the increased fatigue strength is due to

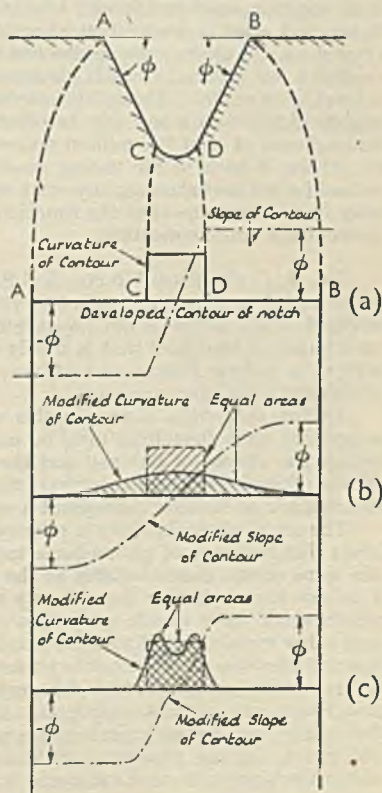


FIG. B.

* Engineering Division, National Physical Laboratory, Teddington.

the internal compressive stresses set up, we are still not out of the wood, because if we carry out ordinary fatigue tests on materials under mean compressive stress, we do not normally get any considerable increase of fatigue strength. At the same time the evidence on the effect of compressive stress on fatigue is scant owing to the great difficulty of carrying out fatigue tests under conditions of high compressive mean stress. I tried a series of such tests some years ago on alloy steels, and, although the test-pieces were moderately short and stumpy, they folded up like cheese and never developed cracks.

The author makes a comment which may give the clue to the answer. He says that he observed cracks at the bottom of some of the notches, and that these cracks did not develop. Is it not possible that the effect of the internal compressive stress is not to prevent fatigue cracking but to prevent the crack spreading after it is produced? I should like the author to comment on that point, and I would recall to his mind some tests in which he and I were associated some years ago on a single crystal of aluminium, of which the reference number was Al 10B. That crystal was tested under alternating torsion with a superimposed compressive end load. We had tested a companion specimen with superimposed tensile end load, and that behaved in a normal fashion; it cracked after a few million reversals, the crack spread, and so on. The crystal Al 10B under compressive end load cracked—or we thought it cracked—after a few million reversals, then it started to twist and finally it developed a total twist of 70° . The crack was still there, but it did not open up or show any tendency to do so. My recollection is that in the end that test-piece had suffered at least 100 million reversals and that we were getting very tired of putting it back in the testing machine, but that it was still only twisting to and fro without showing any other sign of failure. It seems to me that that may be the answer—that the function of the compressive stress is merely to prevent the crack spreading.

Dr. J. C. CHASTON,* B.Sc., A.R.S.M. (Member): I think that this work gives added emphasis to a point of view which is becoming increasingly well realized—that failure is not dependent on the mean load nearly so much as on a localized load, and that in nearly all cases of failure—in tensile failure as well as in fatigue failure—we are very much concerned with the distribution of stresses across the specimen.

I think that what is new in this work, or new to me at any rate, is the suggestion that stretching may be used to redistribute the stresses and so reduce the chance of failure; and the results point strongly to the need for means of studying more accurately than has been possible in the past the distribution of stresses throughout a specimen.

The use of photoelasticity is referred to by the author. I suppose that the great disadvantage of photoelastic methods is that the models do not have the same elastic characteristics as the metals with which they are compared. I do not know whether there is any hope of new materials being developed which would have elastic properties closely resembling those of aluminium and other metals, but if so I am wondering—perhaps the author can give us this information—how valuable photoelastic methods would be in predicting or trying to develop methods of treatment to redistribute the stresses and avoid local concentrations of them. I have mentioned photoelastic methods, but other methods may perhaps be used to determine stress distribution in the metal. If the physicists could develop anything on the lines of eddy-current or similar methods it would be of great help to metallurgists.

The AUTHOR (*in reply*): Dr. Becker asked about the production of the

* Research Laboratories, Johnson Matthey and Company, Ltd., London.

notches. They were turned with a diamond tool with a very slow feed towards the centre of the specimen. I think that diamond turning is recognized as producing a surface which is fairly free from residual stress. On the other hand, I am a little doubtful whether, with a very sharp notch, there is any possibility of the pressure of the sides of the cutter bit outwards (see the arrows in Fig. C) producing a high enough stress at the root of the notch to carry the material in this position into the plastic range in a tensile direction. I do not think that there is any appreciable chance of this having happened except in the case of the sunk tube, where there was a heavy tension already on the surface.



FIG. C.

A number of speakers have asked about the variation in the properties with the difference of heat-treatment. In Table III of the paper there is a certain amount of information about that; the hardness is given for some of the materials after the re-heat-treatment and after the original heat-treatment.

The AUTHOR (*in further, written, reply*): Several speakers raised the question of the magnitude of the quenching stresses obtained in specimens of the sizes used. It was not my intention to attempt to do more than demonstrate that such stresses exist and are significant. However, as further confirmation that such stresses exist, the result of the following test may be of interest. A bar of Duralumin-type material, machined to 10×10 mm.

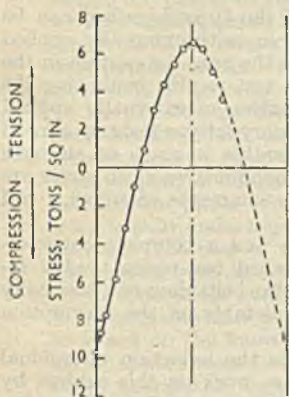


FIG. D.—Longitudinal residual stress distribution in bar of 10 mm. square section, quenched on two opposite sides.

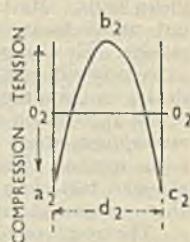
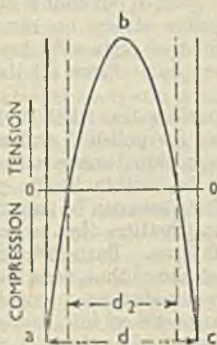


FIG. E.

square section and 7 in. long, was solution-treated for 30 min. at 497° C. and quenched in cold water, two opposite sides being protected by "sindanyo" strips during the quench. Subsequently, a layer about 0.01 in. thick was machined from one of the quenched faces and the resultant curvature of the bar was measured. This was repeated as successive layers were machined off. The longitudinal stress system was calculated using Richards' * method, and the stress distribution thus determined is shown in Fig. D. It must be

* D. G. Richards, *Proc. Soc. Exper. Stress Analysis*, 1945, 3, (1).

emphasized that this does not show the exact distribution in a *cylindrical* bar, but merely confirms that bars of approximately this size will, after quenching, contain stresses of the order indicated in the paper.

Dr. Sutton drew attention to the fact that specimens notched after re-heat-treating have given values not far removed from those re-heat-treated after notching, and deduces that the notches were not deep enough to reach the region of residual tension. If the distribution is axially symmetrical and parabolic across a diameter, an annular notch of the type described can never reach a region of residual tension, for the reason that, the sum of the forces in the remaining cross-section must equate to zero. This is illustrated in Fig. E. Suppose a, b, c , represents the residual-stress distribution over a diameter, d . If the test-piece is turned to a smaller diameter, d_2 , apart from end effects, it can only decrease in length, with the result that the stress distribution will now be a_2, b_2, c_2 about the zero line O_2-O_2 , with the forces above and below O_2-O_2 still balanced. Where a notch is turned, owing to the stress-concentrating effect, the stress distribution will no longer be parabolic, but the forces across the remainder of the section must still be in equilibrium. These comments will, of course, not apply to the case of a hole drilled transversely into a specimen, or necessarily to an annular notch, if the stress distribution is more complicated.

Dr. Sutton also referred to recent work carried out at the National Physical Laboratory, but enough information has not been given to allow of detailed comment. In reply to his final question, I have not so far carried out any tests on materials quenched in ice water, but his suggestion will be borne in mind should a suitable opportunity arise.

Dr. Chalmers has enquired whether tests of the type described can be interpreted in terms of tests on normal test-pieces, with externally applied mean loads, whilst Dr. Jenkin called attention to the need for caution in the too general application of conclusions from such test results, instancing the fact that such results will vary with the application of externally applied mean loads. Mr. Cox has pointed out that if ordinary fatigue tests are carried out under mean compressive stress, no considerable increase of strength results. He also points out that tests with high compressive mean stress are extremely difficult to carry out. Since all these comments are allied, I will deal with them together.

It appears on first consideration that if one had a complete range-of-stress/mean-stress diagram for polished and notched test-pieces, and a reliable method of measuring residual stresses, then the behaviour of a residually stressed test-piece should be, within limits, predictable on the assumption that external and internal stresses can be summed.

The most obvious complication that arises is the reduction of residual stress by the action of fatigue. Barrett* quotes work on this subject by Bühler and Buchholz which shows that, for a low-carbon steel, fatigue stressing may reduce internal stresses due to quenching by a considerable extent. This possibility must also be taken into account in dealing with aluminium alloys. Since, however, such reductions of residual stress will depend on many factors apart from the material, *viz.*, the type of stressing action, the range of stress, the external mean stress, the distribution of internal stress throughout the section, &c., it is obvious that no simple generalization can be made.

A further complication arises when it is considered that maximum residual stresses frequently arise away from any free surface, and that fatigue failure under such conditions will not necessarily bear a known relationship to the fatigue properties as usually determined. In this connection some tests by P. R. Martin of the Royal Aircraft Establishment are of interest. While

* C. S. Barrett, *Metals and Alloys*, 1934, 5, 131.

studying a different problem he had occasion to test unnotched Haigh test-pieces (B.S.S. L1), as received (heat-treated), and re-heat-treated after machining. These were tested with a mean tensile stress of 0.3 of the ultimate static strength of the material. In this case the re-heat-treated specimens gave an increase of stress range (for 20 million cycles) of 10%. (The increase in ultimate tensile strength due to similar re-heat-treatment was only 1-4%.) Since the re-heat-treatment involved quenching in cold water, it is reasonable to suppose that appreciable quenching stresses must have existed.

Two significant points about these tests may be noted. In the Haigh test-piece the applied stress is uniform across the section, and the state of stress over the whole cross-sectional area is of importance. Notwithstanding, therefore, that at the centre of these test-pieces the total static tensile stress must have been appreciably higher than anywhere over the as-received specimens, a higher fatigue result was obtained. Martin does not describe the fractures, but it would be of interest to know whether or not failure started away from the surface of the test-pieces. If in fact inhibition of failure on the surface has as great an effect as these tests suggest, the point is very important. The second point concerns the fact that an increase was obtained in this case, in which the residual surface compression presumably diminished the externally applied mean tension; whereas in the case of the rotating cantilever tests in which there was, of course, no mean stress and where the state of stress in the centre was unimportant, no appreciable effect was obtained. This would not be inconsistent with the assumption that, within limits, the effects of residual stresses can be correlated with tests using externally applied mean loads (if, in the latter case, the range-of-stress/mean-stress curve for wrought Duralumin is assumed to be a parabola with the axis parallel to the "range-of-stress" ordinate and at a mean stress value somewhat to the compression side of the zero).*

Dr. Chaston has drawn attention to the fact that failure generally results from localized load and not average load. This is very important in the present context, since a residual stress in compression in one part of a test-piece implies a complementary residual tension elsewhere. In the case of notched test-pieces of the type used, the material well away from the notch is not usually under high external loads and is fully able to support this residual tension. The case of the polished test-pieces is different in this respect, as has already been discussed with reference to the work by Martin.

In spite of the complexity of residual-stress problems, as outlined above, it is inevitable that practical allowance for such stresses will in many cases be based on the known effects of externally applied mean loads. The two major needs appear to be the further development of methods of determining stress distribution in complicated shapes and over complete cross-sections, and improved methods of finding range-of-stress/mean-stress relationships, including high mean stresses in compression.

Dr. Chaston has emphasized the former necessity and has suggested various ways in which the problem might be attacked. X-ray methods, mentioned by Dr. Becker and others, which seem most promising at present, have the serious shortcoming that they measure only the surface stress, and when material is machined away to allow of determinations below the original surface, the removal of the material in itself alters the distribution of stress in the remainder. This method must therefore be used with extreme caution.

Regarding the second necessity—improved methods of obtaining range-of-stress/mean-stress relationships—and bearing in mind the difficulty of testing with mean compression stresses referred to by Mr. Cox, a technique

* There is little experimental evidence to justify this assumption, but published data are not inconsistent with it for unnotched specimens.

described elsewhere is of interest, in which flat test-pieces, notched on one face, are tested under flexure. It would be possible, by bending in one sense only, to apply a mean compressive stress over the notch without producing failure always on the "tension" side. It may be possible to develop this method of testing for unnotched test-pieces by the use of specimens of roughly triangular or \perp section.

Regarding Dr. Jenkin's further comments on the variation of residual-stress distributions, particularly in tube, I agree that residual stresses will probably vary appreciably from specimen to specimen, especially after such an operation as reeling, if the tube is not dimensionally correct or the mechanical properties are variable; but surely this is just a further complication that must be dealt with in the same way as variations in properties due to tolerances in all production operations. I also agree that the value of the present test results would have been increased by measurements of the exact stress distribution in each piece, but unfortunately it was not possible to make such measurements.

I have to thank Dr. Jenkin for confirmation of the work of other investigators that the residual stresses in tube may be partially controlled by die design.

Regarding Dr. Becker's comments, in which he asked whether machining stresses might have affected the results, I would like to amplify my verbal reply. My suggestion was that, although diamond turning is usually considered to give a reasonably stress-free surface, under certain circumstances the possibility of the notch-turning operation tending to "stretch" the root of the notch plastically should be considered. If this takes place, a resultant residual compressive stress is to be expected on a previously stress-free test-piece. On a test-piece with a heavy longitudinal tension already on the outer surface, the effect would be partially to relieve such tension over and above the relief governed purely by geometrical considerations. Such stresses, if they exist, would with one exception tend to reduce the effects shown in the paper and not to increase them. The one exception is the case of the sunk tube, on which the fatigue properties may be over-estimated.

It would be of interest to consider whether residual stresses due to machining might not be a factor in the relatively low notch-sensitivity values frequently obtained when sharp notches are used, as compared with blunt ones.

In connection with ground notches in hardened steel, mentioned by Dr. Becker, I have understood that grinding produces high residual tension on the surface * mainly because the surface is first raised to a high temperature by the grinding and then virtually "quenched from the inside."

Mr. Warrington, referring to possible effects of the variations of quenching temperature, states that "variations of temperature of quench of that order seem to have a marked effect on the mechanical properties of the material in any case, without any reference to the internal stress." Mr. Murphy raised a similar question with special reference to the cast material. Mr. Warrington supports his argument by hardness values on wrought material quenched at various temperatures. To obtain these large differences of hardness, he has had to quench in boiling water free from sodium nitrate carried over from the salt bath, and in melting ice. If we neglect these extreme cases, the difference of hardness he obtains is only 3%. My own hardness measurements (see Table III) have shown no differences in the case of the wrought materials and only a 6% difference in the case of the cast material. Further considering the wrought materials, there was no increase of fatigue properties on polished test-pieces after re-heat-treatment, but a large increase on notched test-pieces. In addition, the effects on notched test-pieces were repeated with residual stresses induced by plastic straining.

* J. A. Almen, *Mech. Eng.*, 1943, 65, 553.

In view of these facts it is difficult to see how the results contained in my paper can have been appreciably affected by the variable under consideration.

I cannot see the relevance of Mr. Murphy's comments concerning his investigations with rings. Referring to residual stresses in cast Y alloy, he quotes measurements made on rings of about 10 in. dia., but unstated length, quenched in various media. By splitting these rings in the direction shown in Fig. A and measuring the spring, he has, in fact, not measured the residual stresses at all, but merely the "lack of balance" of the forces across the section. If the quenching stresses were distributed symmetrically across the section, however high the stresses were, the spring would be zero.

In addition to his remarks already dealt with, Mr. Cox referred to the possible change of shape of the notch on the pre-stretched test-pieces, and indicated that such a change of shape would result in an increase rather than a decrease of stress concentration. He also mentioned the cracks in the quenched specimens which did not develop and suggested that the function of the internal compressive stress was not to prevent fatigue failure but to prevent the crack spreading when first produced. This is an interesting suggestion, but in considering it, the fact that no cracks could be found in the unbroken pre-stretched notched test-pieces should be taken into account.

In conclusion, I would like to thank all the speakers for the interest they have shown in my paper and for the very helpful discussion to which they contributed.

DISCUSSION ON DR. MAURICE COOK AND MR. EUSTACE C. LARKE'S PAPER: "COMPUTATIONS OF ROLLING LOAD, TORQUE, AND ROLL-FACE PRESSURE IN METAL STRIP ROLLING." *

(*J. Inst. Metals*, 1945, 71, 557.)

DR. HUGH FORD, † Wh.Sc.: The paper makes use to a considerable extent of a theory put forward by Dr. Orowan for calculating the roll-pressure distribution and torque in rolling, and in examining this method I have found that the calculations cannot be carried out in their entirety without data which have first to be obtained from experimentally-determined roll-pressure distribution curves. Indeed, it appears that Orowan's own calculations, in which he

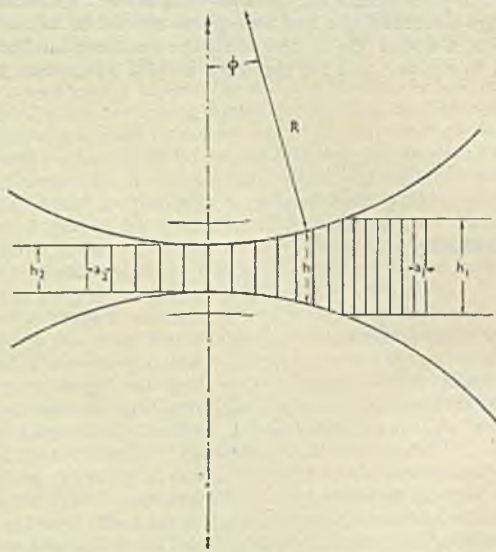


FIG. A.

compares the roll-pressure distribution obtained in experiments by Siebel and Lueg with the calculated values from his own theory, were actually carried out with data obtained from these same experiments.

The difficulty appears to be this. One of the principal claims made for Orowan's method is that it takes into full consideration the fact that deformation between the rolls is inhomogeneous. These terms "homogeneous deformation" and "inhomogeneous deformation" occur throughout the literature on the subject, and the difference between them should be clearly understood. Fig. A shows material going through the roll gap. In this case

* Discussion at the Annual General Meeting on March 13.

† British Iron and Steel Research Association, London.

there is homogeneous compression; in other words, vertical segments of the original material are plane sections, and they remain plane as they pass through the roll gap. That means that there is complete homogeneous compression—a uniform compression—throughout the whole vertical section as it goes through the roll gap. That was the assumption used in the early theories. In Orowan's theory inhomogeneous compression is allowed for, and this type of deformation is illustrated in Fig. B (Plate XLVIII) taken from his paper. Non-homogeneous deformation is obtained when there is friction between the roll and the material, and is well illustrated in the figure, which shows a specimen of plasticine in which the vertical segments are alternate layers of different colours rolled between wooden rollers, so that we have a high coefficient of friction at the surface. The plane sections do not remain plane, but are bent over. There is considerable shear at the surfaces near the rolls, and that shear deformation penetrates more deeply into the material as the latter passes into the roll gap. The material has been taken out of the rolls before it has passed right through and has been sectioned to show what happens to the cross-section.

Now, the yield stress of a metal plays an important part in the calculations, and it is necessary to know how it increases by work-hardening under this inhomogeneous strain. Unfortunately, there exists at present no method of quantitatively assessing the inhomogeneity of the deformation in any particular case, so that the data on yield stress which are necessary for the calculation must first be obtained from rolling experiments carried out under the conditions it is desired to study.

In the course of some informal discussion with Mr. W. C. Hessenberg of the British Non-Ferrous Metals Research Association, the question arose as to how, in the paper which is now under discussion, the authors had got over this difficulty. The answer seems to be given on p. 561, where it is stated that the value of the yield stress used in the equations was obtained from homogeneous compression tests and by multiplication of the results of these by a factor of 1.15 (i.e., $2/\sqrt{3}$) to correct for the restricted spread in rolling. This clearly is the value of the yield stress which would be obtained if deformation between the rolls were entirely homogeneous, and it cannot therefore be said that in these calculations full account has been taken of the effect of the actual inhomogeneity of deformation on the work-hardening—and hence on the yield stress of the material—as is intended by Orowan in his method of calculation.

It is a little difficult to see how the authors could have avoided this difficulty in the absence of any available experimentally-determined roll-pressure distribution curves for the cases of rolling considered, but we should be interested to know whether they feel that, in fact, the assumption of homogeneous compression as far as the rate of work-hardening is concerned is sufficiently unimportant in its effect to have made the calculations worth while and, if so, on what considerations this opinion is based. The authors have considered cases where slipping friction was obtained throughout the arc of contact. The inhomogeneity should therefore not be so great as in cases of sticking, but even so Orowan finds it necessary to make a correction to the yield stress values given by Siebel to make the calculated pressure distribution agree with the experimental pressure distribution for a case where $\mu = 0.14$, and it would seem that some allowance for inhomogeneity is necessary in the cases the authors have considered.

Our own feeling is that there is a real danger of Orowan's method of calculation, in variously modified forms, being indiscriminately applied to all sorts of rolling problems before there has been sufficient opportunity to verify its soundness by experiment. It is hoped that in the course of further rolling-mill research which is being undertaken by the British Iron and Steel Research

Association, Orowan's method may be carefully checked by suitably designed rolling experiments and a proper estimate of its potentialities and limitations obtained.

We should like to conclude, however, by congratulating the authors on their courage in tackling a difficult theory and examining its possibilities as a practical method. The technique of evaluation, based on equations 3 and 4 on p. 561 and charts such as Fig. 3, is very much simpler than that given by Orowan in his paper; anyone who has worked out a few examples will appreciate this.

DR. C. H. DESCH, F.R.S. (Past-President): As Chairman of the Rolling Mill Committee of the Iron and Steel Research Association, I should like to say how welcome this paper is, coming from the non-ferrous side. It represents an enormous amount of work. It is very satisfactory to see that within the limits of the work which has been done such good agreement can be obtained with the formulæ suggested by Ekelund and by Orowan. The facilities now available for the carrying out of research on rolling are much greater than they were some years ago, largely on account of the fact that rolling is carried out on strip. One could not do work of this kind with the same degree of satisfaction when using the old type of mill. The material which has been used here is on the whole thicker than that with which we are usually concerned in steel strip rolling, but the results from the one must have a close bearing on the other. It would be very interesting to see when tension is applied as well (and that is being done in the research now being carried out on steel strip rolling) what effect is produced, but this is one of the most important contributions which we have had to the problem of the behaviour of a metal in the rolls. I hope that the authors will continue it and that they will keep in constant communication with Dr. Ford and his colleagues who are working on steel.

DR. MAURICE COOK (*in reply*): Dr. Ford has raised the interesting but admittedly speculative question of the possible influence of the non-homogeneity of the deformation in rolling. How far this may affect the results is, at present, a matter for conjecture in the absence of definite information. We have done all that it is possible to do now in making calculations of this kind, in employing basic curves of resistance to homogeneous deformation, which we determined experimentally as described in an earlier paper to the Institute,* adjusted for plane deformation, or two-dimensional flow, by use of the $2/\sqrt{3}$ factor in accordance with the Huber-von Mises theory. The extent of any further correction that may be necessary to cover non-homogeneous deformation is not known. Although he has not said this in so many words, Dr. Ford suggests that this may be considerable, but his Fig. B refers to the rolling of plasticine and not metal, and, therefore, to conditions of sticking friction, where, of course, the effect of non-homogeneity is more marked than with slipping friction. In this connection it is interesting to note that in reply to the discussion on his recent paper, Dr. Orowan himself ventured the opinion that the effect of the non-homogeneity of the deformation in rolling is probably very much exaggerated. We are inclined to think that may well be so, and I would point out the rapid flattening of the basic compression curves of soft materials such as copper and aluminium and that all the conditions with which we dealt were for slipping friction.

