

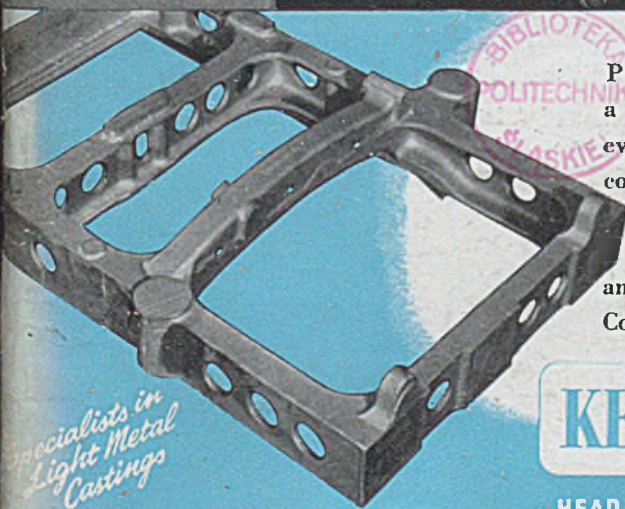