Apart from the fact that in some directions we have simplified the Orowan method and thus made it more readily available for use, one of the chief purposes of the present paper was to show in simple graphical form the effect

of the independent factors on the dependent quantities. Moreover, we have also shown that, for the rolling conditions studied, the Ekelund formula, when suitably modified, provides results in close agreement with those obtained by the Orowan method. These we suggest are, in themselves, results which amply justify the calculations we have made and described.

Finally, I entirely agree with what has been said about the need for carefully planned and carefully executed rolling experiments, including the measuring of roll-face pressure, but in the meantime it would be premature to assume, as Dr. Ford seems to do, that roll-face pressure curves computed by the Orowan method are far removed from actual values.

CORRESPONDENCE.

MR. G. M. BROWN,* B.Sc., M.A., Wh.Sc. (Member): This paper deals with the calculation of rolling pressures and torques and the authors have evidently devoted a great amount of labour and time to its preparation and used the most reliable formulæ available, namely, those devised by Ekelund some years ago and based on the results of Puppe, and those by Orowan, based on the researches of Prandtl and Nadai on the phenomena of plastic flow.

Many measurements of the total separating force acting on a pair of rolls have been made, but these throw little light on the actual rolling process and the variation of roll-face pressure along the arc of contact, and the authors rightly draw attention to the work of Siebel and Lueg, who measured directly the roll-face pressure from point to point along the arc of contact of the rolls and the rolled material. Their results, which are of fundamental importance, are the only ones of the kind we have. Their pressure measurements were made with a pin covering a length of 1.9 mm. of the arc of contact between the rolls and the rolled material, and the rolls themselves were 180 mm. in dia. Two of the curves obtained were corrected to allow for the finite length of the pressure pin, but the method of correction used is open to serious criticism. Orowan has used these corrected curves to check his method of calculating rolling pressures and, incidentally, to produce curves similar to those shown by the authors in their Figs. 4 and 5; but none of these curves indicates correctly the value of the maximum roll-face pressure, for the sharp peak of such a curve does not and cannot occur in practice. This is recognized by Orowan and discussed in Section 20 of his paper;† and presumably the calculation of rolling pressure is carried on as shown in his Fig. 19 and Table II just as it is in the authors' Table II and Fig. 6 for the purpose of locating as accurately as possible the neutral point and so facilitating an accurate calculation of the roll torque (see Orowan's paper, Section 24).

Orowan's solution of the rolling problem is based primarily on Prandtl's solution of the problem of plastic flow under pressure between two rough plates, and this solution is not valid in the region where the direction of flow changes, *i.e.*, the neutral point, or near the ends of the plates, which correspond to the inlet and outlet planes of the roll gap.

With Orowan, the authors assume that the coefficient of friction μ is constant along the arc of contact, but this is certainly not the case, as can be proved by detailed and careful examination of the experimental curves of Siebel and Lueg used by Orowan to check his theory; he has used an average value of μ which has been determined to give a fair overall agreement between his calculated curve and the experimental one.

* Sheffield; Consultant to the British Iron and Steel Research Association.

† *Proc. Inst. Mech. Eng.*, 1943, 150, 140.

Near the place of entry into the roll gap the average forward speed of the material is evidently less than the peripheral speed of the rolls, and near the plane of exit it is known to be greater; there is therefore some intermediate section where the average speed of the material through the rolls is equal to the speed of the rolls. The intersections of this section and the roll surfaces are the neutral points. The frictional drag of the rolls on the material changes sign at these neutral points and is directed towards them from both sides. As both the rolls and the material are here moving with the same speed, there can be no frictional drag at the neutral point; it therefore passes through zero and goes on increasing again till it attains a value sufficiently great to overcome the friction between the rolls and the material, and slip then ensues in both directions—towards the inlet and the outlet planes. Such a change of sign and increase of magnitude cannot take place instantaneously, and there must be a definite length of the arc of contact on either side of the neutral point over which there is no slip, and, to use the words of Orowan, "the material sticks to the rolls." The authors say that "for the range of conditions considered sticking friction does not occur," but it is clear that it must occur in all cases of rolling. In the hot rolling of thick sections or slabs it occurs over practically the whole of the arc of contact, and in the cold rolling of thin sheets or strip it occurs over a short portion only of the arc of contact.

The gradual change of magnitude and direction of the frictional drag in the neighbourhood of the neutral point results necessarily in a friction hill with a well-rounded peak, as seen in the curves of Siebel and Lueg, and the elimination of the sharp peaks of Figs. 4 and 5 of the authors. It has been suggested that the rounded summits of Siebel and Lueg's curves are due to the finite length (1.9 mm.) of their pressure-measuring pin, but such a suggestion is clearly untenable and unnecessary. These matters are discussed by Orowan in Section 20 of his paper, but he does not produce any calculations to support his conclusion that Prandtl's inert wedges at the neutral point are merely unelastic additions to the rolls. The elimination of the peaks of Figs. 4 and 5 would probably not, in ordinary cases, substantially reduce the total load on the rolls, but would materially reduce the maximum stresses applied to the roll surfaces.

The first, and one of the greatest, difficulties encountered in the calculation of roll-pressure curves is the correct determination of the actual length of the arc of contact. In hot rolling it is generally assumed that the rolls are rigid and undergo no distortion under the loads applied to them, and the length of the arc of contact is then given with sufficient accuracy for practical purposes by the simple formula:

$$L = \sqrt{R(h_b - h_a)},$$

or, as the authors put it more accurately:

$$\text{versin. } \phi = \frac{h_b - h_a}{D}.$$

But the rolls are elastic and yield to the applied pressures. In Section 32 of his paper Orowan has discussed this matter and has given results of some of the measurements he has made of the amount of roll flattening under load. The general effect of this elastic yielding of the rolls is to increase the length of the arc of contact and consequently the total rolling force necessary to effect a given reduction. The amount of this increase is very substantial in the case of thin material, for in quite ordinary cases the length of the arc of contact may be increased by some 50% or more, and with thin, hard material and a small reduction the actual length of contact may be several times that given by the "rigid roll" rule.

DR. E. OROWAN *: The roll load and roll torque cannot be represented by formulæ simple and yet accurate enough for practical requirements, and at the same time general enough to embrace all important types of flat rolling. One has to choose between rather cumbersome graphical or numerical methods of computation and relatively simple approximate formulæ which, however, are valid only for limited ranges of the variables that determine the distribution of roll pressure over the area of contact. The first way must be taken if, for instance, the relative advantages of widely different methods of rolling are to be compared; on the other hand, the second way is preferable for frequently recurring calculations confined to sufficiently narrow ranges of values of the coefficient of friction, roll diameter, and thickness of the rolled stock. In narrow ranges of the variables, very simple formulæ may give all the accuracy needed in practical rolling, just as simple French curves are sufficient for drawing limited sections of complicated curves.

The present work of Dr. Cook and Mr. Larke is not only an excellent investigation into the suitability of a simple semi-empirical formula for the calculation of the roll load and roll torque in the cold rolling of thick strip with medium thick rolls; it has also led to valuable simplifications in the general numerical computation of the roll-pressure distribution. I am glad that the authors have chosen the Ekelund formula for comparison with the general calculation, because this formula has accidentally received a somewhat unjust treatment in a paper of mine.† In comparing it with other methods of calculation, I used it with the mean value of the yield stress as obtained from homogeneous compression tests of Siebel and Pomp for the magnitude of the reduction in the pass. The actual yield stress as derived from Siebel and Lueg's measurements of the roll pressure at the point of exit was found to be higher than the value corresponding to the same reduction in Siebel and Pomp's compression test; at the time when I wrote my paper I attributed this to the inhomogeneity of the deformation in rolling, and made allowance for this in the numerical calculation but not in the calculation of the mean stress to be used in the Ekelund formula. In the meantime, however, a more accurate consideration has shown that the discrepancy between the measurement of Siebel and Pomp and that of Siebel and Lueg cannot be due to the inhomogeneity of the deformation, the effect of which must have been very small.‡ Its source must have been some inaccuracy in one of the measurements, and in this case allowance must be made for it in the calculation of the mean yield stress used in Ekelund's formula.

The authors have shown that, in the range of the variables they have investigated, the roll loads obtained from the Ekelund formula for annealed copper can be made to agree within 6-8% with those calculated with the general method if Ekelund's values are increased by about 5%. Since the values given by the Ekelund formula are lower (cf. Figs. 7 and 8), this means that the roll loads calculated with the original Ekelund formula are lower by amounts not exceeding 11-13%. This comparatively good agreement, however, is obtained only if the Ekelund formula is used, not with the mean value of the yield stress, but, as the authors have done, with the value that corresponds to half the percentage reduction in the pass. If the mean height of the stress-strain curve for copper, as given in Fig. 2, is compared with the stress value at half the reduction considered, it is found that, for not too small reductions, the half-reduction value is about 10% higher than the mean value. If, therefore, the Ekelund formula is used in the case of annealed thick copper strip in its original form with the mean yield stress for the pass,

* Cavendish Laboratory, Cambridge.

† *Proc. Inst. Mech. Eng.*, 1943, 150, 140.

‡ Cf. *ibid.*, 1945, 152, 323.

it gives values up to 21 or 23% lower than the numerical computation in the cases considered by the authors. This is a deviation of the same order as that found in my paper.

With Mr. K. J. Pascoe, I have devised a very simple approximate formula for the roll load and torque in the hot flat rolling of steels. (This was described in a report to the Rolling Mill Research Sub-Committee of the British Iron and Steel Federation in 1942, and should be published shortly in a Special Report of the Iron and Steel Institute.) Within the usual range of the variables in hot flat rolling, this approximate formula gave results as good as are required in everyday practical calculations. At the same time, we checked the Ekelund formula in its unabridged form (*i.e.*, including the factor for the dependence of the yield stress of steels upon temperature and composition), by comparing it with rolling experiments by Pomp and Lueg and by Pomp and Weddige. The result was that the Ekelund formula gave, in the extreme cases, values of the roll load up to 30% lower, and up to 50% higher, than the direct measurements. Without a judicious calibration by altering the constants and restricting the use to a narrow range of the variables, such as has been carried out by the authors, therefore, the Ekelund formula can lead to errors far in excess of what is permissible for even the most modest practical requirements. In many cases, its use gives greater errors than the calculation of the roll load by simple multiplication of the area of contact by the mean yield stress.

In the calculation of the roll torque, the conditions seem to be less favourable to the use of the Ekelund formula. According to Figs. 9 and 10, it gives consistently higher results than the numerical computation; this is due to Ekelund's assumption that the effective lever arm of the vertical roll pressure is half the contact length, whereas in most cases it is very much less. Without the correction factor given by the authors, the greatest deviation seems to be over 20%. In addition to this, the torque calculated with equation (5) was that of the vertical component of the forces acting upon the surface of the rolls; this is greater than the total torque which includes the (negative) contribution of the horizontal forces acting upon the roll surface (due to the friction and to the horizontal component of the normal pressure). In some cases, the torque of the horizontal forces is only a few per cent. of the total torque; in others, it may amount to 20 or 30% of the torque of the vertical forces. The authors have mentioned that the torque calculated with equation (5) (*i.e.*, that of the vertical forces) differed by amounts up to about 20% from that obtained by integrating the frictional drag over the arc of contact (*i.e.*, from the total torque). In view of the great accuracy of the calculation of the authors, this difference could not be due to an inaccuracy in the determination of the neutral point; it must have represented the torque of the horizontal forces, so that the actual total torque must have been up to about 20% lower than that used for comparison with the Ekelund formula. Since the total torque was up to about 20% less than the torque of the vertical forces, and this up to about 20% less than the torque given by the Ekelund formula, the latter may have been as much as about 50% higher than the value of the total torque obtained from the numerical calculation, if the maximum deviations of 20% each happened to coincide. The conclusion is that, in the range investigated for copper strip rolling, the Ekelund formula can give the roll load with a limit of error of about $\pm 5\%$ if it is multiplied by the empirical factor suggested by the authors and if the half-reduction value of the yield stress is used instead of its mean value; the roll torque, however, may come out much too high, and it is a question whether a satisfactory approximation can be reached by applying further empirical factors which, in addition, must be different for different materials.

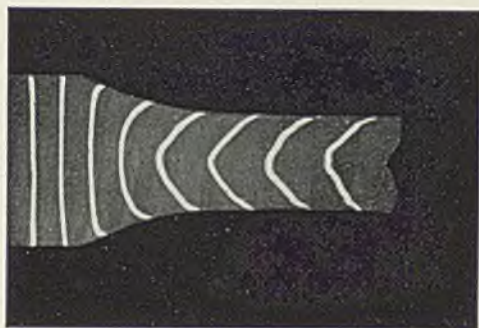


FIG. B.

DR. L. R. UNDERWOOD *: The estimation of rolling load and roll torque for various rolling conditions is of fundamental importance to both the rolling mill designer and the rolling mill operator. Whilst, as indicated by the authors, numerous methods have been proposed for accomplishing this, finality has not been reached owing to the complex nature of the problem. A comprehensive comparison of the results obtained from two different methods for a wide range of rolling conditions is therefore extremely valuable, but is rarely attempted owing to the very considerable amount of labour involved. The authors have not only discharged this onerous task in a very able manner, but they have also set out the complicated Orowan method clearly and introduced a number of improvements which shorten the work without reducing its accuracy. They are therefore to be congratulated on a valuable contribution to the subject.

In connection with the various methods devised for calculating the roll load, the methods of Nadái, Tselikov, von Kármán, and Orowan are all what are termed "friction-hill theories." By considering the case of slipping friction and homogeneous compression, all these investigators establish a differential equation which expresses the condition of equilibrium of an elementary slice of the rolled material in the roll gap, and all of them arrive at virtually the same equation. It is in the mathematical means used in solving this equation that the methods chiefly differ.

With the Nadái and the von Kármán methods, the pressure distribution along the arc of contact can be found by a tedious point-to-point summation, and with the Orowan method by graphical integration, whilst Tselikov has derived an equation from which the average pressure over the arc of contact can be directly calculated. Basing his work on von Kármán's equation, Trinks has produced a series of curves in which s/k is plotted as ordinates and $(h_1 - h_2)/h_1$ as abscissæ, each curve corresponding to a particular value of $\mu L/(h_1 - h_2)$, where h_1 is the thickness before the pass, h_2 that after the pass, L is the contact length, and the other symbols have the meaning attributed to them in the paper. If, in any case of rolling, h_1 , $h_1 - h_2$, μ , and k are known, then s can be readily found from the curves. If k varies along the arc of contact, the average value of k has to be used.

Any of the above methods can be employed to show the effect of the independent variables, roll diameter, μ , reduction, &c., and will give qualitatively similar results to those shown in Figs. 7, 8, 9, and 10 of the paper. Quantitatively, the results will differ to some extent owing to the approximations made in solving the differential equation of the friction hill. A comparison between the methods of Nadái and Tselikov and Trinks' application of von Kármán's equation, made by the writer for a few cases † without strip tension, has shown the differences between the values of s/k to be not greater than 10% for the cases investigated, whilst in Orowan's original paper the difference between his homogeneous graphical method for slipping friction and von Kármán's point-to-point method for a particular case is shown to be nil, and when compared with Trinks' method, using the curves mentioned above, the difference amounted to about 5%. For practical purposes these differences are not serious, and in view of the fact that Trinks' method can be solved in about 3 minutes, this method has much to recommend it for industrial purposes when compared with the Orowan method, which is extremely tedious even when the simplifications introduced by Dr. Cook and Mr. Larke are used.

The Ekelund method differs in certain respects from the above methods. It was derived primarily for the hot rolling of steel ingots, slabs, and bars of

* Messrs. W. H. A. Robertson and Company, Ltd., Bedford.

† *Sheet Metal Ind.*, 1946, 23, 678.

appreciable thickness and, whilst rational in form, contained constants which were found by the application of the equation for specific roll pressure to the results of rolling tests on hot steel pieces in which the roll load or the power to rotate the rolls had been measured.

On applying the Ekelund equation to cold rolling, as has been done by the authors, it is therefore not surprising to find that some modification of the constants is required. That agreement between the Orowan and the Ekelund methods was found possible with relatively small changes in the constants of the latter, shows that the basis of the Ekelund method is less unsound than some critics have tried to show.

The crucial test of any method of determining the roll load is not, however, how closely it agrees with some other theory, but how closely it agrees with the actual roll load found in practice for the same rolling conditions as those used in the calculation. Thus, while the Orowan and Ekelund theories have been found to agree fairly closely over the range of variables examined, it does not follow that either of these values is the actual roll load measured in practice.

It is to be hoped that the authors will find an opportunity of carrying out a series of tests on a rolling mill equipped with suitable load-measuring devices in order to make a comparison between the calculated and the measured loads for as wide a range of variables as possible.

In calculating the torques with the Ekelund method, the authors have assumed that the lever arm is equal to half the contact length, and whilst this is probably substantially true in the case of the hot rolling of relatively thick material there are numerous test results available which suggest that in cold rolling the lever arm lies between 0.4 and 0.45 of the contact length. If the value of about 0.45 of the contact length is used for calculating the torques, the values derived from the Ekelund equation and shown in Figs. 9 and 10 will be found to be in closer agreement with the Orowan values, although, as pointed out above in connection with the roll load determinations, it does not follow that either is correct.

The AUTHORS (*in reply*): We are grateful to Mr. Brown, Dr. Orowan, and Dr. Underwood for the very interesting observations which they have so kindly made. All the methods so far advanced for calculating rolling loads have their limitations and include assumptions in the absence of definite data, but we made our computations, despite this, to show in simple graphical form, as we have said, how changes in the independent factors affect the dependent quantities. It was with this rather than with precise values that we were primarily concerned. Several of the points raised relate to factors affecting the accuracy of the computed dependent quantities, and there can be no question that before any particular method of computation can be accepted as sufficiently accurate and reliable, more data will have to be obtained from carefully considered experiments. We entirely agree with Dr. Underwood when he says that good agreement in results obtained by two different methods does not mean that either would agree with actually determined values.

Although, as Mr. Brown observes, and as we appreciate, it is not possible for a sharp discontinuity to occur at the peak of the roll-face pressure curves, it is not likely that values for the rolling load, as determined from such curves, would be substantially higher than those derived from curves with appropriately rounded peaks. It is true that the coefficient of friction cannot be constant, but in the absence of information regarding its variation over the length of the arc of contact there is, at present, no alternative but to use an average value for the coefficient of friction. Since there must be a change in sign of the frictional forces, it is, of course, quite clear that there must also

at least be momentary sticking over a small length of the arc of contact, but in stating that for the conditions examined sticking friction does not occur, it is implied that this is so small as to have no physical significance.

In determining the most suitable modifications to make to the Ekelund formula without affecting its simplicity, the use of stresses corresponding to half the total percentage reduction, the mean stress for the total reduction, and the stress for half the work done during the total reduction were considered, and the first of these yielded results which approximated most closely to those obtained by the Orowan method of calculation. We are very interested to learn that Dr. Orowan and Mr. Pascoe have devised a simple approximate formula for calculating roll load and torque in the hot flat rolling of steels which should be very useful and we look forward to seeing this. Although Dr. Orowan states that differences of as much as 20% in torque values can occur when calculated by reference to the frictional drag and to the vertical forces, the actual facts are that of all the 114 cases we considered, only one showed such a difference, 80% of the results being within $\pm 4\%$, and 95% within $\pm 5\%$. These figures demonstrate the incorrectness of the assumption that deviations of the order of 20% are typical, and it would therefore seem that differences of the order of 50% suggested as possible by Dr. Orowan on this basis are much too high. The range of variables considered are not narrow, since they cover, certainly in respect of roll diameters and friction conditions, those obtaining in normal strip cold rolling. It is true they are more limited so far as minimum initial thickness is concerned, but it is hardly profitable at present to consider lesser thicknesses, since roll flattening becomes a much more significant factor with decreasing initial thickness, and no method of calculation covers the influence of this complex and important factor.

We quite agree with Dr. Underwood that the methods due to Nadái, Tselikov, von Kármán, and Trinks could be used for demonstrating, qualitatively, the effect of the independent factors on the dependent quantities, but we selected that of Orowan as being the most accurate so far advanced, since it does not assume that homogeneous deformation occurs during the passage of the material through the roll throat. The curves given in Figs. 9 and 10 are based on values calculated from the original unmodified Ekelund formula where, of course, the lever arm is equal to half the projected arc of contact, but in suggesting a suitable modification to the Ekelund formula we have indicated in the paper factors of 0.847, 0.913, 0.887, and 0.924 for copper, 70:30 brass, aluminium alloy of the Duralumin type, and mild steel, respectively; that is, in effect, lever-arm values of 0.429, 0.457, 0.444, and 0.462, which agree well with the range of 0.4–0.45 quoted by Dr. Underwood.

DISCUSSION ON DR. W. HUME-ROTHERY, DR.
G. V. RAYNOR, AND DR. E. BUTCHERS'S
PAPER: "EQUILIBRIUM RELATIONS AND
SOME PROPERTIES OF MAGNESIUM-
LITHIUM AND MAGNESIUM-SILVER-
LITHIUM ALLOYS." *

(*J. Inst. Metals*, 1945, 71, 589.)

Dr. H. SUTTON † (Member): Very seldom indeed, in my view, are the technical experts presented with an up-to-date and enlightened view of the constitution of a new series of alloys as a first step to their possible application; so that this is, perhaps, a unique occasion.

I should like to refer to one alloy which we have found to respond to heat-treatment, an alloy of the ($\alpha + \text{Mg}_3\text{Ag}$) type. On solution-treatment at 420° C. and precipitation-hardening for 9 hr. at 205° C., the hardness of this alloy increased from about 70 to about 87 Vickers. That is a very substantial increase, and, of course, we did not know that there had not been some age-hardening at normal temperature before the elevated-temperature treatment was given. If my recollection is correct, commercial heat-treated magnesium-rich alloys do not generally exceed a hardness of 70-75.

MR. D. C. G. LEES, ‡ M.A. (Student Member): The points that I wish to bring up in the discussion on this paper are in no way connected with the metallographic work reported, but are concerned entirely with the possible application of alloys based on magnesium and lithium in commercial practice. The essence of my remarks is the suggestion that in the same way that with aluminium-magnesium alloys a reaction was found with moisture, as described in the paper by Eborall and Ransley, § something of the same kind is likely to occur with magnesium-lithium alloys, and possibly to a greater extent.

In replying to the discussion on that paper, Dr. Ransley || suggested that for the occurrence of such a reaction one of the elements present should have a greater affinity for oxygen than the other, and the oxide film formed as a result of this selective oxidation should be non-protective. These two conditions are, I think, fulfilled in the case of the magnesium-lithium alloys. The heat of formation of lithium oxide is 142,000 cal./g.-mol., which is about the same as the figure for magnesium oxide. Lithium is likely to be present in increased proportions at the surface of the alloy, so that if a magnesium-lithium alloy is exposed to a high temperature in the presence of moisture, the lithium may be preferentially oxidized, with the formation of hydrogen which may diffuse through the lattice and combine to form molecular hydrogen at internal discontinuities.

The question arises, of course, of whether the oxide film will be protective

* Discussion at the Annual General Meeting on March 14.

† Ministry of Aircraft Production.

‡ British Non-Ferrous Metals Research Association, London, N.W.1.

§ *J. Inst. Metals*, 1945, 71, 525.

|| *Ibid.*, this vol., p. 438.

or not; and here I recall the classical work of Pilling and Bedworth,* who showed that the increase of weight due to the oxidation of an element is linear with time, if the oxide film formed is not protective, and falls off with time if the oxide film is protective. If the ratio of the volume of the oxide formed to the volume of the metal from which it is formed is less than 1, there will be a linear relationship; if greater than 1, the attack diminishes with time, giving the well-known parabolic relation.

With lithium the Pilling and Bedworth ratio is very low—I think as low as 0.5. With magnesium, which oxidizes very readily indeed, it is much higher—about 0.8; so it is probable that there will be very marked attack on these alloys by moisture, particularly when they are in the molten state and during welding. The authors refer here and there to this possibility. For instance, on p. 601, they remark that the alloys are undoubtedly very reactive in the liquid state. They say also that they have made small castings, but in a controlled atmosphere.

I do not wish to suggest that there is no hope at all of using these alloys, but it occurs to me that serious troubles are liable to be encountered. It will be recalled that Dr. Ransley (*loc. cit.*) suggested that attack on the aluminium-magnesium alloys might be decreased or eliminated by the addition of beryllium, since beryllium has a greater affinity for oxygen than has magnesium. Here we may be on rather different ground, since lithium has so great an affinity for oxygen, and it is possible that, in this case, beryllium would not afford any protection.

DR. J. L. HAUGHTON,† (Vice-President): Some years ago we made up a magnesium-lithium alloy with about 3% of lithium and annealed it at about 350° C., and all we found in the furnace after the annealing was a heap of grey powder!

THE AUTHORS (*in written reply*): We must thank Dr. Sutton for his appreciative remarks and are very interested to hear of the age-hardening results.

In replying to Mr. Lees, we should perhaps explain the conditions under which the investigation was made. The intention was to see whether it was possible to obtain alloys which were lighter than magnesium and were reasonably strong. When we began the work it was quite unknown whether magnesium-lithium-silver alloys would be stable in air or would crumble to powder, as happens with some reactive magnesium alloys, and we have shown that the alloys concerned are satisfactorily stable in a normal atmosphere. It is quite obvious, of course, that they are not suitable for use when exposed to moisture, particularly if chlorides are present. There are, however, many applications in which alloys are not exposed to moisture, and for these the magnesium-lithium-silver alloys may be satisfactory. We think Mr. Lees has misread our remark about the casting of the alloys, since even on the very small scale on which our experiments were carried out we have succeeded in casting some of them in air.

We are interested to hear that Dr. Haughton's experience confirms our observation that alloys of this kind crumble to powder when heated to above 300° C., but this does not necessarily imply that they are unsuitable for use at lower temperatures.

* *J. Inst. Metals*, 1923, 29, 529.

† Late Metallurgy Division, National Physical Laboratory, Teddington.

CORRESPONDENCE.

MR. F. A. FOX,* M.Sc. (Member): The work described in this paper is of theoretical interest, and the authors are to be congratulated on their experimental skill in dealing quantitatively with alloys which are so reactive. The fact that a body-centred cubic structure is obtained in an alloy containing as much as about 70 at.-% of magnesium is surprising, as no parallel case in magnesium alloys is known. This discovery may also be encouraging, since it indicates the possibility of developing magnesium-rich alloys with characteristics which are different from those normally expected, and which are possibly improved in some directions by the influence of a cubic lattice.

However, it is of interest to note that in the only reference I can find dealing with the mechanical properties of magnesium-lithium alloys † (a curve relating Brinell hardness to composition in the range 0-10 wt.-% of lithium), the hardness rose to a maximum (from about 38 to about 53) at about 5 wt.-% of lithium, and thereafter began to fall smoothly, reaching about 43 at 10 wt.-% of lithium, the curve still having a downward trend. The point at which the drop in the curve begins is roughly the same as that at which the β -phase first makes its appearance. The hardness-composition curve was not continued far enough to include alloys which were in the pure β -phase region, but the result quoted suggests (though admittedly not clearly, since in magnesium alloys hardness measurements do not correlate well with strength or ductility characteristics) that the β -phase has a weakening effect. Have the authors carried out any hardness or other mechanical-property determinations on samples in the pure β -phase range and have they ascertained the possibility of age-hardening the α/β magnesium-lithium-silver alloys which they mention on p. 590?

I should also like to ask whether Dr. Hume-Rothery and his colleagues think that the present work supports their earlier suggestion that a Brillouin-zone overlap in the c -direction causes a reduction in mechanical properties? It may be observed that it is not necessary to envisage a change from a hexagonal to a cubic lattice before good ductility is obtained. Magnesium alloys with elongations of 30% and reductions of area of about 50% can be regularly prepared which are still entirely hexagonal in structure, and in fact in which the lattice parameters are substantially the same as those of pure magnesium.

It seems improbable that the alloys described in the paper will prove to be of particular interest in themselves. There are several reasons for this; they are mainly those touched upon in the paper, though in some cases not strongly emphasized. Firstly, lithium of the high degree of purity necessary for making the alloys is little more than a highly expensive laboratory curiosity, and seems likely to remain so; it must, moreover, be added in more than minor amounts to magnesium before the cubic structure appears. Secondly, the alloys were melted under argon in this work, and would, it appears, also have to be melted under argon in practice if violent oxidation and fluxing difficulties were to be avoided. Then the alloys are prone to serious loss of lithium on reheating, and hence annealing, stress-relief, or heat-treatment operations are in practice severely limited or even excluded altogether.

These drawbacks are so severe that, even though the atmospheric corrosion

* Chief Metallurgist, Magnesium Elektron, Ltd., Clifton Junction, near Manchester.

† A. Beck, "Technology of Magnesium and Its Alloys," London: 1940, p. 139.

of the alloys is not a serious disadvantage, the high-lithium alloys can scarcely be considered even the germ of a practical development proposition.

Mr. J. B. WILSON,* B.Eng. (Student Member): This is possibly the only paper descriptive of research in new alloys in which the approach has been entirely from the standpoint of metal physics and has been without any consideration of previous *ad hoc* experiments in alloy research. It is gratifying that Dr. Hume-Rothery's school has advanced sufficiently to enable some measure of successful prediction to be made of alloy systems likely to be of technical interest. From this point of view no criticism can be raised against the paper; there are, however, one or two points of practical interest which will require consideration before such alloys can be regarded as having technical utility.

There appears to be practically no information in the literature regarding the effect of additions of lithium on the corrosion of magnesium; however, we have had considerable experience of the deleterious effect of additions of silver on the corrosion-resistance of magnesium. Silver in the amounts considered in the paper will probably increase the corrosion rate of pure magnesium in 3% sodium chloride solution by a factor of several hundreds. This will render the alloys somewhat unattractive for service conditions in which exposure to chloride-containing media is likely to be encountered.

In work in our own laboratories on alloys of magnesium containing quite small amounts of lithium, we have observed effects which lead us to regard this element as a distinctly unfavourable addition. About 0.05 wt.-% of lithium increases the inflammability of magnesium very considerably, and makes the normal sulphur-dusting process practically worthless as a protective measure during pouring. We have also observed vigorous reaction between magnesium alloys containing lithium and the moulding sands normally used in the magnesium industry in this country, and have so far been unable completely to suppress this effect.

We do not as yet know whether additions of lithium will produce blistering effects similar to those observed in the aluminium-magnesium alloys, as suggested by Mr. Lees, but I think that his suggestions are very possible.

The AUTHORS (*in reply*): We have not been able to carry out investigations on the mechanical properties of the magnesium-lithium-silver alloys, although, as Dr. Sutton explained, hardness tests made at Farnborough definitely established the existence of age-hardening.

We suggest that Mr. Fox may be unduly pessimistic regarding the possible use of these alloys. It must not be forgotten that 30 years ago pure aluminium was a laboratory curiosity, and although the difficulties of preparing pure lithium are considerable, there is no reason why they should not be overcome. Further, Mr. Fox appears to have misread our remarks on the melting of the alloys. Even on the very small scale of the present work, we have succeeded in melting some of the alloys under flux without using an enclosed vessel filled with argon; on the large scale, these difficulties should be less pronounced. It is freely admitted that the alloys will be unsuitable where salt-water corrosion or high temperatures are involved, but under other conditions they may be suitable. One might, for example, use a magnesium-lithium-base alloy as the middle layer of a clad material; alternatively, the alloys might well be used for components of engines which are shielded from corrosive conditions. Much clearly depends on the value which is placed upon obtaining an ultra-light alloy.

In reply to Mr. Fox's question about Brillouin-zone overlaps, we may

* Metallurgist, Magnesium Elektron, Ltd., Clifton Junction, near Manchester.

perhaps explain that the harmful effect should be apparent mainly under conditions of *alternating* stress; we have not been able to examine this problem experimentally.

In reply to Mr. Wilson, we fully agree that the alloys will be unsuitable where salt-water corrosion is concerned, and this fact has already been stated in the paper. As regards reaction between the molten alloys and the moulding sands, it is, of course, obvious that in many cases the development of new alloys requires new moulding techniques. This is the province of the industrial research worker, and we suggest that the position may be summarized by saying that where an extremely light alloy is required the magnesium-lithium-silver alloys may be useful; their success will depend upon whether the industrial research workers can overcome on the large scale those difficulties which have been successfully dealt with on the small scale.

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METALLURGICAL ABSTRACTS

(GENERAL AND NON-FERROUS)

Volume 13

JULY 1946

Part 7

I.—PROPERTIES OF METALS

Beryllium—The Light Metal Steel. Z. J. Atlee (*Modern Metals*, 1945, 1, (3), 7-8).—A general outline of the metal, its properties and alloys, is presented.—L. H.

The Production of Beryllium Compounds, Metal, and Alloys. Henry C. Kawecki (*Electrochem. Soc. Preprint No. 89-11*, 1946, 133-140).—The history and applications of beryllium are briefly reviewed. Recent developments in the processing of beryl and the present fluoride process for production of beryllium oxide are described. Electrolytic and electrothermal methods of reduction to produce beryllium or copper-beryllium alloy are described.

—A. B. W.

The Production of Metallic Calcium by Thermal Reduction. C. C. Loomis (*Electrochem. Soc. Preprint No. 89-9*, 1946, 119-126).—Details of a process for the production of calcium by the reduction of CaO with aluminium *in vacuo* at 1200° C., are given.—A. B. W.

Cerium. (Ahrens.) See p. 274.

***Internal Friction of Single Crystals of Brass, Copper, and Aluminium.** George H. Found (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 120-138; discussion, 138-139).—See *Met. Abs.*, 1945, 12, 345.

***Determination of the Photoelectric Threshold of Copper.** André Blanc-Lapierre (*Compt. rend.*, 1942, 215, 321-323; *C. Abs.*, 1944, 38, 3193).—A quartz cell with a cathode of electrolytic copper, fused in a vacuum and thoroughly degassed and cleaned by heat and hydrogen treatment, has a threshold response at a wave-length of 2660 Å. This figure is in agreement with values obtained by Rentschler (*Rev. Sci. Instruments*, 1932, 3, 794) and by Schulze (*Z. Physik*, 1934, 92, 212) for pulverized copper and copper volatilized in a vacuum and also with values calculated from thermionic-emission data.

Indium. (Murray.) See p. 274.

***Hydrogen Content of Electrolytic Manganese and Its Removal.** E. V. Potter, E. T. Hayes, and H. C. Lukens (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 373-381).—See *Met. Abs.*, 1945, 12, 346.

***Electrostriction in a Column of Mercury.** O. Yadoff (*Compt. rend.*, 1940, 211, 465-467; *Brit. Abs.*, 1945, [A I], 338).—When a vertical column of mercury is traversed by a heavy current, the density of the metal varies parabolically from the periphery to the axis. The c.d. varies in the opposite direction. An explanation is given.

***Effect of Longitudinal Magnetic Field on Torsional Oscillations of a Nickel Wire.** H. Billot (*Compt. rend.*, 1944, 218, 453-454; *Brit. Abs.*, 1945, [A I], 239).—The damping of torsional oscillations of a nickel wire in a longitudinal field of strength H varies with H . As H increases, the log. decrement (δ) first increases, passes through a maximum (at $H \sim 80$ gauss), and then decreases. When H diminishes the original curve $\delta = f(H)$ is not re-traversed. A non-ferromagnetic wire (copper) does not show these effects.

* Denotes a paper describing the results of original research.

† Denotes a first-class critical review.

*Investigation of the Thomson-Nernst Thermomagnetic Effect in Nickel Crystals. R. Annajev (*J. Physics (U.S.S.R.)*, 1945, 9, (4), 289-298).—[In English.] The Thomson-Nernst effect, i.e., the variation of thermoelectromotive force under the action of a magnetic field, was investigated for polycrystalline nickel specimens, and for single crystals of nickel. In the latter case, studies were made along the principal crystallographic axes and in the planes of the crystal. The apparatus is described and illustrated. The Thomson-Nernst effect depends markedly on the shape of the specimen, and thus upon the distribution of heat currents in the sample. The influence

of shape on the ratio $\frac{\text{change of thermoelectric force}}{\text{initial thermoelectric force}}$ is less marked and can to a first approximation be neglected. Measurements were also made of the effect of internal elastic strains on the phenomena. The results, given graphically, are described and discussed in the light of the theory of ferromagnetism.—G. V. R.

*The Experimental Proof of the Non-Supraconductivity of Grey Tin Down to 1.32° K. G. Sharvin (*J. Physics (U.S.S.R.)*, 1945, 9, (4), 350-351).—[In English.] By measurement of the magnetic moment of grey tin powder in a weak magnetic field at temperatures down to 1.32° K., it is shown that, above this temperature, no supraconductivity occurs. In stronger fields, a small magnetic moment is observed, due to the presence of a small amount of white tin, which may be demonstrated by X-ray experiments. It is concluded that grey tin is not a superconductor.—G. V. R.

The Theory of Hard-Drawn Materials, on the Basis of the Theory of Plasticity. Theodor Pöschl (*Arch. Eisenhüttenwesen*, 1943, 16, (10), 425-429; discussion, 1943, 17, (3/4), 99-100).—By the extension of a hardness formula, derived for elastic deformation, to the case of plastic deformation, the Brinell hardness in the plastic range is related to the quantity V , which represents the slope of the stress-strain curve. V is not a constant, but to a first approximation a mean value may be used. The Brinell hardness is proportional to Vd/D , where d and D are respectively the diameters of the impression and the indenting ball. Knowing the relation between the load and d/D , it is possible to derive by integration, from hardness measurements, the stress-strain curve for the material in compression.—G. V. R.

Problems in Non-Elastic Deformation of Metals. Clarence Zener and J. H. Hollomon (*J. Appl. Physics*, 1946, 17, (2), 69-82).—A general article assessing the potentialities of the various paths along which further research may profitably proceed. Anelastic phenomena are discussed, and the mechanism of plastic deformation by twinning and slipping is described in general terms. The possibility of a mechanical "equation of state" is dealt with in detail. Emphasis is laid throughout on unsolved problems and deficiencies in existing knowledge, and some specific recommendations for future research are made.—G. V. R.

Problems in Fracture of Metals. J. H. Hollomon and C. Zener (*J. Appl. Physics*, 1946, 17, (2), 82-90).—The phenomena associated with the fracture of metals are discussed in general terms, and features which are imperfectly understood are emphasized. The future research which might lead to a better understanding of fracture is reviewed, and specific recommendations are made, particularly with reference to the effects of various variables on fracture stresses, the hindrance of plastic deformation by sharp stress gradients, and the introduction of stress concentrations.—G. V. R.

Terminology in the Science of the Fatigue of Metals. Luigi Locati (*Met. Ital.*, 1942, 34, 237-241).—A review.

Viscous Flow of Crystalline Bodies Under the Action of Surface Tension. J. Frenkel (*J. Physics (U.S.S.R.)*, 1945, 9, (5), 385-391).—[In English.] It is suggested that the viscous flow usually attributed to amorphous bodies,

which occurs by the motion of a small number of holes or cavities, may also take place in crystalline substances. In the latter case flow would proceed by the diffusion under stress of vacant sites of the crystal lattice. This process is distinct from plastic deformation. The conception is developed mathematically, and applied to the rate of welding of crystalline powders, at temperatures below their melting points, into a crystalline body. The development of crystal faces on the surface of a spherically ground single crystal is also discussed from the same point of view, the common factor in each case being the reduction in surface energy caused by the change.—G. V. R.

***Oxidation by Friction Considered as a Chemo-Mechanical Process.** Kurt Dies (*Arch. Eisenhüttenwesen*, 1943, 16, (10), 399–407).—Using a special apparatus, the behaviour of various pairs of metallic materials when rubbed together under various loads, with and without lubrication, was examined. The materials included iron, hardened chromium steel, nitrided steel, austenitic chromium-nickel steel, tin, zinc, copper, aluminium, Elektron, Hydronalium, and a tungsten-cobalt-carbon sintered compact. The results of 17 experiments are tabulated and discussed, and the chemical analyses of the material removed are given. With lubrication, no frictional oxidation occurs, owing to the exclusion of oxygen. Without lubrication, the effects depend upon the materials which are paired together. The amount of wear is not always related to the hardness of the material, but depends on the hardness and adherence of the abrasion product. In the case of aluminium, the production of corundum was proved by X-ray and chemical methods; owing to the hardness of this oxide, most materials are badly abraded by aluminium. The bearing of the results on technical practice is discussed.—G. V. R.

Graphical Methods for the Determination of Velocity of Solidification. Miloslav Hampl and Václav Vodička (*Arch. Eisenhüttenwesen*, 1944, 17, (7/8), 185–191).—The mathematical equations governing the solidification of materials are developed, and new graphical methods are given for the solution of the fundamental equation $\dot{d} = q\sqrt{T}$, where d is the instantaneous depth (in m.) of the solidified layer and T is the time (in hr.). The method consists in finding q in terms of the physical constants, the freezing point, and the initial and final temperatures of the material involved. It is applied to the freezing of water and of steel. The solidification of steel in contact with cast-iron moulds and fireclay moulds is considered and discussed.—G. V. R.

Melting Process in Non-Polar Crystals. I. N. Stranski (*Naturwiss.*, 1942, 30, 425–433; *Brit. Chem. Abs.*, 1943, [A I], 55).—A lecture in which recent work is summarized and theories are discussed.

Behaviour of Non-Polar Crystals Just Below the Melting Point and at the Melting Point. I. N. Stranski (*Z. Physik*, 1942, 119, (1/2), 22–34; *Brit. Chem. Abs.*, 1943, [A I], 55).—Equilibria at the surfaces of non-polar crystals are discussed. It is supposed that the loosely bound structural units at the surface of a crystal undergo a change corresponding to melting at a temperature below the melting point. The appearance of new surfaces under these conditions is discussed. Small crystals must in general have a higher melting point than a large crystalline mass. The theory is compared with the results of experiments on certain metallic crystals.

Preparation of Single Crystals. Armando Durán (*Anal. Fis. Quím.*, 1941, 37, (Suppt.), 33–46; *Chem. Zentr.*, 1943, 114, (II), 6; *C. Abs.*, 1944, 38, 5123).—A review which includes: theory of crystallization, production of single crystals in molten masses, production by heating in the solid state, other methods, and determination of orientation. Bibliography.

The Vapour Phases of Metals. R. C. Vickery (*Metallurgia*, 1946, 34, (199), 4–7).—The thermodynamical basis of metal distillation is reviewed, together with aspects of the application of metal vaporization. The industrial applications, including large-scale zinc, aluminium, and magnesium distillation, and

recent technique for the formation of light filaments and metal coatings of silver, beryllium, and chromium by distillation, are collated, and distillation data are given for the more important physical properties of the commoner metals.—J. W. D.

Active Substances. LVIII.—Calculation of the Surface Energy of Non-Polar Solids from the Heat of Sublimation. R. Fricke (*Z. physikal. Chem.*, 1942, [B], 42, 284–294; *C. Abs.*, 1943, 37, 5308).—The temperature dependence of the total and free surface energy of metal surfaces can be calculated for the range in which the Dulong–Petit law is valid. Both the total energy and entropy are constant; the free energy decreases linearly with increasing temperature. Formulæ are given for many types of crystal lattice and numerical results are quoted for 12 metals.

Surface Energy and the Heat of Sublimation of Solids. R. Fricke (*Naturwiss.*, 1942, 30, 544–545; *Chem. Zentr.*, 1942, 113, (II), 2772; *C. Abs.*, 1944, 38, 3178).—Cf. abstract above. From the third law, the potential energy of surface formation in the Dulong and Petit region is represented by $\sigma_T = \sigma_0 + A - BT$; the values of the constants A and B can be expressed on the basis of the concept of the crystal as a system of independent, harmonically vibrating Planck oscillators. The numerical values of σ_0 and σ_{298} for the (100) and (111) faces of the face-centred lattices of aluminium, nickel, copper, silver, platinum, gold, and lead were calculated.

***On the Diffusion of Inert Gases Through Metals.** W. Lumpe and R. Seeliger (*Z. Physik*, 1943, 121, (9/10), 546–559).—Experiments on the initial distribution and diffusion of neon in a 0.3-mm. thick iron cathode of a glow discharge tube at temperatures up to 1100° C. for 15 hr. are described. Marked diffusion started at 100° C., while at any temperature the rate of gas evolution was at first rapid, then fell off and became asymptotic. Microscopic investigation of the cathode showed the distribution of the neon to be in a surface layer 0.002 to 0.005 mm. thick, containing a maximum of 45 c.c. of gas in 1 c.c. of metal.—E. N.

On the Absorption of High-Frequency Sound in Metals. L. Gurevich (*J. Physics (U.S.S.R.)*, 1945, 9, (5), 383–384).—[In English.] Theoretical. The absorption in metals of sound waves of such a short wave-length that the frequency exceeds the inverse time of the free path of the Debye waves, is investigated mathematically. Absorption takes place in a time of the order of the period of the sound, and such sounds cannot propagate in metals to any extent. According to the equations developed, the absorption coeff. is proportional to the frequency.—G. V. R.

***The Closure and Partial Separation of a Metallic Contact.** Alan Fairweather (*J. Inst. Elect. Eng.*, 1945, [I], 92, (56), 301–321).—F. has investigated the phenomena associated with nominally static contacts and those relevant to separating contacts up to the instant when the metallic path between the contacts ceases to exist. All the effects encountered in the change of resistance with current and mechanical pressure are shown to be predictable on the basis of the existence of contact spots. New light is thrown on the cause of the unequal wear of the two members of a contact pair, and it is suggested that alloys having a zero Thomson coeff. near their boiling point should be developed to overcome this trouble.—E. V. W.

On the Measurement of the Depth of Generation of the Secondary Electrons in Metals. A. Kadyshovich (*J. Physics (U.S.S.R.)*, 1945, 9, (5), 436–438).—[In English.] In order to determine the thickness of the emitter layer taking part in the creation of secondary electrons when metals are bombarded with electrons, it is usual to sputter thin layers of the metal under test on to the surface of another metal for which the secondary emission characteristics are known. Building-up of the layer is continued until the characteristics of the emission are identical with those of the massive metal which is being

deposited. The thickness of the layer is then taken as that of the emitting region for the particular metal. This method is discussed and criticized. It is pointed out that the deposition of a film alters the work-function of the original basis metal, so that its characteristics are no longer known. The method is therefore only justified for two metals with approximately equal work-functions, and with widely differing emission coeff.—G. V. R.

Electrophysics of Solid Bodies. Iib.—Metallic Electron Conductors. F. Möglichen and R. Rompe (*Physik regelmässig. Ber.*, 1942, 10, 1-19; *Chem. Zentr.*, 1943, 114, (I), 1451; *C. Abs.*, 1944, 38, 4165).—A report on publications between 1937 and 1941. The following topics are considered: general structure of metals, electrical and thermal conductivity, magnetic effects on conductivity and related phenomena, thin wires and films, supraconductivity, specific heat and thermoelectric phenomena. Investigations of metallic structure by X-rays are also dealt with.

Magnetic Spectra of Diverse Materials at Various Frequencies. V. Arkadiev (*J. Physics (U.S.S.R.)*, 1945, 9, (5), 373-378).—[In English.] A theoretical discussion of the dependence of the permeability of ferromagnetic materials exposed to the action of electromagnetic radiation on the frequency of the electromagnetic waves. A practical method for the elimination of the influence of eddy currents in experimental investigations is referred to, by means of which a true value of the complex permeability $\mu - i\rho'$ may be evaluated. The quantity ρ' is connected with the circumstance that the magnetic induction B lags behind the alternating field H . The determination of magnetic spectra by investigations over a range of frequencies is discussed.—G. V. R.

Theory of Ferromagnetic Hysteresis and Initial Permeability. M. Kersten (*Physikal. Z.*, 1943, 44, 63-77; *Brit. Abs.*, 1945, [A I], 90).—The displacement of boundary layers between neighbouring spontaneously magnetized Weiss regions requires a certain min. field strength, H_0 , the mean value of which agrees approx. with the coercivity H_c . The strain theory of coercive force gives a quantitative value for H_0 if the variation of the surface strains (γ) is taken into account. Initial permeability (μ_0) is given by the reversible displacement of the boundary layers. K.'s theory considers particles of impurities or local heterogeneities as energetically favoured points in the boundary layers, from which a definite coercive field is necessary to produce displacement of the boundaries. A quantitative interpretation of H_0 and μ_0 is derived for magnetically hard and soft materials; and these magnitudes are expressed in terms of the crystallographic anisotropy of work of magnetization and the dimensions of the foreign particles. Concordant results are obtained for carbon steels.

Fundamentals of the Supraconducting State. J. Stark (*Physikal. Z.*, 1943, 44, 211-212; *Brit. Abs.*, 1945, [A I], 90).—The view that conductivity electrons, and, in general, electrons set free from their atomic ions, have a magnetic moment is supported by phenomena connected with supraconductivity. Conductivity electrons exert rotational and translational forces on each other on account of their magnetic moments. If they are not affected greatly by the magnetic fields of the opposite ions, and if the thermal perturbations are weak, the electrons will arrange themselves in more or less extended bands when an external magnetic field is applied. It is this condition which exists in supraconducting metals. The electrons do not now move singly, but as a band. The formation and destruction of the electron band is the process responsible for the magneto-caloric effect. The view that the electron has an annular structure is supported if the electron has a magnetic moment, the latter being regarded as the consequence of an inherent motion of its charge on a ring about its figure axis. The destruction of the electron band by a longitudinal magnetic field is also considered on the above theory.

On the Surface Energy and the Behaviour of Supraconductors of Small Dimensions. V. Ginsburg (*J. Physics (U.S.S.R.)*, 1945, 9, (4), 305-311).—[In English.] Theoretical. The depth of penetration of a magnetic field into a supraconductor is discussed, and the effect of the surface energy at the boundary between a supraconductor and a vacuum or a metal in the normal state is stressed. It is pointed out that bad agreement between the previous theories and the measured values of the critical fields for supraconducting films and massive specimens is due to neglect of the surface-energy factor. The relation between the critical field and the thickness of the film is developed taking this factor into account, and fair agreement with experiment is obtained.

—G. V. R.

Some Observations on Supraconducting Hollow Bodies. Karl Michael Koch (*Z. Physik*, 1941, 118, (1/2), 1-21; *Chem. Zentr.*, 1943, 114, (I), 252; *C. Abs.*, 1944, 38, 4847).—A homogeneous magnetization of the inner field strength is assumed for the walls of a supraconducting hollow sphere. For very small primary field strengths at the poles, there must be a breakdown of the supraconducting state. In the neighbourhood of the transition state, such a distribution of the micro-region is stable that only a narrow ring at the equator is completely supraconducting. Comparison of the results of Meissner and Heidenreich (*Z. ges. Kälte-Ind.*, 1934, 41, 125; *Met. Abs.*, 1935, 2, 211) on a supraconducting hollow cylinder, with the experiments of Shalnikov (*Nature*, 1938, 142, 74; *Met. Abs.*, 1938, 5, 527) on supraconducting hollow spheres, shows that the results can be explained by the distribution of micro-regions expected from the theory. From the effects present in a magnetic field (appearance of an induced continuous current in the equatorial zone and screening of the external field by surface current), it is concluded that the appearance of a macroscopic screening current arises from structural rearrangements that are determined by surface forces. Thus a new structural rather than electrical theory of supraconducting arises.

An Attempted Electron-Physical Interpretation of the Meissner-Ochsenfeld Effect. K. M. Koch (*Z. Physik*, 1940, 116, (9/10), 586-597; *Phys. Abs.*, 1944, 47, 57).—The transition from the normal conducting to the supraconducting state requires a temperature difference between the body under investigation and its environment, i.e., a heat flow from inside outwards. This heat flow, with the magnetic field constant, is shown to give an Ettingshausen-Nernst effect which, like the Corbino effect, produces a circular current. This current, with supraconduction present, changes to the screening current which nullifies the interior magnetic field.

II.—PROPERTIES OF ALLOYS

***Evolution of Heat During the Precipitation in Aluminium-Copper Alloys at 225° C.** G. Borelius and Lennart Ström (*Arkiv Mat., Astron. Fysik*, 1945, [A], 32, (21), 10 pp.).—[In English.] The heat evolution corresponding to precipitation at 225° C. was measured as a function of time for alloys containing 2.0, 2.5, 3.2, and 4.5% of copper. This temperature is above the range in which Guinier-Preston aggregates are formed, and the dominating process is the precipitation of fine flat grains of the metastable θ' phase with the composition CuAl_2 . Curves of heat evolution (cal./g.-atom/hr.) against time are reproduced; they are initially linear, pass through a maximum, and then decrease approx. exponentially with time. The results are interpreted and discussed, and their bearing on the fluctuation theory for the production of precipitation nuclei is considered.—G. V. R.

***Effect of Assembly Ageing on the Properties of Several Aluminium and Magnesium Alloys.** G. R. Bailey and Max E. Tatman (*Aluminum and Magnesium*, 1945, 2, (1), 24-25, 29-30).—It may happen that assemblies

containing two or more heat-treatable alloys will be built up and then artificially aged. The ageing conditions for 24S aluminium alloy (super-Duralumin type) are 6½ hr. at 375° F. (190° C.), and those for 75S (which contains zinc and magnesium as principal hardening elements with smaller additions of copper and other elements) 24 hr. at 250° F. (121° C.). The principal alloys used in aircraft construction were heat-treated under these conditions both before and after ageing (for alloys which are normally aged) and as supplied (for alloys normally strain-hardened). It was found that in some cases the mechanical properties were affected, though not sufficiently to bring them below American specification minima, and that while the corrosion-resistance was sometimes reduced, the reduction was not sufficient to prevent satisfactory use.—E. C. E.

Fatigue Strength of Aluminium and Magnesium Alloys. H. F. Moore (*Aluminum and Magnesium*, 1945, 2, (2), 14–17, 28, 29).—An account in general terms addressed principally to designers, in which the main factors affecting fatigue strength are discussed.—E. C. E.

The [Aluminium] Alloy FKG II and Its Manufacture. András Domonyi (*Vegyí Ipar és Kereskedelem*, 1941, 3, (2), 3–4; *Chem. Zentr.*, 1943, 114, (I), 1928; *C. Abs.*, 1944, 38, 4551).—The alloy FKG II is easily workable, has a silvery lustre, and looks, when polished, like a metal with chromed surfaces. The strength of sand castings is 15–18 kg./sq. mm. and elongation 1.5–2.5%; when cast in metal moulds the corresponding figures are 18–20 kg./sq. mm. and 1.5–3%. Mylius No. = 7–8, density = 2.75, shrinkage = 3%. During melting, casting, and working it behaves like other aluminium alloys. The correct melting and casting temperatures are 730–750° C. and 710–720° C. respectively.

Some Important Features of the Development of High-Strength Aluminium Alloys. W. Bleicher (*Deut. Motor-Z.*, 1942, 19, 316–322; *Chem. Zentr.*, 1943, 114, (II), 566; *C. Abs.*, 1944, 38, 4894).—The tensile and corrosion-resisting properties are described for aluminium alloys of the aluminium–copper–magnesium type (DIN 1713), as well as for the same materials after cladding with pure aluminium, aluminium–magnesium–silicon alloy, or aluminium–manganese alloy. The three-layer cladding (with aluminium, aluminium–manganese, and aluminium layer) gives the most effective corrosion protection at present. The aluminium–zinc–magnesium alloys are more resistant to corrosion than aluminium–copper–magnesium alloy; likewise their stress-corrosion sensitivity can be removed by suitable refining measures and by correct alloying.

***The Supraconductivity of a Compound [Bi₂Ni].** N. Alexeevsky (*J. Physics (U.S.S.R.)*, 1945, 9, (4), 350).—[In English.] Experiment indicates that the compound Bi₂Ni, prepared by alloying bismuth and nickel in a H.F. furnace, annealing at 460° C., and quenching, shows supraconductivity. It is suggested that other compounds of bismuth with transitional elements behave similarly.—G. V. R.

The Production of Beryllium Oxide and Beryllium–Copper. Bengt R. F. Kjellgren (*Electrochem. Soc. Preprint No. 89-5*, 1946, 83–93).—The production of beryllium oxide from beryl is first described. The production of beryllium–copper in laboratory experiments and on an industrial scale in an arc furnace by reduction of beryllium oxide with carbon in presence of copper, is then dealt with.—A. B. W.

The Production of Beryllium Compounds, Metal, and Alloys. (Kawecki.) See p. 241.

***Phantom Laminations in Brass.** Daniel R. Hull, H. F. Silliman, and John R. Freeman, jun. (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 203–212; discussion, 212–213).—See *Met. Abs.*, 1945, 12, 172.

*The Alpha-Solid-Solution Field of the Copper-Manganese-Zinc System. R. S. Dean, J. R. Long, T. R. Graham, and A. H. Roberson (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 232-243).—See *Met. Abs.*, 1945, 12, 352.

*A White-High-Manganese Brass. R. S. Dean, J. R. Long, T. R. Graham, and C. W. Matthews (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 244-252; also (abridged) *Metal Ind.*, 1945, 67, (13), 198-200).—See *Met. Abs.*, 1945, 12, 353.

*The Constitution of the Gold-Germanium System. [Hardness of Gold-Germanium Alloys.] Robert I. Jaffee, Eugene M. Smith, and Bruce W. Gonser (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 366-372).—See *Met. Abs.*, 1945, 12, 353.

Modern Wrought Magnesium Alloys. W. Ballantyne (*Modern Metals*, 1945, 1, (2), 24-25).—Tables showing specified min. properties of sheet, forgings, and extrusions of magnesium alloys are presented, and a bibliography of wrought magnesium alloys is given.—L. H.

*The Solubility of Manganese in Liquid Magnesium. [Effect of Aluminium and Zinc.] N. Tiner (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 351-357; discussion, 357-359).—See *Met. Abs.*, 1945, 12, 353.

*Grain-Size and Properties of Sand-Cast Magnesium Alloys. R. S. Busk and C. W. Phillips (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 266-276; discussion, 276-277).—See *Met. Abs.*, 1945, 12, 210.

*Factors Affecting Abnormal Grain Growth in Magnesium Alloy Castings. A. T. Peters, R. S. Busk, and H. E. Elliott (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 291-313; discussion, 313-314).—See *Met. Abs.*, 1945, 12, 354.

*The Electrical Resistance of Iron Wires and Permalloy Strips at Radio Frequencies. Alva W. Smith, J. H. Gregory, and J. T. Lynn (*J. Appl. Physics*, 1946, 17, (1), 33-36).—The "skin effect" for iron and Permalloy specimens was investigated, and the ratios of the resistances using A.C. to those using D.C. were measured. The range of frequency studied extended from 1.5 to 6.0 megacycles/sec. Results are given in the form of empirical relations which are discussed in terms of existing theoretical equations derived on the assumption of constant permeability.—G. V. R.

*The Hardness of Silver-Antimony Solid Solutions. R. M. Treco and J. H. Fryc, jun. (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 360-365).—See *Met. Abs.*, 1945, 12, 45.

*Thermodynamic Studies of Dilute Solutions in Molten Binary [Tin] Alloys. A. Yanko, A. E. Drake, and Frank Hovorka (*Electrochem. Soc. Preprint No. 89-13*, 1946, 151-164).—The systems tin-gold, tin-antimony, and tin-silver were studied in the dilute solution range on the tin-rich side over the temperature range 269-412° C., using a refined technique whereby measurements were made with a precision of ± 0.01 mV. The calculated activities of the more dilute solutions were in all cases ideal. Negative deviations of the activities of the solvent, increasing with the concentration of the solute, were obtained for the molten tin-gold and tin-antimony alloys. Positive deviations of the activities of the solvent, increasing with the concentration of the solute, were obtained for the tin-silver alloys. An increase in temperature caused a small but measurable decrease in the deviations of the activities from ideality for the molten tin-silver alloys, but not for the tin-gold and tin-antimony alloys.—A. B. W.

Remarks on the Strength of Cast Zinc Alloys. F. K. T. Beukema toe Water and H. C. J. de Decker (*Gas (Netherlands)*, 1943, 63, 34-38; *Chem. Zentr.*, 1943, 114, (II), 175; *C. Abs.*, 1944, 38, 5190).—In the practical use of cast zinc alloys, creep is of the greatest importance, within the stress range 2.5-3.5 kg./sq. mm. At greater stresses, e.g., with nuts on the bolts of gasometers, made from cast zinc alloys, fractures are frequently observed. Such nuts must not be tightened too much.

III.—STRUCTURE

(Metallography; Macrography; Crystal Structure.)

[For all abstracts on the constitution of alloy systems, including X-ray studies, see II.—Properties of Alloys.]

***A New Microscopy and Its Potentialities.** Charles S. Barrett (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 15–64).—See *Met. Abs.*, 1945, 12, 212.

A New Method for Producing Flat Metallographic Specimens. P. M. Trismakov, F. A. Mikulchik, and Sh. L. Dobrushkin (*Zavod. Lab.*, 1941, 10, 323–324; *Chem. Zentr.*, 1942, 113, (II), 2737; *C. Abs.*, 1944, 38, 2910).—[In Russian.] The polishing disc consists of an iron or steel plate coated with a 50 : 50 lead–tin alloy having 60° grooves approx. 0.03 in. deep and 0.25 in. apart. Such an alloy or pure lead can be used in place of emery powder. As imbedding materials, a mixture of 40% wax + 60% rosin (for emery) or 40% paraffin + 60% rosin (for rouge or Al_2O_3) is used.

Quantitative Microscopic Analysis of Binary Alloys. Salvatore Amari (*Ind. Meccan.*, 1943, 25, 99–105; *Chem. Zentr.*, 1943, 114, (II), 1143; *C. Abs.*, 1944, 38, 5469).—A good estimate of the composition of aluminium bronze or of steel can be obtained by metallographic study. With the former the relative contents of the α and β phases can be estimated by microscopic study and with the latter the relative contents of ferrite and pearlite are determined.

Applications of Metallic Shadow-Casting to Microscopy. Robley C. Williams and Ralph W. G. Wyckoff (*J. Appl. Physics*, 1946, 17, (1), 23–33).—It is pointed out that, for micrographic work and especially for electron microscopy, the lower limit of visibility is often fixed by lack of contrast, and that contrast can be obtained by a metal shadow-casting technique. Thin films of metal are deposited obliquely on to the surface (specimen or replica) to be studied, and protuberances cast shadows, from the length of which heights may be estimated. The thickness of the metal film varies according to the inclination of surface irregularities to the metal source, and the variations in thickness are recorded on the photographic plate. The techniques, and the preparation of specimens, are discussed in detail, and the use of metal replicas is described. The paper is well illustrated with photographs showing the type of result obtained.—G. V. R.

***Recrystallization of Aluminium in Terms of the Rate of Nucleation and the Rate of Growth.** W. A. Anderson and R. F. Mehl (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 140–167; discussion, 167–172).—See *Met. Abs.*, 1945, 12, 213.

***Textures, Anisotropy, and Earing Behaviour of Brass.** [Directional Variations of Mechanical Properties of Rolled Brass and Copper.] F. H. Wilson and R. M. Brick (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 173–200; discussion, 200–202).—See *Met. Abs.*, 1945, 12, 357.

On the Surface Motion of Particles in Crystals and the Natural Roughness of Crystalline Faces. J. Frenkel (*J. Physics (U.S.S.R.)*, 1945, 9, (5), 392–398).—[In English.] Theoretical. It is pointed out that crystalline faces are not necessarily ideally plane with orientations corresponding to a small value of the surface energy. In reality vicinal faces, with only slightly higher surface energy, arise on them as a result of thermal fluctuations. The vicinal faces may be regarded as irregular terraces formed on the basis of the main faces, which are therefore not smooth but rough. The boundaries of the terraces are not fixed, but advance and retreat, and the process may be considered quantitatively as a type of Brownian movement. The mechanism of evaporation of atoms from the crystal, and the converse deposition, is discussed, in terms of the motion of atoms in the surface layer. It is concluded that adsorbed atoms from the two-dimensional adsorbed phase, on the surfaces of steps of the terraces, to the one-dimensional adsorbed line of atoms situated

at step edges, and pass thence into the gas phase. The bearing of the theory on heterogeneous catalysis is discussed.—G. V. R.

***The Orientation Texture at the Surface of Cast Metals.** Gerald Edmunds (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 114; discussion, 115-119).—See *Met. Abs.*, 1945, 12, 176.

***Standards for Identifying Complex Twin Relationships in Cubic Crystals.** C. G. Dunn (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 90-97).—See *Met. Abs.*, 1945, 12, 214.

***Orientation Changes During Recrystallization in Silicon Ferrite.** C. G. Dunn (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 98-113).—See *Met. Abs.*, 1945, 12, 215.

Calculation of Debye-Scherrer Diagrams of Very Small Crystals by the Gas-Interference Method. H. Boersch (*Z. Physik*, 1942, 119, (3/4), 154-163; *Brit. Chem. Abs.*, 1943, [A I], 53).—The Debye-Ehrenfest interference function for a single rotating molecule is applied to the calculation of intensity distribution in the Debye-Scherrer diagram of crystalline particles containing 1, 2, and 8 unit cells for the cases of simple, body-centred, and face-centred cubic lattices. The method gives new maxima at low dispersion angles, which are not present in Bragg reflections from crystal planes.

X-Ray Methods of Determining Size and Shape of Submicroscopic Crystals. G. S. Zhdanov (*Zavod. Lab.*, 1940, 9, 732-740).—[In Russian.] A review.

***A Study of Age-Hardening [of Copper-Beryllium and Iron-Molybdenum Alloys] Using the Electron Microscope and Formvar Replicas.** D. Harker and M. J. Murphy (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 75-89).—See *Met. Abs.*, 1945, 12, 356.

***Investigation of Secondary Phases in Alloys by Electron Diffraction and the Electron Microscope.** R. D. Heidenreich, L. Sturkey, and H. L. Woods (*J. Appl. Physics*, 1946, 17, (2), 127-136).—The application of electron diffraction and the electron microscope to metallurgical investigations on very small amounts of secondary phases and impurities in metals and alloys is described. It is pointed out that by the use of suitable etching techniques the secondary phase may be made to stand out from the surface sufficiently to give diffraction patterns, at grazing incidence, which contain no diffraction rings due to the matrix. Surface preparation is fully discussed, and electrolytic polishing is advised. Sources of error, such as redeposition of a component of the alloy on to the surface during etching, are described, and the potentialities of the method illustrated by brief references to work on magnesium, aluminium, and copper alloys, and on steel. Illustrative photographs and diffraction patterns are reproduced.—G. V. R.

***On the Improvement of Resolution in Electron-Diffraction Cameras.** James Hillier and R. F. Baker (*J. Appl. Physics*, 1946, 17, (1), 12-22).—The electron optics of the conventional electron-diffraction camera are described, special emphasis being laid on resolving power. It is shown that the resolving power depends on the size of the central spot caused by the focused electron beam in the plane of the diffraction pattern. A two-lens arrangement is described which decreases the size of the central spot and makes very high resolution possible. Further, by an alteration of the focal length of the second lens (the lens nearer the photographic plate) the arrangement may be converted into a shadow-type electron microscope. Intermediate arrangements are possible, in which the photograph records individual diffraction spots which are dark-field images of the diffracting particles, while the central spot is a bright-field shadow image of the same particles. The construction of a typical instrument is described, and common pitfalls in electron microscopy are fully discussed. Many excellent photographs are reproduced to show the potentialities of the method, and the high resolving power attainable.

—G. V. R.

V.—POWDER METALLURGY

*The Mechanism of the Pressing of Metal Powders. Hermann Unckel (*Arch. Eisenhüttenwesen*, 1945, 18, (7/8), 161–167).—The pressure distribution in the compact during the pressing operation in making sintered metal compacts was investigated in terms of the sp. gr. and the Brinell hardness of the resulting material, determined at various positions on the cross-section. The influence of friction at the walls of the mould cylinder, and the flow distribution in the powder during pressing were examined, and the effects discussed. From the results obtained, mainly on copper and iron powders, quantitative relations are derived.—G. V. R.

Symposium on Production and Design Limitations and Possibilities for Powder-Metallurgy Parts: Foreword. F. N. Rhines (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 525–526); Design Factors for the Metal Forms with which Powder Metallurgy May Compete. Fred P. Peters (*ibid.*, 527–529; discussion, 530); Powder Metallurgy as Applied to Machine Parts. A. J. Langhammer (*ibid.*, 531–534; discussion, 534–535); Bearings from Metal Powders. W. R. Toeplitz (*ibid.*, 542–549; discussion, 549); Brushes and Allied Powder-Metal Parts. R. R. Hoffman (*ibid.*, 550–554); Electrical Contacts Manufactured from Metal Powders. E. I. Larsen (*ibid.*, 554–557); Friction Articles from Metal Powders. C. T. Cox (*ibid.*, 565–567; discussion, 567–568); *Certain Characteristics of Silver-Base Powder-Metallurgical Products. F. R. Hensel and E. I. Larsen (*ibid.*, 569–579; discussion, 579); *Some Properties of Sintered and Hot-Pressed Copper-Tin Powder Compacts. Claus G. Goetzl (*ibid.*, 580–593; discussion, 593–595); *The Sintering of Metal Powders—Copper. C. J. Bier and J. F. O'Keefe (*ibid.*, 596–611); *Some Experiments on the Effect of Pressure on Metal-Powder Compacts. Jerome F. Kuznick (*ibid.*, 612–630; discussion, 630–632); General Discussion (*ibid.*, 632–634).—See *Met. Abs.*, 1945, 12, 48, 177–179.

VI.—CORROSION AND RELATED PHENOMENA

*Study of the Oxidation of Aluminium by Air at the Ordinary Temperature by Measuring the Potential of Solution. Pierre Morrice and Paul Lacombe (*Compt. rend.*, 1946, 222, (12), 658–659).—It has been shown (L. and Chaudron, *Rev. Mét.*, 1936, 33, 697; *Met. Abs.*, 1937, 4, 390) that ordinary mechanical polishing of aluminium cannot produce a surface entirely free from oxide; in fact, the abrasion of polishing raises the surface temperature sufficiently to increase the rate of oxidation. An entirely oxide-free surface on very pure (99.99%) aluminium was obtained by electrolytic polishing in a bath of 2 : 1 acetic anhydride and perchloric acid ($d = 1.61$), avoiding all contact of the metal with air or water. After polishing, the metal was plunged into pure acetone to remove the viscous polishing film, and then washed in alcohol. The entire absence of an oxide film was demonstrated by measuring the potential of electrolytic dissolution, which is more sensitive than electronic diffraction (see Koch and Lehmann, *Aluminium*, 1941, 23, 304). It was observed during these experiments that the humidity of the air played an essential part in the reaction of aluminium to air at ordinary temperatures; the presence of water appreciably increases the rate of the reaction. This fact explains why only the polishing bath described above will give oxide-free surfaces, since phosphate and fluoroborate baths contain a considerable proportion of water.—J. H. W.

*Corrosion-Resistance of Heat-Treated 24S Aluminium Alloy. Charles Nagler (*Aluminum and Magnesium*, 1945, 2, (1), 26–29).—An investigation

into the effect of the interval between removal from the salt bath after solution-treatment and immersion in the quenching bath on the susceptibility to intercrystalline corrosion in 24S alloy (4.6% copper, 0.6% manganese, 1.5% magnesium, balance aluminium). The samples were subjected to a corrosion test in NaCl/H₂O₂ solution, and under the conditions of the experiments intercrystalline corrosion was observed when the time interval was 15 sec. or longer. The susceptibility to corrosion was not revealed in tensile tests on the material before the corrosion test.—E. C. E.

Corrosion of Light Metals and Its Prevention. András Domony (*Bányász. Kohász. Lapok*, 1943, 76, 221-230; *Chem. Zentr.*, 1943, 114, (II), 1846; *C. Abs.*, 1944, 38, 6266).—Various types of corrosion (chemical, electrochemical, and intercrystalline) occurring in light alloys, and the effect of alloying elements, impurities, and heat-treatment, are discussed. Protective methods are described in detail, and operating suggestions are given for anodic oxidation, chemical oxidation, plating, galvanizing, and lacquering.

***Corrosion Studies on Electrolytic Chromium.** Norman Hackerman and Donald I. Marshall (*Electrochem. Soc. Preprint No. 89-15*, 1946, 171-180).—The corrosion of electrolytic chromium stripped from the basis metal has been studied in both active and passive states in solutions of NaOH, HCl, H₂SO₄, CH₃COOH, and NaCl at various concentrations, and in the last case over a pH range of 0-11. Passive metal showed only isolated instances of attack, while in the active state attack occurred in all media with pH lower than 3. At higher pH the metal usually became passive after a short time, even in de-aerated solutions. Short exposures in acid media resulted in attack along the crack network system. Attack at isolated points in alkaline NaCl solutions was not related to the crack system.—A. B. W.

***Corrosion of Yellow Brass Pipes in Domestic Hot-Water Systems—a Metallographic Study.** E. P. Polushkin and Henry L. Shuldener (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 214-230; discussion, 230-231).—See *Met. Abs.*, 1945, 12, 49.

Corrosion Damage in Surface Condensers. F. Börsig (*Maschinenschaden*, 1943, 20, 5-16; *Chem. Zentr.*, 1943, 114, (I), 2731; *C. Abs.*, 1944, 38, 4898). The types and causes of corrosion are reviewed. Water causes more damage than steam. Brass is very liable to corrode, though the addition of as little as 0.02% of arsenic protects it.

Fatigue Cracking of Coated Lead Alloys. Lawrence Ferguson (*Bell Lab. Record*, 1946, 24, (2), 53-56).—A description is given of an investigation carried out to determine the effect of a coating of polyisobutylene on the fatigue strength of U.S. chemical lead and antimonial lead alloys. The coating is helpful at high rates, but harmful at slow rates of stress reversal. It is also protective with small stresses, but harmful at large ones.—E. V. W.

Field-Laboratory Tests of Alloy Cable Sheath. F. B. Livingston (*Bell Lab. Record*, 1944, 22, (10), 441-444).—L. describes field trials carried out on aerial cables with some of the failures experienced.—E. V. W.

***Experimental Study of Some Corrosion Phenomena of Zinc.** E. Lagrange (*Métaux, Corrosion-Usure*, 1942, 17, 164-167; *Chem. Zentr.*, 1943, 114, (I), 1755; *C. Abs.*, 1944, 38, 3946).—Metallic zinc was attacked by immersing the two ends of a curved strip in oxygen-containing aqueous solutions, which also contained 2% of gelatin to increase viscosity, 1% of NaCl, a trace of acetic acid, and a few drops of phenol red. Of the two alkaline regions which formed round each immersed end at the beginning of the experiment, one grew continuously, and the other decreased and finally disappeared. The formation of the asymmetry was promoted by the reduced ion mobility in the viscous solution. L. explains the phenomenon by assuming inhomogeneity in the zinc. Iron and aluminium show similar effects.

*The Time-Temperature Relation for the Solution of Zinc in Dilute H_2SO_4 . Gustav Nilsson (*Tekn. Tidskr.*, 1942, 72, (37), 65–68; *Chem. Zentr.*, 1943, 114, (I), 498; *C. Abs.*, 1944, 38, 2871).—The speed of solution of zinc in H_2SO_4 was determined by the quantity of hydrogen developed. It varies with temperature and concentration and again with the final quantity of zinc dissolved. The speed increases rapidly between 20° and 40° C., increases more slowly between 40° and 50° C., then decreases, very pronouncedly, to about 60° C., and is the same at 70° C. as it was at 20° C. Reasons for the decrease in speed are structural changes, impurities on the cathodes, protective films formed on the metal, and more uneven attack by the acid. Addition of ZnSO_4 has a greater retarding effect at 70° C. than at 20° C.

Intercrystalline Corrosion and Its Dangers. L. Tronstad (5 *Nord. Kemiskermøde*, 1939, 74–95).—A review.

VII.—PROTECTION

(Other than by Electrodeposition.)

Recent Studies of the Anodic Oxidation of Aluminium and Its Alloys. J. Héranguel (*Chim. et Ind.*, 1945, 54, (6), 389–395).—A summary of the results of recent French work on anodic oxidation. See *Met. Abs.*, this vol., pp. 52–53.—E. C. E.

Sulphamic Acid in Electrochemical Processes, Including Anodic Oxidation. (—). See p. 256.

*Studies of the Chemical Properties and Structure of Anodic Deposits and Coatings. IV.—Polar-Optical Analysis of the Disperse Structure of Oxide Coatings on Aluminium. K. Huber (*Helv. Chim. Acta*, 1945, 28, (7), 1416–1420).—[In German.] Anodic deposits of oxide show marked double refraction if precipitated from an oxalic acid bath; deposits of this type on aluminium sheet were isolated, usually by Treadwell's method, and examined by polarized light. The refractive qualities of the deposit depend on the orientation of the crystallites in the basis metal. The double refraction observed is uniaxial when a cube face is parallel with the surface of the metal, and biaxial when the quaternary axes are oblique with respect to the metal surface. A tabular summary contrasts the behaviour of aluminium with that of zinc under similar conditions.—P. R.

Detection and Removal of Protective Coatings on Aluminium. H. Couturier (*Lait*, 1943, 23, 15–17; *Chem. Zentr.*, 1943, 114, (II), 191; *C. Abs.*, 1944, 38, 5484).—The aluminium sheet is immersed, coated surface downwards, in a 1% HgCl_2 solution in a developing tray which is gently rocked. The metal turns grey in 1–2 min. It is rinsed with water and placed in a 1% H_3PO_4 or HgCl_2 solution. All the aluminium dissolves in about 10 min.; the coating remains and can be examined. If the aluminium is coated on both sides, the coating on one side must first be removed by rubbing it off with a solvent. The protective coating can be detected simply by means of a 5% HCl solution. With uncoated aluminium the solution develops considerable heat in 1 min., but if it is thickly coated there is no reaction.

The Alplate Process. Colin G. Fink (*Aluminum and Magnesium*, 1945, 2, (2) 26–27).—F. describes a process for coating steel with aluminium. The principal steps are as follows: The steel strip or wire is surface-cleaned in alkali and acid, then dried and fed into a hydrogen furnace, and from there directly into the molten aluminium bath. It goes next through a wiper and on to a receiving drum or reel. The steel absorbs hydrogen in the furnace. The hydrogen is liberated in the nascent state in the aluminium bath and reduces the alumina formed, thus ensuring perfect union between the aluminium

and iron. The coated strip or wire is free from pinholes and may be rolled, drawn, or anodized.—E. C. E.

Clad Light Metals. H. Kalpers (*Wien. Chem.-Zeit.*, 1943, 46, 81-84; *Chem. Zentr.*, 1943, 114, (II), 1751; *C. Abs.*, 1944, 38, 5784).—Duralplat (copper-free Duralumin on copper-containing Duralumin in a layer of thickness 5.0-7.5% that of the basis metal) has greater resistance to sea-water and atmospheric corrosion than has Duralumin. The mechanical properties are identical, but frequent or long-continued annealing should be avoided, because of the danger of diffusion of copper to the surface. Albondur and Bondurplat (pure aluminium and aluminium alloy, respectively, on the aluminium-copper-magnesium alloy Bondur, in layers of 5% thickness) have a high resistance to corrosion. The mechanical properties of the first are somewhat inferior to those of Bondur. Bondurdiff (Albondur 1% layer) is similar in mechanical properties to Bondur. Cupal (electrodeposited copper on aluminium) in layers of 10-30 or 5-15% is utilized for sheet, tubing, and wire. It can be plated with other metals.

Laminated Aluminium Solves Protection Problems. John M. Cowan (*Modern Metals*, 1945, 1, (7), 13).—L. H.

Saving Chromium by Chromizing. H. Kalpers (*Oesterr. Chem.-Zeit.*, 1942, 45, 109-111; *C. Abs.*, 1944, 38, 4897).—In the BDS (Becker, Daeves, and Steinberg) process a superficial layer of chromium is formed upon steel by leading HCl and hydrogen in gaseous form over ferrochrome and then the CrCl_2 so produced acts upon the metal to be chromized, replacing iron by chromium; a kind of cementation takes place, but of molecular dimensions, and by proper heating and rolling or other treatment the layer of chromium can be made of the desired thickness. Results are much better than in chromium plating, with its intermediate layers of copper, nickel, &c. Zones with 13% or less chromium are attacked or corroded, but those with more than 13% chromium are very resistant to corrosion. The composition of the steel treated is important. Chromizing cannot replace ordinary rustless (alloy) steels in all cases, but can take their place, with great saving of chromium, in many instances.

On Homogeneous Lead Coating. A. Kufferath (*Schleif- u. Poliertechn.*, 1943, 20, 54-55; *Chem. Zentr.*, 1943, 114, (II), 1132; *C. Abs.*, 1944, 38, 5191).—Homogeneous lead coating is preferred to coating by rolling. The preliminary treatment of the surface to be coated, the use of lead alloys, and different chemical methods which improve the coating, are discussed.

Anodic Process for Protecting Magnesium. N. H. Simpson and Paul Cutter (*Modern Metals*, 1945, 1, (2), 18-21).—An anodic process is described which produces a finish on magnesium alloys by using either A.C. or D.C., which is claimed to be superior in corrosion- and abrasion-resistance to the finishes produced by the acid dichromate and chrome pickle treatments. After degreasing, the magnesium parts are placed in the alkaline bath as cathode for electro-cleaning with D.C. If D.C. is employed in producing the finished coating, the current is reversed and the work is made the anode. If A.C. is used for the finish, the magnesium parts are connected to a low-voltage A.C. transformer after electro-cleaning. The corrosion-resistance of the finish coating so produced is somewhat enhanced by certain inorganic additions to the bath, high temperatures, and A.C. The anodic coating is an excellent dielectric and accordingly acts as an insulator in inhibiting galvanic corrosion when magnesium parts so protected are brought in contact with dissimilar metals.—L. H.

Processing [Protection] of Magnesium Alloys. N. H. Simpson (*Aluminum and Magnesium*, 1945, 2, (3), 18-22, 36-38).—An account of conditions which cause corrosion of magnesium alloys, and ways of preventing corrosion.

—E. C. E.

A Protective Finish for Magnesium Alloys. R. B. Mason (*Iron Age*, 1946, 157, (12), 48–52).—A method is described of producing relatively heavy protective coatings on magnesium alloys by anodic oxidation in a caustic soda electrolyte, followed by sealing in a chromate solution. This finish provides a heavy oxide coating with high abrasion- and corrosion-resistance.—J. H. W.

Electrolytic Oxidation of Magnesium and Magnesium Alloys. W. Hanswald (*Z. Metall- u. Schmuckwaren-Fabrik. Verchrom.*, 1943, 24, 99–101).—A review of the patent literature.

Magnesium for Cathodic Protection. Arthur Smith, jun. (*Modern Metals*, 1945, 1, (9), 22–23).—S. describes how the corrosion of underground installations occurs, and shows how the use of magnesium anodes may result in large savings in gas, water, and oil pipe-lines and cables by protecting them galvanically. The manufacture of the anodes and the method of locating them to prevent corrosion, are described.—L. H.

Surface Protection and Chemical Colouring of Zinc and Zinc Alloys. H. Krause (*Z. Metall- u. Schmuckwaren-Fabrik. Verchrom.*, 1943, 24, 15–16; *Chem. Zentr.*, 1943, 114, (I), 1931; *C. Abs.*, 1944, 38, 4239).—Recipes for colouring zinc, and data for protection by phosphatizing and chromatizing, are given.

Lockheed Requirements for Protective Coatings. Maxwell Stiles (*Indust. Finishing*, 1944, 20, (5), 18, 22, 24, 28, 30, 32, 38).—Accounts are given of the following cleaning and painting processes in the production of aircraft parts: application of zinc chromate priming coat of controlled thickness; treatment of joints and seams; prevention of contact between dissimilar metals; treatment of threaded or bearing surfaces; surface treatment of aluminium and its alloys; anodic oxidation; chemical treatment of magnesium; protection of cables and fittings; treatment of junction boxes; protection of ornamental work, plastics, and woods.—P. R.

Protection Against Corrosion of Apparatus for the Chemical Industry. P. Bourgois (*Chim. peintures*, 1943, 6, 171–177; *Chem. Zentr.*, 1943, 114, (II), 1035; *C. Abs.*, 1945, 39, 52).—A review of conditions promoting corrosion (nature of the aggressive agent, operating temperature, &c.), and the physical and chemical properties of materials used for such equipment, including metals and metal alloys and such mineral products as acid-resistant brick and tile, concrete, cement, acid-resistant cements, glass, quartz, and hydrocarbons.

The Theory and Use of Zinc Chromate Primers. Paul O. Blackmore (*Indust. Finishing*, 1944, 20, (7), 24–35; (8), 38–48, 52, 54, 59).—The functions of the priming coat are briefly reviewed. The compositions of primers containing zinc chromate are tabulated, with information regarding the nature of the vehicle, weight per gallon, viscosity, and colour. The main factors in the protective action of zinc chromate are considered, as are the functions and optimum proportions of such additions as asbestine. The nature and causes of adhesion between paint and metal are reviewed in some detail, and recommendations are made with regard to the testing of viscosity and specific gravity.—P. R.

VIII.—ELECTRODEPOSITION

Copper Plating on Aluminium. Marcel Ballay (*Métaux, Corrosion-Usure*, 1942, 17, 133–138; *Chem. Zentr.*, 1943, 114, (I), 88; *C. Abs.*, 1944, 38, 2882).—The aluminium is dipped in $\text{Fe}(\text{ClO}_4)_2$ solution (100 litres water, 6 litres $\text{Fe}(\text{ClO}_4)_2$ solution of 45° Bé., and 3 litres of HCl (d 1.19)); then a flash of nickel is given and afterwards one of copper. The method is applicable to pure aluminium and to Alpac (13% of silicon).

Brass Plating: Automatic Plant for Treating Steel Components. Alan Smart (*Elect. Rev.*, 1944, 135, (3501), 911–913; *Elect. Eng. Abs.*, 1945, 48, 88).—Describes an automatic plant carrying out the following brass-plating

schedule: alkaline electro-cleaning, rinsing, anodic H_2SO_4 etching, rinsing, immersing in cyanide solution, plating, rinsing, passivating, rinsing, and drying. The plating solution used contains: zinc 30, copper 15, sodium carbonate 20 g./litre; and pH 12.6-12.8. Mechanical details of the equipment for transferring the components from tank to tank are briefly described. Oil-immersed selenium rectifiers supply currents up to 4000 amp. at 8 V. for the various baths.

***Rapid Determination of Copper and Zinc in Cyanide Brass Baths.** F. I. Verdin (*Zavod. Lab.*, 1941, 10, 648; *Chem. Zentr.*, 1943, 114, (I), 1303; *C. Abs.*, 1944, 38, 3213).—[In Russian.] The procedure described calls for the deposition of Cu and Zn by electrolysis of the solution as it is to begin with and after periodic additions of NaOH. The two metals are weighed together, the deposit is dissolved in acid, and the Cu alone then determined by electrolysis.

***The Protective Value of Lead and Lead-Tin [Electro]Deposits on Steel.** A. H. Du Rose (*Electrochem. Soc. Preprint No.* 89-7, 1946, 101-112).—The protective value of deposits from fluoborate baths has been evaluated by outdoor exposure and salt-spray tests. The results were surprisingly good. In the case of the lead deposits the covering power and protection were improved by glue additions to the bath. Lead-tin alloy deposits containing 5-6% of tin were superior to pure lead and also to alloy deposits containing more tin. This is possibly related to the limit of solid solubility of tin in lead.—A. B. W.

Newer Methods for the Preparation of Bright Zinc Coatings. Kurt Nischk (*Schleif-, Polier- u. Oberflächentechn.*, 1943, 20, 81-82; *Chem. Zentr.*, 1943, 114, (II), 2204; *C. Abs.*, 1944, 38, 5784).—Review of German patents, with data on bath compositions, for the production of bright zinc coatings.

†Plating Die-Castings. [I.—] Preliminary Processes Before Plating. [II.—] Methods of Adding Nickel Cover. [III.—] Control and Purification of the Nickel Solution. [IV.—] The Application of the Final Chromium Plate. E. A. Ollard and E. B. Smith (*Metal Ind.*, 1946, 68, (13), 246-248; (15), 286-288; (17), 325-328; (19), 366-368).—In direct plating zinc-base die-castings containing 3-4% of aluminium and small quantities of other metals, special precautions are required to overcome the difficulties encountered owing to the solubility of the alloy in the plating solution and to the ease with which the hard thin skin of the alloy can be removed by cleaning. Hence, over-polishing and over-cleaning are to be avoided; the time of the degreasing operation is especially important in automatic working. These die-castings can be plated in an ordinary copper cyanide bath in which the free cyanide is kept as low as possible. The methods are detailed for the production of a dull nickel deposit for polishing and chromium plating using a Watts type of bath, and a bright deposit for chromium plating without intermediate polishing using the Weisberg and Stoddard and the Hinrichsen processes. Cobalt is required in the bath and is added as the sulphate. The control of the solution and the detection, estimation, and removal of impurities, such as iron, copper, and organic matter, are described. Full details of chromium plating the castings and the control of the bath are given, and the application of silver, speculum, and bronze finishes is described.—J. H. W.

Sulphamic Acid in Electrochemical Processes, Including Anodic Oxidation. — (*Metallurgia*, 1946, 34, (199), 7-8).—A brief *résumé* of some of the work carried out with sulphamic acid in electrochemical processes, including anodic oxidation, is given. Results of work on the electrodeposition of Rh, Cu, Fe, Ni, Co, Ni-Co alloy, Pb, Ag, Zn, Cd, Mg, and Th using a sulphamic acid electrolyte are tabulated. In the case of the last five metals no particular advantage is gained with sulphamic acid over sulphuric acid,

except possibly in the case of cadmium, using glue and nickel sulphate as addition agents.—J. W. D.

Electroplating and the Motor Industry. H. Silman (*J. Electrodepositors' Tech. Soc.*, 1946, 21, 65-78).—Specifications and practice in the electroplating of automobile components are reviewed, possibilities of improvement are noted, and future prospects of the industry are considered.—A. B. W.

Electroplating Facilities at Murray Hill. R. A. Ehrhardt (*Bell Lab. Record*, 1944, 22, (16), 609-613).—A description is given of the Bell Laboratories experimental electrodeposition plant.—E. V. W.

Soft Mipolam 1014, a Valuable Lining for Plating Tanks, Especially Those for Hard Chromium. Hans A. Sagel (*Metallwaren-Ind. u. Galvano-Techn.*, 1943, 41, 60-61; *Chem. Zentr.*, 1943, 114, (II), 476; *C. Abs.*, 1944, 38, 5459).—Soft Mipolam 1014 (vinyl polymer) in the form of ribbon, tubing, and sheet is used in the plating industry as a stop-off for racking frames, and for shielding metal parts not required to be plated. It resists most electroplating baths, especially chromium baths up to 60-70° C.; it possesses high flexibility, stability on ageing, and can easily be removed after use. The exact composition of Mipolam is not disclosed.

IX.—ELECTROMETALLURGY AND ELECTROCHEMISTRY

(Other than Electrodeposition.)

***The Anodic Passivation of Copper in Dilute Sodium Hydroxide.** W. Feitknecht and H. W. Lenel (*Helv. Chim. Acta*, 1944, 27, (3), 775-789).—[In German.] The voltages and current densities at which copper becomes passive in dilute sodium hydroxide have been determined and the metallic or oxidized surface resulting in each case has been examined microscopically and by X-rays. The electrolyte must be stirred, as otherwise action takes place mainly at the anode, which rapidly becomes coated with cupric hydroxide and ceases to function; this occurs most quickly at high current densities and at low concentrations of sodium hydroxide. The relationship between current density and rate of passivation follows the "law of surface coating" stated by W. J. Müller. Stirring of the electrolyte causes the deposition on the electrode of cuprous oxide; this is quickly transformed to cupric oxide, whilst if stirring ceases a coating of hydroxide forms over the oxide. The potentials corresponding with possible reactions between electrode and electrolyte are tabulated for normal sodium hydroxide solution. It is stated that the rapidity of these reactions depends on the orientation of the crystallites at the surface.—P. R.

***On the Electrolytic Preparation of Tungsten-Iron Alloys.** Jean-Lucien Andrieux and Georges Weiss (*Compt. rend.*, 1946, 222, (12), 646-647).—Alloys of iron and tungsten were prepared from the secondary reactions occurring in the electrolysis of the two oxides dissolved in a bath of molten borax. Two compounds were so prepared, Fe_3W_2 containing 68.72% of tungsten, and Fe_2W containing 62.23%. They have very similar chemical properties and both form beautiful clusters of grey metallic crystallites. They resist the action of hydrochloric acid, but are easily decomposed by *aqua regia* and nitric and sulphuric acids, with the precipitation of tungstic acid. Sodium peroxide and molten alkaline reagents attack them rapidly.

—J. H. W.

***Electrolysis of Manganese into a Metal Cathode from Suspensions of Manganese Oxide and Carbon in Molten Manganous Chloride.** Burke Cartwright and S. F. Ravitz (*Electrochem. Soc. Preprint No. 89-4*, 1946, 73-81).—Manganese was electrodeposited at 700° C. into a molten tin cathode from manganous chloride melts and from suspensions of manganese oxide and carbon in fused

manganese chloride, with a current efficiency of 88% in the former case and 57-75% in the latter. Practically all the chlorine was utilized in regeneration of manganous chloride. The possibilities of using this method for the production of pure manganese or usable manganese alloys are discussed, and zinc rather than tin is suggested as probably the most suitable cathode metal for either purpose.—A. B. W.

*On the Electrolytic Reduction of Aqueous Solutions of Chromic Acid.—II. Erich Müller (*Z. Elektrochem.*, 1943, 49, (1), 16-37).—Continues the discussion of the electrolytic reduction of chromic acid solutions (see *ibid.*, 1940, 46, 82; *Met. Abs.*, 1940, 7, 215). A description is given of the polarization phenomena occurring when solutions of pure and 30% chromic acid, sulphate-free and sulphate-containing, are electrolysed with cathodes of gold, silver, iridium, chromium, and copper. Graphs are given of cathode potential plotted against current density, for each type of cathode. Müller's theory of ionic-film formation is further developed and is shown to explain all the phenomena observed.—E. N.

*The Change of Overvoltage with Temperature. György v. Sigmund (*Magyar Chem. Folyóirat*, 1941, 47, 173-192; *Chem. Zentr.*, 1943, 114, (I), 373; *C. Abs.*, 1944, 38, 2883).—Hydrogen overvoltage is determined on cathodes of pure mercury, platinum, rhodium, and palladium, the electrolyte being 2*N*-HCl or H₂SO₄ solutions. The absolute values decrease as the temperature is increased. On the mercury cathode the Tafel equation holds from 0 to 80° C. Constant *a* decreases with temperature according to the equation $a = A/Te^{mT}$. Constant *b* increases with temperature in accordance with the theory of Erdey-Grúz and Volmer. On platinum the Tafel equation holds only for saturation with hydrogen; constant *a* decreases with temperature, constant *b* increases from 0° to 10° C., then decreases. On rhodium or palladium the Tafel equation does not hold.

*New Action of Magnetism. G. Destriau (*Compt. rend.*, 1940, 211, 380-382; *Brit. Abs.*, 1945, [A I], 338).—It is shown that when a nickel electrode is placed in a solution of NiSO₄ and is then submitted to the action of a magnetic field, an e.m.f. arises, which is distinct from the magnetization e.m.f. The experiment is repeated with non-ferromagnetic electrodes so that no magnetization e.m.f. can interfere. The system copper-CuSO₄-copper is studied. The copper electrodes are placed in the two limbs of a U-tube, and the magnetic field is applied to one of them. The electrode in this limb develops a very small negative e.m.f. for the first hour, and then a strong positive potential tending towards a limit, *E*₁. The initial negative potential being neglected, the potential *E* after time *t* is given by $E = E_1 e^{\theta/t}$, where θ is a constant. The potential does not depend on the orientation of the electrode. Fields of 3000-10,000 gauss are used, and there is no saturation effect within these limits. *E*₁ is independent of the concentration of the electrolyte. If the solution around the electrode is replaced by a fresh solution, the potential falls at once to zero, but the "activated" electrode slowly acts on the new solution, and in 15-20 min. the e.m.f. resumes the value which corresponds to the applied field. The electrode only slowly becomes deactivated and the solution can be replaced several times with similar results. A similar effect is obtained if the solution is in the magnetic field but the electrodes are not.

XI.—ANALYSIS

Spectrochemical Analysis for the Examination of Metals. R. Schmidt (*Polytechn. Weekblad*, 1943, 37, 257-261).—A review.

Introduction of Rapid Spectral-Analytical Methods for the Testing of Metals. Rudolf Holzhauser (*Anz. Maschinenwesen*, 1944, 66, (2), Suppt., 5-7).—A review.

*Effect of "Fixed Burning" of a Spark Discharge on the Analytical Results, Investigated on the System Zinc-Copper-Aluminium-Magnesium. A. Schöntag (*Z. wiss. Phot.*, 1942, 41, 237-250; *C. Abs.*, 1944, 38, 5745).—In the resonance spark generator, the spark at first wanders from point to point on the electrode; after a time the character of the discharge changes, so that the spark remains for a considerable time at the same point on the electrode; this latter form of discharge is called "fixed burning." The two forms are discussed in relation to conditions of the discharge, and the possible effect of the transition from one discharge form into the other on the analytical error is quantitatively investigated in respect of Zn-Cu-Al-Mg alloys.

*The Use and Performance of Colorimetric Methods. A. Schleicher (*Z. anal. Chem.*, 1943, 125, (11/12), 385-405).—S. discusses the usefulness, performance, and sensitivity characteristics of colorimetric analysis with special reference to the determination of Cu. Using a Lange photoelectric colorimeter, results are given for the following methods: ammonia, sulphide, benzidine, ferrocyanide, dithizone, salicylic acid, iodide, and diethyldithiocarbamate. It is concluded that the best results are given by the ammonia determination using a red filter, and that, generally, colorimetric analysis is worthy of greater consideration.—E. N.

Application of the Photocolorimeter in Volumetric Analysis. Yu. Yu. Lur'e and E. M. Tal (*Zavod. Lab.*, 1940, 9, 702-714; *Brit. Chem. Abs.*, 1943, [A I], 316).—[In Russian.] In the simplest cases the light absorption of the solution is measured after three additions of standard solution, one being before and two after the end-point has been reached; the end-point is the crossing of the straight lines drawn through the zero point and the first measured point, and through the two other measured points. This method is used for permanganometry (determination of Fe in presence of coloured cations, e.g., Ni and Co) and alkalimetry in the presence of phenolphthalein. A suitable light filter facilitates the titration. In more complicated cases, when the solution is coloured throughout (titration with methyl orange, methyl red, &c.), the light absorption must be measured for many additions, and the end-point found graphically. The method is indicated for coloured solutions, e.g., for determining the acidity of commercial Ni and Co sulphates and of Ni and Co electroplating baths.

*A Contribution to the Working Technique of Polarographic Analysis. A. Dravnieks and M. Straumanis (*Z. anal. Chem.*, 1942, 124, (1/2), 31-34).—A new type of self-contained cell is described, which has the following advantages: (1) contamination of the mercury with rubber and grease is avoided, (2) the drop rate can be easily regulated and the drops instantly checked, and (3) the anode is smaller than usual. Methods for the purification and storage of the mercury are discussed.—E. N.

*Determination of Traces of Aluminium with Aluminon. L. M. Kulberg and E. I. Rovinskaya (*Zavod. Lab.*, 1940, 9, 145-148; *Brit. Chem. Abs.*, 1943, [A I], 316).—[In Russian.] 10^{-6} – 10^{-5} g. of Al can be determined in the presence of <4 mg. of Ca, <0.5 mg. of Mg, $<2 \times 10^{-5}$ g. of Cu, Mn, and Zn, and <3 mg. of PO_4^{3-} , if the solution contains also 0.5–2 mg. of Fe^{+++} . Al + Fe are precipitated with 8-hydroxyquinoline in dil. CH_3COOH at 50°C ., and the precipitate is transformed into chlorides and extracted with 50% KCNS and $(\text{C}_2\text{H}_5)_2\text{O}$. The residue is transformed into Al aurintricarboxylate and the colour intensity measured with a photo-cell using a green filter, since the absorption maximum of the salt is 530 m μ .

*Identification of the Cations of Arsenic and of Some Neighbouring Elements (Antimony, Tin, and Cerium).—I.-II. P. Wenger, R. Duckert, and J. Renard (*Helv. Chim. Acta*, 1945, 28, (6), 1309-1315; (7), 1479-1489).—[In French.] [I.—] Reagents for trivalent and pentavalent As and some allied cations are considered in detail, with numerous bibliographical references. Only two

reagents—aluminium + KOH + HgCl for trivalent As and ferrous molybdate for pentavalent As—are considered sufficiently sensitive and reliable; discrimination between trivalent and pentavalent As in the presence of each other remains a problem. For trivalent Sb methyl-9-*m*-hydroxy-2:3:7-fluorone-6 is recommended. [II.—] The reactions of a large number of phenolic derivatives in the presence of As, Sb, Sn, and Ce compounds have been studied. Characteristic reactions were observed only for pentavalent As and Sb and tetravalent Sn and Ce. Pyrocatechol can be used for the detection of pentavalent in the presence of trivalent As; pentavalent Sb reacts characteristically with *o*-carboxy-pyrogallol under suitable conditions, and Sb⁺⁺⁺⁺ and Ce⁺⁺⁺⁺ quickly oxidize hydroquinone to quinhydrone.—P. R.

Critical Study of Reagents for Cations. XVII.—Reagents for Beryllium. Paul Wenger, Roger Duckert, and Y. Rusconi (*Helv. Chim. Acta*, 1945, 28, (5), 925-929).—[In French.] Non-recommended and recommended reagents are separately tabulated, the latter group consisting of pentanedione-2:4 (acetylacetone), quinalizarin + ethylenediamine, and *p*-nitrobenzene-azo-orninol.—P. R.

***Volumetric Determination of Chromium and Vanadium.** Lucien Ducret (*Bull. Soc. Chim. France*, 1943, [v], 10, 334-338; *C. Abs.*, 1944, 38, 4213).—From a study of oxidation potentials, a procedure is proposed for determining Cr and V in the presence of one another. After oxidizing to Cr₂O₇⁼⁼ and H₃VO₄, the solution is treated with a measured volume of standard FeSO₄ solution, which causes reduction to Cr⁺⁺⁺ and VO⁺. Then by titrating with K₂Cr₂O₇ in the presence of Ba diphenylamine sulphonate only the excess Fe⁺⁺ is oxidized and from the titration the equivalent of Cr + V is known. Then, at a different pH, the VO⁺ is oxidized back to H₃VO₄ by KMnO₄ in the presence of ferrous *o*-phenanthroline as indicator. The Cr is then known by difference.

Critical Study of Reagents for Cations. XV.—Reagents for Indium. P. Wenger, R. Duckert, and Y. Rusconi (*Helv. Chim. Acta*, 1945, 28, (3), 539-542).—[In French.] Analytical reagents for the detection and separation of In, especially for micro-analysis, are tabulated in two groups. The first contains reagents whose use is not recommended, the reason being shown in each case. The second group, containing only (a) hexamethylenetetramine + ammonium thiocyanate, and (b) dihydroxy-1:2 anthraquinone (alizarin), gives bibliographical references, method of use, temperature, sensitivity, nature of reaction, dilution limits, and "masking" or "interfering" cations.—P. R.

***A New Method of Fractionating the Rare Earths (with Nitrilo-Triacetate); Separation of Lanthanum and Cerium.** G. Beck (*Helv. Chim. Acta*, 1946, 29, (2), 357-360).—The mixed oxalates and/or fluorides of the rare-earth metals are dissolved in nitrilo-triacetate. Ce is precipitated quantitatively and free from didymium if a faintly alkaline solution is treated with H₂O₂; La is precipitated from an oxalate solution by acidifying with acetic acid. The method is also applicable to Sm-Gd mixtures.—P. R.

***A Critical Investigation of Lead Determination by the Chromate Method.** Friedrich Grote (*Z. anal. Chem.*, 1941, 122, (11/12), 395-399).—The Pb was precipitated from a boiling ammonium acetate and acetic acid solution by 0.5*N*-K₂Cr₂O₇, boiling being carried on for a further 10 min. After cooling and standing for 2 hr., the precipitate was filtered off, washed with distilled water, and then dried for 1 hr. at 105° C., and 2 hr. at 160° C. It is shown that the use of the empirical factor 0.6378 in place of the theoretical factor 0.6411 gave results in good agreement with the sulphate method to ±0.05%. (See also abstract below).—E. N.

***The Adsorptive Properties of Lead Chromate and Their Influence on the Analytical Determination of Lead as Lead Chromate.** Friedrich Grote (*Z. anal. Chem.*, 1943, 126, (4), 129-132).—Continues the investigation of the

chromate determination of Pb (see previous abstract). When Pb is estimated gravimetrically as PbCrO_4 by precipitation from acetic acid solutions with KCrO_4 or $\text{K}_2\text{Cr}_2\text{O}_7$, there is a uniform adsorption of CrO_4^{2-} in the PbCrO_4 . To compensate for this the empirical factor 0.6378 should be used. Variations in the methods of adding the precipitation reagent, lengthening of the drying time and increasing the drying temperature from 160° to 200°C . are shown to be without influence on the weight of the precipitate.—E. N.

***On the Thiocyanate Volumetric Method for the Determination of Mercury.** Z. Karaoglanov (*Z. anal. Chem.*, 1943, **125**, (11/12), 406–416).—An investigation of the thiocyanate estimation of Hg is described. The method was found to be reliable if carried out under the following conditions: (1) the Hg should be present as mercuric nitrate or sulphate, (2) there should be excess HNO_3 and a sufficiency of indicator solution, which may be either ferric nitrate or iron alum, (3) if phosphates are present, the quantities of HNO_3 and indicator solution must be increased, (4) halogens must be absent, (5) the titration must be carried out at room temperature, as warm solutions give erroneous results. The Hg can be titrated by the thiocyanate or the thiocyanate by the Hg. The preparation of a standard Hg solution is described; AgNO_3 can also be used for this purpose, but care must be taken to reach the final end-point. The theory of the reaction is discussed, together with the conditions which lead to complex salt formation between: (a) the thiocyanates of mercury, iron, and ammonia, and (b) ferric and phosphate ions.—E. N.

Critical Study of Reagents for Cations. XVI.—Reagents for Scandium. P. Wenger, R. Duckert, and Y. Rusconi (*Helv. Chim. Acta*, 1945, **28**, (5), 872–875).—[In French.] Non-recommended and recommended reagents for Sc are separately tabulated, grounds for criticism being indicated. Recommended reagents are hexammino-cobalt nitrate (luteo-cobaltic series) + NaF, and commercial tincture of cochineal.—P. R.

***On the Iodine Determination with the Aid of Ferric Chloride and Its Application to the Separation from Chlorine Ions and to the Determination of Silver.** W. Erber (*Z. anal. Chem.*, 1942, **123**, (5/6), 161–165).—The oxidation of iodine by FeCl_3 , according to the equation $\text{Fe}^{+++} + \text{I}^- = \text{Fe}^{++} + \frac{1}{2}\text{I}_2$, was investigated as a rapid and quantitative method for use in the determination of iodine. The solution, with an iodine concentration of $>0.012N$, has 0.6–1.2% of FeCl_3 and 2–12% of HCl added and is heated for 8–9 min. at 60°C . It is cooled, the excess Fe^{+++} neutralized by NaF, diluted, and the iodine titrated with $0.1N\text{-Na}_2\text{S}_2\text{O}_3$ solution, after the addition of 2–3 c.c. CCl_4 and using starch as indicator. Under these conditions the method is quantitative, a reliable separation being obtained when chlorine is present within very wide limits and if bromine is not in excess of $0.2N\text{-HBr}$. The method can be adapted for the microchemical determination of Ag. The Ag, of approx. known composition (if as AgCl it is dissolved in NH_4OH), is treated with a known volume of $0.1N\text{-KI}$ solution, so that it contains an excess of 0.5–3 c.c. of KI, diluted to 40 c.c. and the excess iodine determined as described above. With Ag contents of 5.7–284.6 mg. AgCl the error was found to be 0.3–1.4 mg. of AgCl .—E. N.

***Estimation of Traces of Sodium in Aluminium of Very High Purity by Spectral Analysis.** F. Rohner (*Helv. Chim. Acta*, 1944, **27**, (2), 268–273).—[In German.] Na in high-purity Al can be estimated spectrographically either by sparking small cast rods of the metal or by using a solution, e.g., that prepared for check analysis by the uranyl acetate method, with a glass or quartz spectrograph. The *D*-lines can then be distinguished against the Al band, the second *D*-line being more readily seen if a glass spectrograph is used. Owing to the possible segregation of Na in the Al, 4 parallel estimations should be made.—P. R.

***Estimation of Traces of Sodium by Spectral Analysis of Solutions.** F. Rohner (*Helv. Chim. Acta*, 1944, **27**, (3), 572–575).—[In German.] Na

can be estimated spectro-analytically in solutions containing down to 0.003 g. of Na per litre; the method is applicable to solids containing Na provided that Na-free solvents are available. An account is given of the estimation of Na in high-purity Al (see also preceding abstract). The solution is sparked between carbon electrodes. The method, though very laborious and having only one-tenth the sensitivity of the ordinary spectrographic analysis of metal specimens, eliminates segregation effects and is also recommended because of the ease with which standard solutions can be prepared.—P. R.

***Polarimetric Estimation of Sodium in Aluminium and Aluminium Alloys.** P. Urech and R. Sulzberger (*Helv. Chim. Acta*, 1944, 27, (5), 1074–1079).—[In German.] A modification of Heyrovsky's polarimetric method has been applied to the analysis of untreated or remelted specimens of aluminium and of Raffinal (aluminium of 99.991–99.997% purity). The sample is dissolved in tetramethylammonium hydroxide, most of the Al is precipitated as chloride by passing HCl gas, and the mother-liquor concentrated. Several estimations are necessary to establish the "blank" polarization curve. A tabulation of results shows that the accuracy attainable considerably exceeds that obtained by spectrographic methods. (See also abstracts above of papers by F. Rohner.)—P. R.

***Titrations with Solutions of Chromous Salts. II.—The Chromometric Estimation of Tungsten and Uranium.** R. Flatt and F. Sommer (*Helv. Chim. Acta*, 1944, 27, (6), 1518–1522).—[In German.] The estimation of W can be carried out by converting the salt to ammonium tungstate (5–20 mg./litre), strongly acidifying with HCl, and titrating with chromous chloride in a specially designed apparatus (see *ibid.*, 1942, 25, 684) in which changes in electrical conductivity can be observed. The end-point of the reaction is marked by a sharp drop in voltage, corresponding with the complete reduction of hexavalent to tetravalent W. U is similarly estimated, preferably in the presence of a trace of Fe, hexavalent being reduced to tetravalent U.—P. R.

***Titrations with Chromous Salts. III.—The Chromometric Estimation of Fe, Cu, Ti, V, Cr, Mo, and W in Mixtures.** R. Flatt and F. Sommer (*Helv. Chim. Acta*, 1944, 27, (6), 1522–1532).—[In German.] An apparatus (*ibid.*, 1942, 25, 684) which permits the observation of changes in conductivity has been used for the estimation, by titration with chromous chloride, of the following metals in presence of each other: Fe and Ti; Fe and V; Fe and Mo; Mo and Cu; Mo and Ti; Mo and V; W and Fe; W and Cu; W and Cr; W and Mo; Fe, Mo, and W. In each case the reaction noted is a reduction by the chromous salt, and the end-point is marked by a drop in potential. The reduction of one constituent of the mixture apparently becomes complete before that of the second constituent begins.—P. R.

***Micro-Separation of Zinc from Aluminium by Means of Potassium Ethylxanthogenate.** Paul Wenger, E. Abramson, and Z. Besso (*Helv. Chim. Acta*, 1946, 29, (1), 49–51).—Potassium ethylxanthogenate precipitates Zn quantitatively from a solution slightly acidified with acetic acid and containing sodium acetate; Al is not precipitated. Accurate micro-separation is practicable for mixtures containing Al and Zn cations in the proportions 25 : 75 to 75 : 25.—P. R.

Critical Study of Reagents for Cations. XVIII.—Reagents for Zirconium. Paul Wenger, Roger Duckert, and Y. Rusconi (*Helv. Chim. Acta*, 1945, 28, (5), 929–934).—[In French.] Non-recommended and recommended reagents are separately tabulated. The latter group includes rubidium chloride + ammonium fluoride, carminic acid, sodium alizarinsulphonate, and dimethyl-amino-4-phenylazo-phenylarsinic-4 acid.—P. R.

***Rapid Determination of Zirconium.** T. A. Uspenskaya, E. I. Guldina, and M. S. Zverkova (*Zavod. Lab.*, 1940, 9, 142–145; *Brit. Chem. Abs.*, 1943, [A I], 317).—[In Russian.] A solution of 0.2 g. of Zr in 5% HCl is mixed with

1.5 c.c. of 0.03% alizarin and with enough 0.1N-NaF to produce a yellowish-pink colour. To another solution containing the same amounts of HCl, alizarin, and NaF, a titrated solution of ZrOCl_2 is added to give the same colour. Fe^{+++} and SO_4^{--} , but not Fe^{++} , interfere.

A New General Method of Cation Analysis, Based on the Use of Potassium Ethylxanthate.—I.—II. P. Wenger, R. Duckert, and E. Ankadji (*Helv. Chim. Acta*, 1945, 28, (6), 1316–1325; (7), 1592–1606).—[In French.] Cf. *Met. Abs.*, this vol., p. 58. [I.—] Potassium ethylxanthate is proposed as a "group" reagent in place of H_2S . The proposed reagent is soluble in water and in common organic solvents containing oxygen; alcoholic solutions are more stable than aqueous ones. Non-reacting cations include the alkali and alkaline-earth metals, Al, Sc, Y, Me, Ce^{III} , Ti^{III} , Ti^{IV} , Zr^{IV} , Hf^{IV} , Th^{IV} , Mn^{II} , Re^{III} . Full descriptions are given of the reactions of the remaining cations (excluding certain rare elements) at 15° C. and a number of pH values. The reactions have been carried out in the presence of a large number of anions, a list of which is given; most of them do not influence the result. Excess of the reagent is removed by oxidation, resulting in the formation of sulphates, or by treatment with caustic alkali, which produces hydroxides and/or thio-compounds. [II.—] The systematic separation of metallic cations by means of potassium ethylxanthate is described. The metals should preferably be present as chlorides or sulphates, in a solution free from phosphates or organic acids; recommendations are made for the preparation of such solutions in analysing organo-metallic compounds, salts of organic or inorganic acids, minerals, metals, or alloys. The successive stages in the separation are: (1) Precipitation of Ag, Hg^{I} , Ti^{I} , Pb as chlorides; (2) precipitation of Pb, Ba, Ca, Sr as sulphates; (3) precipitation of Hg^{II} , Cu^{II} , Bi^{III} , As^{III} , As^{V} , Sb^{III} , Sb^{V} , Sn^{II} , Sn^{IV} , Au^{III} , Rh^{III} , Pd^{II} , Os^{IV} , Pt^{IV} , Se^{IV} , Se^{VI} , Te^{IV} , Te^{VI} , Mo^{V} , Mo^{VI} , Re^{III} , Re^{VII} , Co^{II} , Ni^{II} , with potassium ethylxanthate, Se and Te being precipitated uncombined; most of these xanthates are dissolved as thio-compounds on treatment with warm caustic alkali, Cu, Bi, Rh, Pd, Os, Pt, Re, Co, and Ni being precipitated as sulphides; (4) precipitation of hydroxides or sulphates of Cd^{II} , Ge^{IV} , Fe^{II} , Cr^{III} , $\text{O}_2\text{U}^{\text{II}}$, Ce^{III} , Y^{III} , Ti^{IV} , Th^{IV} , Tl^{III} , Sc^{III} , In^{III} , Mn^{II} , Mg^{II} with caustic alkali. Ru, [Os], Ir, U, Al, Be, [Ti], Ga, [In], Zn, [Ca] and the alkali metals remain in solution. Directions are given for isolating the members of each group, and a list of anions likely to interfere with the reactions is given.—P. R.

XII.—LABORATORY APPARATUS, INSTRUMENTS, &c.

(See also "Testing" and "Temperature Measurement and Control.")

*An Accurate Cooling Method for the Absolute and Relative Determination of the Temperature Variation of the True Specific Heat of Metals. Adolf Knappwost (*Z. Elektrochem.*, 1943, 49, (1), 1–6).—Previous methods of determining the specific heat of metals are reviewed and a new form of apparatus is described. The cylindrical specimen with a narrow axial hole drilled almost to the bottom, is heated to about 250° C. and inserted into a hollow aluminium cylinder, in which it rests on and is centred by small quartz or glass rods, leaving an air space of about 0.2 cm. around it. A copper-Constantan thermocouple is inserted into the hole in the specimen and the aluminium cylinder closed with a gas-tight lid, through which the thermocouple wires pass and are connected to a galvanometer reading to 0.01° C. The lid is fitted with two stopcocks which permit evacuation and introduction of another gas, air or hydrogen. Measurements of the capacity of the arrangement as a condenser enables the thermal conductivity of the gas layer between the specimen and container to be calculated. The aluminium container is immersed in an

ice-water mixture and measurements are made of the rate of change of temperature at the centre of the specimen. Equations are developed for calculating the thermal conductivity of the metal from the results obtained.—E. N.

***An Arrangement for the Rapid Photographic Recording of Magnetostriction Curves.** Max Kornetzki (*Wiss. Veröff. Siemens-Werken*, 1941, 20, (2), 48-53; *Elect. Eng. Abs.*, 1943, 46, 109).—The change in length of the specimen is transferred through a lever system to one plate of a capacitor supplied with current at 35 kc./sec. Results for various iron-cobalt alloys, "Sendust," and "1040" high-permeability alloys, are given.

Metallurgical Aspects of X-Ray Tube Manufacture. M. J. Zunick (*Iron Age*, 1946, 157, (15), 56-59).—Some of the unusual operations involved in X-ray tube manufacture are described, including casting of the anodes, mounting of the filament, preparation of the tungsten targets, glass-to-metal sealing, and tube exhaustion. From a metallurgical point of view, the important requirements are: (1) density and melting points of targets and anode castings, (2) purity of the metals with respect to both metal and gas impurities, (3) cleanliness of surfaces and absence of low-melting constituents, and (4) chemical composition.—J. H. W.

XIII.—PHYSICAL AND MECHANICAL TESTING, INSPECTION, AND RADIOLOGY

New Ideas for the Estimation of the Elastic Limit and Proof Stress. Wilhelm Späth (*Arch. Eisenhüttenwesen*, 1943, 16, (11/12), 465-468).—It is pointed out that the usual method of determining the proof stress as that stress which is required to produce a fixed permanent deformation has certain disadvantages. These are discussed, and it is suggested that the required permanent deformation to be used to obtain comparable results for different materials should be proportional to the elastic deformation. The derivation of suitable values for the permanent deformation is discussed, together with the potentialities of the new method.—G. V. R.

A New Approximate Method of Measuring the Percentage Elongation of Metals at Fracture. A. I. Mikhailov (*Vestn. Metalloprom.*, 1939, 19, (7), 71; *Elect. Eng. Abs.*, 1944, 47, 74).—[In Russian.] An empirical relation is established between percentage elongation (δ_{10}) at fracture (as obtained in tensile tests on cylindrical specimen with length = $10 \times$ dia.), and deformation when undergoing a Brinell indentation test with a 5-mm. ball at 750 kg.

***Systematic Investigation of the Applicability of Journal-Bearing Materials.** E. Heidebroek (*Automobiltechn. Z.*, 1942, 45, 652-656; *Chem. Zentr.*, 1943, 114, (II), 465; *C. Abs.*, 1944, 38, 5480).—A special laboratory testing machine is described with which ten different bearing metals were studied with regard to friction coeff. for speeds up to 15 mm./sec., lubrication, and loads up to 600 kg./sq. cm. The tests show that loads of over 400 to 600 kg./sq. cm. cannot be satisfactorily applied in practice with the present known materials.

Inspection of Bronze Bearings for Aircraft. Francesco Villani (*Met. Ital.*, 1943, 35, 59-66; *Chem. Zentr.*, 1943, 114, (II), 771; *C. Abs.*, 1944, 38, 5784).—Aircraft bearings of lead bronze should be examined by X-rays; the Seifert apparatus can be used for this purpose. A nomograph for determination of exposure time as a function of bearing thickness is given, and X-ray pictures of sound and faulty bearings of 80 : 20 and 75 : 25 copper-lead alloys are shown. The main defects are segregation (especially if the lead content is over 20%), large grain-size, and porosity.

Automaton Bubble-Tests Light-Metal Castings. Roy Cummings (*Machinist (Eur. Edn.)*, 1946, 90, (1), 32-33).—Pressure testing of hollow aluminium and magnesium castings is intensified and accelerated by the use of a semi-automatic pressure-testing fixture, which is here described.—J. H. W.

Structural Experiments and Determination of Internal Stresses of Metallic Materials by X-Rays. Edmondo Di Giacomo (*Il Calore*, 1942, 15, 148-160, 176-182).—A review.

RADIOLOGY

Relationship of X-Ray Inspection to Light Metals Foundry Control. Robert Taylor (*Aluminum and Magnesium*, 1945, 1, (11), 20-24).—The advantages of radiographic inspection from the point of view of correcting faulty foundry technique and of rejecting faulty castings are discussed. The appearance of the common defects on the X-ray negative is described, and an elementary account of radiographic technique is given.—E. C. E.

Fluoroscopy of Light Alloy Castings. B. Casson and D. S. Clark (*Iron Age*, 1946, 157, (16), 48-50).—See *Met. Abs.*, this vol., p. 99. The basis for acceptance or rejection of castings on fluoroscopic tests must be a rational one, and the significance of observed defects on the usability of castings and the use of higher X-ray voltages to obtain greater screen brightness, are discussed.—J. H. W.

Industrial X-Ray Developments. C. D. Moriarty (*Elect. Eng.*, 1945, 64, (12), 433-435).—Advances in the production of X-ray materials and methods of recording X-ray results are reviewed, and some applications are given.—E. V. W.

A Survey of X-Rays in Engineering and Industry. V. E. Pullin (*J. Inst. Elect. Eng.*, 1945, [I], 92, (54), 226-233; discussion, 233-238).—P. deals with (1) the development of the X-ray technique from the time of Röntgen's discovery, (2) its use during the war, and (3) possible future developments. Only the radiographic aspect is considered.—E. V. W.

Problems of a Small Gamma-Ray Department. John H. G. Williams (*Indust. Radiography*, 1942, 1, (2), 35-37; *C. Abs.*, 1944, 38, 3544).—Numerous miscellaneous features of gamma-ray work are discussed, including protection, an adjustable support for the radium capsule, the use of a calibrated density strip for approximate measurements of density, and the properties of the characteristic curve of the film.

XIV.—TEMPERATURE MEASUREMENT AND CONTROL

An Electronic Potentiometer Pyrometer. J. J. Fraser (*Electronic Eng.*, 1945, 17, 340-344; *Elect. Eng. Abs.*, 1945, 48, 169).—The instrument described measures temperature by balancing the e.m.f. generated by the thermocouple against a known voltage from a battery. The operating principle is discussed and the various components are studied. The balancing circuit is continuous, and not periodic. It is claimed that the instrument possesses several advantages over those normally used in pyrometry, e.g., stability of calibration, greater accuracy, robustness, speed of operation, &c.

XV.—FOUNDRY PRACTICE AND APPLIANCES

†**Fundamental Principles Involved in Segregation in Alloy Castings.** R. M. Brick (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 65-72; discussion, 72-74).—See *Met. Abs.*, 1945, 12, 30.

Symposium on Continuous Casting: Opening Remarks. Carl E. Swartz (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 478-479); †**Continuous Casting Yesterday and To-Day.** T. W. Lippert (*ibid.*, 479-486); †**The Continuous Casting of Molten Metals—History, Requirements, Metallurgy, and Economics.** N. P. Goss (*ibid.*, 487-510; discussion, 510-511); **Improvements in the Direct Rolling of Strip Metal.** C. W. Hazlett (*ibid.*, 512-514); **The Soro**

Process [of Casting]. E. I. Valyi (*ibid.*, 514-519); The Williams Process of Casting Metals. Edward R. Williams (*ibid.*, 520-523).—See *Met. Abs.*, 1945, 12, 229-230.

Treatment and Casting of Metals by Electromagnetic Forces. W. W. Hoke (*Trans. Amer. Inst. Elect. Eng. (in Elect. Eng.)*, 1944, 63, 986-992; *Elect. Eng. Abs.*, 1945, 48, 288).—A discussion of the normal forces exerted on impurity particles in a mass of molten metal is followed by examination of how the application of a unidirectional electromagnetic field through the metal increases the forces which assist in the elimination of impurities by increased buoyancy. The beneficial effect of a superimposed A.C. field in forcing impurities towards the top of the metal under treatment is outlined. It is shown to be possible to regulate the current through the metal on cooling so as to cause it to solidify from the bottom upwards. The method is claimed to eliminate all comparatively non-conductive undissolved impurities from the treated metal. The application of electromagnetic force on a casting permits greater complexity of casting with greatly reduced casting pressure. A special application to the casting of dental forms is described.

Degassing and Pouring Aluminium. Hiram Brown (*Modern Metals*, 1945, 1, (2), 12-17).—The degassing of molten aluminium, the control of temperature, and the pouring into sand and permanent moulds, is described and illustrated.—L. H.

British Aluminium Permanent-Mould Practice. Jack W. Wheeler (*Modern Metals*, 1945, 1, (8), 8-12).—It is expected that aluminium die-castings will be employed in many ways in the new British automobiles. Close co-operation between foundry and consumer has a direct bearing on low-cost production.

—L. H.

Centrifugal Casting Aluminium. — (*Modern Metals*, 1946, 1, (12), 14-16).—The process, design characteristics, production equipment, production methods, and control are discussed.—L. H.

Chills for Light Alloy Castings. A. E. Cartwright (*Aluminum and Magnesium*, 1945, 2, (3), 23-24, 38).—Aluminium is effective as a chill material for light alloy castings on account of its high specific heat, latent heat of fusion, and thermal conductivity. It was shown experimentally that of the four materials, cast iron, copper, aluminium-5% silicon alloy and magnesium-8% aluminium alloy, cast iron was best and the aluminium-base alloy next best as a chill material for aluminium-4% copper alloy.—E. C. E.

Aluminium Bronze Permanent-Mould Castings. B. Johnson (*Iron Age*, 1946, 157, (14), 80-83).—Details are given of mould construction and of the casting operations for casting aluminium bronze, containing copper 85-88, aluminium 10-11, iron 2-3%, in gravity-filled die moulds to produce castings having superior hardness, grain and surface characteristics, and with close tolerances.—J. H. W.

The Loss of Metal in the Casting of Brass and Its Prevention. Gillis Em. Huss (*Tekn. Tidskr.*, 1942, 72, 443-446; *Chem. Zentr.*, 1943, 114, (I), 671; *C. Abs.*, 1944, 38, 3582).—The following measures will, to a large extent, prevent loss of metal: preheating of the metal before its introduction into the crucible, covering the metal with 2-3 cm. of powdered charcoal before fusion begins, regulation of the combustion in the furnace, stirring the melt, avoiding heating above the casting temperature, pyrometric control of the temperature of the melt, and rapid casting after the casting temperature is reached, especially when the casting temperature required is high.

Fundamentals of Pouring Magnesium Sand-Cast Alloys. E. J. Vargo (*Aluminum and Magnesium*, 1946, 2, (4), 14-17, 21).—A discussion of the melting of magnesium and the pouring of the molten metal in the mould. Melting under a flux is carried out in tilting furnaces holding 2000 lb., the charge consisting of 20% virgin ingot and balance segregated scrap, from which all

sand is cleaned. The molten metal is transferred to steel crucibles and refined by stirring in refining flux for 2 min. at 1300–1350° F. (687–715° C.). The metal is then superheated to 1650–1700° F. (881–909° C.) with exact temperature control. The pots are removed from the furnace and cooled to pouring temperature. The flux is dry after superheating, and burning at this stage is controlled by the use of dusting fluxes containing sulphur, boric acid, and ammonium borofluoride. The moulds are filled with SO₂, the crucible lip is cleaned and the flux crust removed or held back, and the metal is poured. A pouring box is used on the mould to act as a reservoir of molten metal and to trap oxides. The pot is never emptied completely. The defects which may result from malpractice during pouring are listed and the probable causes are given.—E. C. E.

***A Study of Factors Influencing Grain-Size in Magnesium Alloys and a Carbon-Inoculation Method for Grain Refinement.** [Tensile Properties of Magnesium Alloys.] C. H. Mahoney, A. L. Tarr, and P. E. Le Grand (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 328–347; discussion, 347–350).—See *Met. Abs.*, 1945, 12, 373.

***Grain Refinement of Magnesium Alloys Without Superheating.** Ralph Hultgren and David W. Mitchell (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 323–327).—See *Met. Abs.*, 1945, 12, 373.

***Grain Refinement of a Carbothermic Magnesium Alloy by Superheating.** Ralph Hultgren, David W. Mitchell, and Bernard York (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 315–322).—See *Met. Abs.*, 1945, 12, 374.

***Oxidation Inhibitors in Core-Sand Mixtures for Magnesium Castings.** O. Jay Myers (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 253–261; discussion, 261–265).—See *Met. Abs.*, 1945, 12, 230.

Magnesium Foundry. — (*Aluminum and Magnesium*, 1945, 2, (1), 31–34; (2), 22–25; (3), 25–24).—An account of the new foundry of Messrs. J. Stone and Co., Ltd.; see *Met. Abs.*, 1945, 12, 297.—E. C. E.

Impregnating Magnesium Castings. Samuel A. Moore (*Iron Age*, 1946, 157, (11), 76–80).—The behaviour of various types of agents for sealing up the microporosity of magnesium castings is described, with particular reference to the relation of baking time and pressure to the efficacy of the sealing action. The impregnating properties of a newly-developed resin-styrene, “No. 988,” are also described. This compound is non-thermoplastic and does not require an expensive chemical catalyst.—J. H. W.

Babbling Large Cast-Iron Bearing Shells. L. F. Train (*Iron Age*, 1946, 157, (14), 84–85).—The method of babbling cast-iron is described in which the half bearing shell is completely immersed in a tinning bath in an especially constructed furnace.—J. H. W.

A Buyer Looks at Some Foundry Problems. R. V. Elms (*Aluminum and Magnesium*, 1946, 2, (4), 18–21).—The need for the buyer to state his specifications more exactly, and for the average small foundry to meet these requirements by increasingly exact control, is stressed.—E. C. E.

Thermal Reclamation of Sand. Gordon H. Curtis (*Aluminum and Magnesium*, 1946, 1, (12), 16–20).—C. describes the reclamation of sand in a foundry using upwards of 300 tons of sand a day. All moulds are assembled from baked oil-bonded cores and no clay-bonded sand is used. The used sand is roasted in a multiple-hearth ore-roasting furnace to about 1500° F. (798° C.), at which temperature the carbonaceous material from the binder, sulphur, and inhibitors if present are oxidized or decomposed and driven off. About 5% of raw sand is required per cycle and the reclaimed sand is as good as the original sand. A flow diagram of the process is given.—E. C. E.

XVI.—SECONDARY METALS: SCRAP, RESIDUES, &c.

Secondary Aluminium and Aluminium Alloys. Louis Frenot (*Rev. Aluminium*, 1945, (117), 164–170).—F. describes the work and recommendations of the French Technical Committee on Secondary Aluminium. The aluminium scrap was segregated into the following groups. Group 1. *Pure metal*: (a) 99.8%, (b) 99.5%, and (c) 98–99.4%. Group 2. *Sheet and forgings*: (a) aluminium–copper with magnesium and manganese, (b) aluminium–magnesium–silicon, (c) aluminium–magnesium, and (d) aluminium–copper–nickel–magnesium. Group 3. *Casting alloys*: (a) aluminium–copper (4–12%), (b) aluminium–copper–silicon (5% Cu, 4% Si), (c) aluminium–silicon–magnesium (5% Si, 1% Mg), (d) aluminium–silicon (13%), (e) aluminium–silicon–copper (15% Si, 2.3% Cu), (f) aluminium–magnesium, and (g) miscellaneous. Tables showing the composition limits and mechanical properties of the various groups of alloys are given. The alloys are also classified according to their behaviour during anodizing. Uses for which the various alloys are suitable are given.—E. C. E.

[U.S.] Navy Recovers Aluminium from Aircraft. Donald L. Colwell (*Modern Metals*, 1945, 1, (9), 8–12).—A review of the policy and technique applied in the disposal of obsolete and worn-out military aircraft is given.

—L. H.

The Influence of Scrap Aluminium on the Post-War Market [in America]. N. H. Engle (*Aluminum and Magnesium*, 1945, 2, (2), 18–21, 27).—E. C. E.

Recovery of Non-Ferrous Heavy Metals. R. Piontelli (*Met. Ital.*, 1942, 34, 394–396; *Chem. Zentr.*, 1943, 114, (II), 272; *C. Abs.*, 1944, 38, 4888).—A critical survey of the working up of copper, lead, zinc, &c.

Detinning Plant Uses 20,000-Foot Pipe. C. P. Stolberg (*Heating and Ventilating*, 1944, 41, 41–43; *C. Abs.*, 1944, 38, 5192).—Discarded tin cans are freed from tramp iron and other material having no tin content, shredded, incinerated in an oven, and washed. Cleaned cans are detinned in NaOH solution, from which tin oxide is precipitated, filtered, dried, and packed for shipment.

XVII.—FURNACES, FUELS, AND REFRACTORY MATERIALS

Some Recent Heat-Treatment Furnace Installations. — (*Metallurgia*, 1946, 34, (199), 29–40).—A review of furnace installations developed recently for the heat-treatment of both ferrous and non-ferrous metals includes descriptions of a roller-hearth furnace for clean-annealing non-ferrous material; of a continuous roller-hearth gas-fired furnace for bright-annealing; of furnaces for light alloy heat-treatment, including conveyor, pusher, and tubular furnaces; and of different types of furnaces for brazing.—J. W. D.

Furnaces and Heat-Treatment for Permanent-Mould Magnesium Castings. A. V. Keller (*Modern Metals*, 1945, 1, (7), 20–21, 23).—K. explains the building and operation of a heat-treating furnace and discusses some of the causes responsible for sub-standard castings.—L. H.

H.F. Inductor Heating. — (*Elect. Rev.*, 1946, 138, (3564), 399–403).—Equipment for heat-treatment and brazing is described.—J. C. C.

XVIII.—HEAT-TREATMENT

Refrigerating Aluminium to Arrest Age-Hardening. M. L. Rask (*Modern Metals*, 1945, 1, (9), 19–21).—The purpose of refrigerating is to keep the aluminium alloy in a soft and workable condition before forming; e.g., high-strength alloys like 75S can be prevented from natural ageing. Refrigeration may be

used after the solution heat-treatment and quenching, and before the precipitation heat-treatment.—L. H.

Heat-Treatment of Metals and Alloys. J. W. Donaldson (*Metallurgia*, 1946, 34, (199), 25–28, 24).—In a review of the more recent developments and improvements in the industrial heat-treatment of both ferrous and non-ferrous metals and alloys, special reference is made to bright annealing and age-hardening.—J. W. D.

Uniformity Problems in Heat-Treating. Victor Paschkis (*Aluminum and Magnesium*, 1946, 2, (4), 12–13, 17).—A general discussion of the conditions necessary to give minimum thermal gradients for both heating and cooling during heat-treatment. The type of furnace, means of heating, and type of charge are discussed.—E. C. E.

Theoretical Principles of the Annealing of Metals in Protective Gases. W. Baukloh (*Gas u. Elektrowärme*, 1943, 5–8; *Chem. Zentr.*, 1943, 114, (II), 1407; *C. Abs.*, 1944, 38, 5480).—Physico-chemical principles of oxidation, carburization, decarburization, and sulphurization, and the reactions taking place in protective gases are described. Directions are given for the calculation of equilibrium diagrams.

XIX.—WORKING

Fabricating Aluminium Into Difficult Shapes. — (*Modern Metals*, 1946, 2, (1), 27, 29).—Several applications are described in which aluminium is now being used, e.g., for the manufacture of a deep-drawn bomb-tube and a communications tube. The development (which is outlined) of aluminium presses during the war made many of the novel applications possible.—L. H.

Design-Rolling or Rigidizing Light Metals. Richard S. Smith (*Modern Metals*, 1946, 2, (1), 8–11).—Rigidizing or design-rolling is a method of form-finishing which adds stiffness and impact and buckling strength, and thereby permits the use of lighter-gauge sheet than is normal. It is shown how the cost of this process is more than offset by the saving in metal. This process is being applied in the automobile and aircraft industries, and in architecture.—L. H.

Flexible Tools for Stamping Light Metals. — (*Modern Metals*, 1945, 1, (7), 14–15).—L. H.

Stamping Light Metals. — (*Modern Metals*, 1945, 1, (3), 4–6).—The progress made in stamping aluminium and magnesium is outlined.—L. H.

Experiences in the Working of Copper Billets Into Copper Wires. C. Scharwächter (*Gas u. Elektrowärme*, 1943, 56–58; *Chem. Zentr.*, 1943, 114, (II), 2097; *C. Abs.*, 1944, 38, 5766).—The origin of the “hydrogen sickness” of copper as a result of the reduction of CuO_2 in a reducing atmosphere is explained. Means of avoiding it are discussed, especially by the elimination of contact of red-hot copper with unburned hot gases.

Spinning Magnesium. Robt. J. Schneider (*Modern Metals*, 1945, 1, (2), 8–11).—The forming of magnesium by spinning as carried out in U.S.A. is described and illustrated.—L. H.

Machining Practice for Magnesium Castings. H. E. Linsley (*Aluminum and Magnesium*, 1945, 1, (12), 12–14, 21, 28).—The need for care in clamping magnesium castings to machine beds is pointed out. Machining is generally performed at the max. spindle speed obtainable on the machine. Surface speeds of 150–1200 ft./min. with feeds up to 0.040 in. and relatively heavy depths of cut, occasionally as deep as 0.5 in., are used. The cutting angles and design of cutting tools for milling, drilling, reaming, and tapping are discussed. Grinding, lapping, and polishing operations are also described.—E. C. E.

The Cold Sawing of Light Alloy Bars by the Circular Saw. Henri Poulain (*Rev. Aluminium*, 1945, (117), 175–177).—The cold sawing of Duralumin

billets is discussed from the point of view of the spacing of the saw teeth, the speed of rotation, and the rate of feed. The power consumption for sets of arbitrary conditions is calculated, and estimated cutting times are found to agree very well with those obtained experimentally.—E. C. E.

XX.—CLEANING AND FINISHING

Cleaning Aluminium. C. W. Smith (*Modern Metals*, 1945, 1, (7), 16-17).—S. describes the steps necessary in the cleaning process before spot welding or paint-bond treatments.—L. H.

Metal Cleaning. II.—Soil-Removal Performance Methods. Jay C. Harris (*Bull. Amer. Soc. Test. Mat.*, 1945, (136), 31-39).—Cf. *ibid.*, 1945, (133), 23; *Met. Abs.*, this vol., p. 107. The direct evaluation of metal cleaners by measurement of their relative ability to remove a given soil by laboratory methods is considered. The methods covered include soak tank, mechanical tank or spray, electrolytic, solvent or vapour degreasing, and emulsion degreasing. The types of soil or foreign matter generally encountered have been classified: mineral oil blanking lubricant, cutting oils, soap emulsions used in cutting and pressing, drawing soaps, buffing compounds, graphite drawing compounds, carbonized oils or greases or food products, asphaltic or tarry materials, corrosion products, food residues and paints, varnishes, waxes, &c. In determining the effectiveness of soil removal, the "water-break" has most often been used, but methods giving numerical comparisons have recently been applied. These depend on such things as photometric reflectance measurements, ultra-violet photography for measurement of retention of oil-soluble fluorescent dye, and petroleum ether washing for the removal of retained oil.—A. B. W.

Survey of Methods for Cleaning Metals. J. M. Bialovsky (*Indust. Finishing*, 1944, 20, (5), 41-48).—The following processes are briefly described: solvent cleaning; alkali cleaning, usually by means of mechanical washers; removal of mill scale by pickling; and "flame-priming" with the acetylene torch.

—P. R.

Different Processes for Cleaning Metal. G. C. Close (*Indust. Finishing*, 1944, 20, (4), 42-46).—Recommendations for metal cleaning, and especially for that of brass and bronze, include the provision of a separate tank for each of these alloys; their phosphoric-dipping after cleaning with alkali; the use of "emulsion degreasing" before immersing metal parts in the hot cleaning solution; the electro-cleaning of steel, copper, brass, and some die-cast alloys; the steam-cleaning of plant and equipment; and phosphatizing, which both cleans and passivates a surface, and can be effected by brush application in the case of large parts.—P. R.

Fundamentals of Finishing Magnesium. — (*Modern Metals*, 1945, 1, (9), 26-28).—L. H.

Cleaning, Surface Treating, and Protectively Coating That New, Lightest Metal—Magnesium. G. C. Close (*Indust. Finishing*, 1944, 20, (9), 30, 34, 36, 38, 40, 42; (10), 38, 42, 44, 49-50, 55).—The properties of magnesium with respect to corrosion are reviewed, and an account is given of various methods of cleaning. Magnesium alloy parts are usually supplied after a chrome-pickling treatment, and the coating should be removed before fabrication; allowance should be made in design for the considerable amount of material so removed. Accounts are given of chrome-pickling, acid and alkaline dichromate treatments, anodic oxidation, and several organic finishes; bath compositions and common commercial designations are given.—P. R.

Soap in Aluminium Finishing and Maintenance. Georgia Leffingwell and Milton A. Lesser (*Aluminum and Magnesium*, 1945, 1, (12), 15, 21, 28, 34).—An account of the cleaning of aluminium by soap solutions and abrasive

powders containing soap. The formulæ of some cleaning powders are given.—E. C. E.

Electrolytic Finishes on Metal Improve Corrosion-Resistance. E. L. Cableck (*Product Eng.*, 1944, 15, 754-755; *C. Abs.*, 1945, 39, 667).—The coating becomes softer and less corrosion-resistant as its porosity increases. Anodized aluminium is superior to cadmium-plated steel in wear- and corrosion-resistance. The Ano-zinc process of zinc plating is satisfactory when a black coating is required. Where black is not required, the Iridizing treatment is successful.

XXI.—JOINING

The Aluminium Dip-Brazing Process. C. L. Bensen and R. N. Weber (*Aluminum and Magnesium*, 1945, 2, (3), 14-17).—The parent aluminium alloy has a thin sheet of lower-melting-point alloy rolled on to one or both sides. When an assembly of such material is immersed in a flux bath at a temperature between the melting points of the two parts of the sheet, the lower-melting-point alloy runs and forms pressure-tight joints. Many examples of successful fabrication by the process are described and illustrated.

—E. C. E.

Filler Metal Flow in Brazed Steel. — (*Iron Age*, 1946, 157, (15), 60-61).—An investigation was carried out to determine the distance silver alloy filler metal will flow in steel brazing in relation to joint spacing, type of parent metal, and direction of flow.—J. H. W.

Spraying Filler Metal on Brazed Joints. — (*Iron Age*, 1946, 157, (13), 52-54).—The results of an investigation on the possible advantages of applying filler material for copper or silver brazing by spraying are given. A comparison of bond areas and shear strength of a sprayed filler metal joint against the usual wire filler joint showed that, although there is a small decrease in brazed joint strength and percentage bond, the use of gun-sprayed filler results in an increase in production and a saving in man-hours.—J. H. W.

***Substitute Solders of the 15 : 85 Tin-Lead Type.** J. B. Russell and J. O. Mack (*Trans. Amer. Inst. Min. Met. Eng.*, 1945, 161, 382-397; discussion, 397-398).—See *Met. Abs.*, 1945, 12, 64.

Tin in Solder. J. H. Collins (*Proc. Amer. Gas Assoc.*, 1943, 25, 354-363; *C. Abs.*, 1944, 38, 4243).—A solder containing tin 38, antimony 2, and lead 60, or tin 40 and lead 60%, is satisfactory for repairing gas meters. Solder reclaimed from meters is used by the industry.

Substitute Solders of Low Melting Point. M. Dannenmuller (*Mécanique*, 1943, 27, 35-39, 58; *Chem. Zentr.*, 1943, 114, (II), 367; *C. Abs.*, 1944, 38, 4557).—The following practical conclusions are drawn from phase diagrams of 2- and 3-component alloys: bismuth, cadmium, and lead are not miscible in the fused state with either aluminium or iron. Bismuth and lead are only slightly miscible with zinc. Cadmium dissolves a great deal of zinc as well as copper at low temperatures, although the Cu_2Cd_3 compound formed is brittle and therefore not useful for soldering. The solubility of copper in either bismuth or lead is very slight below 350° C. These metals, therefore, only render the solder more readily fusible and do not improve its ability to adhere to copper. Copper, iron, and zinc dissolve readily in molten tin even below 350° C. Aluminium, however, does not dissolve well in molten tin at low temperatures, but, like iron and copper, dissolves well in molten zinc. The presence of impurities (more than 0.1% of copper or more than 0.05% of iron) in lead-tin solders low in tin (10-20%) is injurious. Such solders, however, may contain zinc, which can be substituted for 2-3% of the tin in 20% tin solders. Solders with 20% of tin are especially suitable for use with the soldering lamp, since those with 15% of tin give dry melts and those with

more than 33% give melts which are too mobile. Compositions of various solders and directions for using them on various metals are given.

Tests Prove Advantages of Flame-Soldering Cable Joints. R. C. Fitzgerald (*Elect. Light Power*, 1944, 22, (3), 70-72; *C. Abs.*, 1944, 38, 5789).—Considerable saving in solder can be effected by the use of flame soldering instead of wiped joints. Solders containing as little as 20% of tin can be used. Microscopic examination showed that one source of pinholes was an untinned or dirty area in the seal itself.

Welding Aluminium Structures. W. J. Conley (*Modern Metals*, 1945, 1, (3), 14-16).—A few examples of the automatic arc-welding process employed in fabricating aluminium structures, are given.—L. H.

Welding as an Important Tool in Aluminium Fabrication. W. J. Conley (*Aluminium and Magnesium*, 1945, 1, (11), 28-31).—The most easily welded aluminium material is commercially pure aluminium, followed by the 1.25% manganese alloy. The aluminium-magnesium-silicon alloys containing 0.5-1% of each added element are more difficult to join by fusion welding. The heat-treated alloys with copper as the main alloying element are suitable, with certain reservations, for resistance-welded designs, but the mechanical properties and corrosion-resistance are impaired by fusion-welding. The electric-arc process of welding is described, and the technique employed for various types of joint is illustrated. Special reference is made to automatic shielded carbon-arc welding.—E. C. E.

***Weld Cracks in Magnesium-Manganese-Cerium Alloys.** H. Mader and F. Laves (*Magnesium Rev.*, 1946, 6, (1), 28-33).—Translated from *Aluminium*, 1943, 25, (4), 157-159; see *Met. Abs.*, this vol., p. 144.

Electrical Technique in Resistance Welding. T. E. Calverley (*J. Inst. Elect. Eng.*, 1946, [1], 93, (62), 97-98).—C. discusses briefly the effect of current and time on the heat produced in a weld.—E. V. W.

XXII.—INDUSTRIAL USES AND APPLICATIONS

Aluminium Alloys and Their Structural Use. H. K. Hardy and C. G. Watson (*Structural Eng.*, 1946, 24, (2), 65-112).—I.—*Metallurgical*. A concise account of the production of aluminium, the melting, alloying, and casting of the metal into ingots and billets, and their fabrication to semi-finished components by rolling, extrusion, and forging and subsequent heat-treatment. The further fabrication of the semi-finished products by machining, forming, and joining is described. The composition and properties of the principal aluminium alloys are given, and their resistance to corrosion and protection against it are discussed. II.—*Structural Use*. An investigation was made to determine the economic value of aluminium alloys for structural work. It was concluded that for bridging long spans and for suspension bridges aluminium would have an economic advantage; that the construction of masts and towers will not be economical on a first-cost basis; and that the special field of aluminium alloys is in mobile structures, *i.e.*, in transport.

—E. C. E.
Aluminium Bridges. A Gateway to Further Structural Applications. — (*Modern Metals*, 1945, 1, (7), 18-19).—L. H.

Bridges of Aluminium. — (*Modern Metals*, 1945, 1, (6), 4-5).—Details of the manufacture of the U.S. Army M4 aluminium bridge are given.—L. H.

Aluminium Alloy for Ships' Superstructures. — (*Motor Ship*, 1946, 27, (316), 40-41).—A report on the examination of aluminium alloys, which were used in the superstructure of the M.S. *Ferrplant* to the extent of 14 tons, shows that there was virtually no corrosion in any of the alloys after four years' severe sea service. The behaviour of the alloys in the superstructure

was greatly aided by the careful caulking of joints where the aluminium contacted dissimilar metal, which in most cases was steel. The aluminium alloys examined were closely related to Alcoa alloys 52S and 53S.—J. W. D.

[The Use of Aluminium in] Naval Constructions. Arne Brinck (*Rev. Aluminium*, 1945, (117), 183–188).—For constructions of the same strength, aluminium alloys could replace mild steel with a saving in weight. This saving could be used to increase the load carried, to increase the speed, or to decrease the power required. Equations are given illustrating the last two points. The corrosion-resistance of aluminium alloys is discussed, together with the need for protection against electrolytic corrosion at the junctions between aluminium and steel. Examples of constructions in which aluminium alloys are used are given.—E. C. E.

[Use of Aluminium Alloys in] Life-Boats. Pierre de Lapeyrière (*Rev. Aluminium*, 1945, (117), 189–192).—A discussion on the use of aluminium alloys for the construction of life-boats, with a description of a French product.—E. C. E.

Light Metals in a New-Type Cruiser. Karl Brocken (*Modern Metals*, 1946, 2, (1), 17–19).—Some novel applications of light alloy, especially in the engine ventilating system and in the form of structural parts, are described.—L. H.

Aluminium for Boats. — (*Modern Metals*, 1945, 1, (10), 21).—L. H.

Two Commercial Vehicles: The Citroën P45 Truck and the Berliet G.D.M. Tanker. Jacques Valeur (*Rev. Aluminium*, 1945, (117), 178–182).—A description with technical data regarding weight and pay load of the two vehicles. Aluminium and magnesium alloys are used to reduce the unladen weight.—E. C. E.

Projected Designs for Light-Weight Automobiles. W. C. Nichols and Joseph Palma, jun. (*Modern Metals*, 1945, 1, (8), 4–7).—L. H.

Aluminium Semi-Trailer. — (*Modern Metals*, 1945, 1, (10), 18–19).—The weight of a refrigerated trailer was cut by 57% by the use of high-strength light alloys.—L. H.

Aluminium Aeroplane Hangar. — (*Modern Metals*, 1946, 2, (1), 31).—A brief outline is given of the design of an aircraft hangar which will be constructed of aluminium.—L. H.

Aluminium Alloy Scaffolding. G. O. Taylor (*Metallurgia*, 1946, 34, (199), 15–17).—The use of aluminium alloys for tubular scaffolding is discussed, with particular reference to weight, facility in erecting, and resistance to rust and scale. Details are given of a series of loading tests carried out with light alloy aluminium tubing and three different types of standard couplings—right angle, cam lock, and swivel couplings. A suitable aluminium alloy can also be used with advantage to replace clamps and couplings made from malleable iron.—J. W. D.

Aluminium Lightning Rods. — (*Modern Metals*, 1945, 1, (7), 7).—L. H.

Largest Aluminium Rotor. — (*Modern Metals*, 1946, 1, (12), 18–19).—L. H.

Aluminium Butter Churns. — (*Modern Metals*, 1945, 1, (9), 24–25).—The application of cast aluminium for butter churns is described.—L. H.

The Aluminium Salvajor. E. H. Benson (*Modern Metals*, 1946, 2, (1), 21, 23).—A machine for dish-washing in large restaurants and now made largely of aluminium, is described.—L. H.

The Aluminium Bazooka. — (*Modern Metals*, 1946, 1, (12), 12–13).—L. H.

Aluminium Clothes-Pins. — (*Modern Metals*, 1946, 2, (1), 24).—L. H.

A Designer Looks at Light Metals. George Walker (*Modern Metals*, 1945, 1, (3), 10–13).—Some novel designs in which light metals form the construction material are described and illustrated.—L. H.

Light Metals and Personal Flying. Frederick H. Roever (*Modern Metals*, 1945, 1, (6), 10-12).—The application of light metals in privately owned aircraft is discussed.—L. H.

Light Metal Seating. — (*Modern Metals*, 1946, 1, (6), 14, 15).—Novel designs of seats made from aluminium and magnesium are described and illustrated.—L. H.

Light-Weight Stampings. Economical for Many New Products. — (*Modern Metals*, 1945, 1, (8), 22-23).—L. H.

Cerium. G. Ahrens (*Modern Metals*, 1945, 1, (8), 20-21).—Some of the properties of cerium, as well as some of the present-day applications, are presented. Cerium has been used during the war as a minor alloying component with both aluminium and magnesium, and certain properties have thereby been improved in cast and in wrought parts. 37 references.—L. H.

Working and Application of Copper-Plated Steel and Aluminium Pipes and Wires. Edmund R. Thews (*Schleif-, Polier- u. Oberflächentechn.*, 1943, 20, 21-23; *Chem. Zentr.*, 1943, 114, (II), 2203; *C. Abs.*, 1944, 38, 5774).—Steel and aluminium pipes achieve properties through copper plating which could never be attained with solid copper pipes; they retain, however, the characteristic properties of the latter. Tensile strengths of the steels used for plating and the plating procedures are given. Fields of application for copper-plated aluminium pipes are discussed. No difficulties are encountered in the copper plating of aluminium pipes.

†**Copper Conductors for Overhead Lines.** G. W. Preston and H. G. Taylor (*J. Inst. Elect. Eng.*, 1944, [II], 91, (23), 451-463; discussion, 463-468).—A comprehensive review of the subject, dealing with conductors of hard-drawn copper (solid and hollow), cadmium-copper, reinforced copper, and copper-clad steel. Consideration is given to such aspects as (1) the creep of conductors and their initial non-elastic extension in relation to their effect on sags, (2) max. safe operating temperatures, and (3) corrosion-resistance. Details are given of developments in the application of compressed sleeve-joints.—E. V. W.

Indium. Wm. S. Murray (*Modern Metals*, 1945, 1, (6), 6-9).—A general outline. Properties and applications, including plating light metals with indium for surface protection, hardening, and decorative finishes, are briefly described.—L. H.

Wrought Magnesium. Irving T. Bennett (*Modern Metals*, 1946, 1, (12), 6-11).—Available wrought alloys, alloy additions, fabrication methods, design considerations, and applications, are described.—L. H.

Aircraft Oil Tanks of Magnesium Alloy. J. B. West (*Aluminum and Magnesium*, 1945, 1, (11), 16-19, 34).—A general account is given of the fabrication of magnesium alloys in sheet form to aircraft oil tanks, with special reference to forming at elevated temperatures.—E. C. E.

Portable Magnesium Gravity Conveyors. M. M. Moyle (*Modern Metals*, 1946, 2, (1), 12-14).—Very light portable gravity conveyors are being applied where speedy transportation of materials is essential. Construction methods, a service record, and the advantage of magnesium over steel, are discussed.—L. H.

Thin Magnesium Strip. H. W. Porth (*Modern Metals*, 1945, 1, (9), 13-15).—P. deals with the properties, fabrication, joining, and uses of "Thinstrip." Thin-gauge magnesium has been used advantageously for specific war-time purposes, and it is expected that it will now find use for instruments parts such as pointers, damping vanes, and moving condenser plates.—L. H.

Magnesium Canoes. M. M. Moyle (*Modern Metals*, 1945, 1, (9), 16-18).—M. gives some service records of magnesium canoes which have been in use for 10 years. The methods employed in manufacturing a canoe are described.—L. H.

Magnesium in Portable Tools. M. M. Moyle (*Modern Metals*, 1945, 1, (8), 14-16).—L. H.

Magnesium in Textile Equipment. M. M. Moyle (*Modern Metals*, 1945, 1, (7), 4-6).—L. H.

Opportunities for Magnesium in the Petroleum Industry. — (*Modern Metals*, 1945, 1, (6), 13).—A few of the possibilities for magnesium products offered by the petroleum industry are outlined.—L. H.

Magnesium To-Day. Thur Schmidt (*Modern Metals*, 1945, 1, (9), 4-6).—S. deals with some war-time magnesium applications and discusses several advantages and disadvantages of magnesium.—L. H.

Rhodium. C. C. Downie (*Min. Mag.*, 1944, 71, 265-269; *C. Abs.*, 1945, 39, 483).—Rhodium withstands corrosive influences, including that of *aqua regia*. Although high in price per unit weight, it is relatively inexpensive as a plating agent on account of the exceedingly thin deposit possible. D. discusses development, applications, and recovery.

Silver for Electrical Purposes. R. A. Collacott (*Elect. Times*, 1944, 105, 42-44; *Elect. Eng. Abs.*, 1944, 47, 44).—C. discusses the application of silver to current-carrying contacts, commutators, and slip-rings. The addition of 0.05% of silver reduces the corrosion of lead alloys containing 4 to 12% of antimony used in accumulators. The use of silver in the electroplating industry is discussed.

Use of Zinc Alloys as Substitute Materials for Other Metals and Alloys. A. Portevin, — Patin, — Wagner, and — Grunberg (*Usine*, 1942, 51, (9), 31-33).

Zinc Alloys for Die-Casting Purposes. H. Patin (*Métaux, Corrosion-Usure*, 1942, 17, 139-151; *Chem. Zentr.*, 1943, 114, (I), 1814; *C. Abs.*, 1944, 38, 3935).—Improving the purity of the zinc metal to 99.993% resulted in an essential improvement of the zinc alloys. Zamak 2, 3, 5, and 6 are discussed as regards composition, chemical and physical behaviour, ageing, conditions for working, and possibilities for use.

The Metallurgy of the Jeep. Roger F. Mather (*Metallurgia*, 1946, 32, (198), 283-286; 33, (199), 9-14).—In a description of the metallurgy of the jeep, materials *versus* design is first considered and attention given to testing and to various material specifications. In dealing with the ferrous and non-ferrous alloys, used for the more important parts, reference is made to an aluminium alloy piston, tin-base and lead-base bearing metals, leaded bronze and sintered bronze containing 10% tin for bushings, and bronze for thrust washers. Surface treatments include the tinning of the aluminium piston and of some of the piston rings. Copper was deposited on the cam of the steering gear.—J. W. D.

Babbitt Bearing Metals Developed During War-Time. T. E. Eagen (*Power Plant Eng.*, 1944, 48, (11), 81-83; *C. Abs.*, 1945, 39, 483).—Owing to the war-time 12% limit for tin, various problems have arisen and these are discussed. The discussion covers cleaning, casting, bonding, and thickness of Babbitt.

Modern Bearing Materials. Fritz Wehrmann (*Gas- u. Wasserfach*, 1943, 86, 420-421; *C. Abs.*, 1944, 38, 3940).—In Germany only thin shells of copper alloys could be used in bearings, fused on to the backing metal. Entire bearings can be made of zinc or lead alloys, but even these must be used economically. The chief defect of synthetic resin bearings is their poor heat conductivity, leading to carbonization, &c.; in some cases this can be avoided by using thin layers or by special water-cooling means. Cast-iron bearings are suitable for special purposes, and have been improved. Ball and roller bearings, when usable in permitted sizes, are very economical and save lubricating oils. Sintered iron bearings offer promise, but require special machining methods, and like the cast-iron bearings are rather brittle under conditions of recurring shock.

Innovations in Gas-Using Appliances in Budapest. Josef Beczkóy (*Gas-u. Wasserfach*, 1943, 86, 353-357; *C. Abs.*, 1944, 38, 3453).—The outer jackets and draught breakers on water heaters are often of aluminium, lacquered or polished. Consideration must be given to the avoidance of galvanic corrosion on parts in contact with water; so that the same material must be used throughout, or all parts given the same metallic coating. Lacquer coatings can be used to a limited extent, but are apt to be somewhat porous. Insulating joints are of value in limiting corrosion of dissimilar metals, especially in gas and water meters. In water pipes, connection of aluminium to brass causes rapid corrosion of the aluminium. Hard aluminium alloys must be used for parts which have to be threaded. Stuffing boxes are best made of rustless steel, and a special design is illustrated. Luminous water-heater burners gave trouble owing to enlargement of the orifices. Better results were secured with a Bunsen-type burner with the orifice away from the combustion zone; the burner itself was constructed of aluminium. Pilot burners are made of steatite in three sizes for 12, 16, and 20 litres/hr., and these have proved relatively free from stoppages formerly encountered. For water-heater construction, steel is satisfactory only for continuous service; otherwise condensate formation causes rapid corrosion. When condensation is avoided, steel corrodes less than copper. The low thermal conductivity of iron and its alloys is also a disadvantage. One successful water heater was made from pure aluminium. Aluminium is frequently used in range construction. Gas-cocks are often of zinc or aluminium, sometimes with cast-iron plugs, but these metals require lubrication with a mixture of cylinder oil and paraffin to avoid "freezing." Brief reference is made to radiant space heaters.

The Development of Tin-Free Containers for Foods. H. Ketterl (*Metallwirtschaft*, 1943, 22, (33/35), 493-496; *C. Abs.*, 1944, 38, 4889).—The saving of tin in making food containers has been accomplished by (1) making tinplate electrolytically instead of by dipping; (2) tinning only the inside of containers, and using an aluminium-lacquer on the outside; (3) employing black iron (plate) instead of the customary tinned iron; (4) use of lacquered ware—at first of poor quality, but later much improved; (5) use of folded containers; (6) use of metal protected from corrosion; and (7) aluminium containers. The advantages and suitability of each type for specific foods are discussed.

XXIII.—MISCELLANEOUS

Quartz Crystal Plating. H. G. Wehe (*Bell Lab. Record*, 1945, 23, (12), 475-479).—A description is given of the vacuum evaporation of metals on to quartz plates for use in radio and telephone equipment.—E. V. W.

***Distribution of Tensile Load in Relation to Temperature and Sag of Steel-Cored Aluminium Conductors.** E. W. W. Double (*J. Inst. Elect. Eng.*, 1945, [II], 92, (28), 349-361; discussion, 361-364).—D. concludes that the final load distribution is determined by the rate of creep in the aluminium wires and is independent of the stringing temperature. It is shown that inelastic stretch of a conductor can cause large increases in sag which far outweigh those that might result from creep, and since inelastic stretch is mostly removed when the conductor is tensioned up to the max. design load, prestressing is recommended before final stringing of the conductors.—E. V. W.

The Application of Sound in Metallurgy. V. Bekker (*Novosti Tekhn.*, 1941, (4), 25-26).—[In Russian.] A sound vibrator used to obtain a uniform distribution of lead in aluminium and zinc alloys, is described. It is possible by this method to introduce 10% of lead into aluminium and 7% of lead into zinc.—N. A.

***The Action of Metals and Metal Salts on the Vitamin C Content of Milk.** G. Reif (*Milchwirtschaftl. Forsch.*, 1941, 21, 1-9; *Chem. Zentr.*, 1941, 112, (II 1340; *C. Abs.*, 1944, 38, 1803).—The effect of metal chlorides and of

sheet aluminium on the vitamin C content of milk was investigated. Aluminium, magnesium, and titanium were found to be indifferent, while tin, zinc, nickel, manganese, iron, and copper reduced the vitamin content, the effect of the last two ions being most pronounced. Acids inhibited the destruction of the vitamin, while alkalis promoted the action. With metal salts, the effect of the metal was found to be dependent on that of the acid constituent. The salts of indifferent metals were either without effect or the acid residue had only slight effect in preventing the destruction of the vitamin. With metals having a more or less vigorous destructive action on vitamin C, the salts of the metals also reduced the vitamin content, so that in this case the effect of the metal portion of the salt was stronger than that of the acid residue. Salts of nickel, zinc, and tin repressed the destruction of the vitamin; with these salts, therefore, the influence of the acid residue predominates over that of the metal to a greater extent than in the case of the salts of aluminium, magnesium, and titanium. The salts of copper, iron, and manganese were still effective in 0.01% solution; salts of the other metals were no longer effective at this concentration. The presence of slight amounts of other metals in aluminium alloys was without effect. On the other hand, the manner of treatment of the sheet metal did have a certain effect. Bright surfaces had no effect while the effect of oxidized surfaces varied with the manner of production of the oxidized coating. Sheets of metal which had already been used showed no further effect.

***Beryllium Poisoning.** H. S. Van Ordstrand, Robert Hughes, J. M. DeNardi, and Morris G. Carmody (*J. Amer. Med. Assoc.*, 1945, 129, 1084–1090; *C. Abs.*, 1946, 40, 968).—Various beryllium compounds are toxic. In the group studied the highest incidence of disease was found in workers employed in the sulphating and in the oxyfluoride processes. Prophylaxis consisting of safety clothing, masks, and proper ventilation, proved most effective.

The Biophysical or Biochemical Remote Action of Metals and the Prospect for the Application of the "Atomoligodynamism" of Metals. A. Bertuzzi (*Chim. Ind. Agric. Biol. Realizzaz. Corp.*, 1942, 18, 12–32; *Chem. Zentr.*, 1942, 113, (II), 2309; *C. Abs.*, 1944, 38, 2860).—If certain metals, such as lead, cadmium, and mercury, are brought within a distance of 2–90 mm. of schizomycetes, eumycetes, protozoa, coelenterata, or platelminthes by means of the air, the biological subject quickly dies. The cause of death is not a radiation, but an accumulated, diffusible, air-borne gas which consists of vapour which the metals give off at ordinary temperature. The metals have at ordinary temperature a vapour pressure calculable by extrapolation. The metals with higher vapour pressure are more active than those with lower vapour pressure. The biological remote action on the subject is the same as that of a very dil. solution of the corresponding metal salt (cation effect). The effect of the metals is reduced if the pH of the culture liquid lies in the neighbourhood of the isoelectric point of the subject. The negative electric charge of bacteria in water is reduced by the remote action of the metals. B. denotes the described remote action of the metals as "atomoligodynamic" effect to differentiate it from the oligodynamic effect, which he defines as "ionoligodynamic effect." B. proposes investigating the remote action of metals for the control of peronospora.

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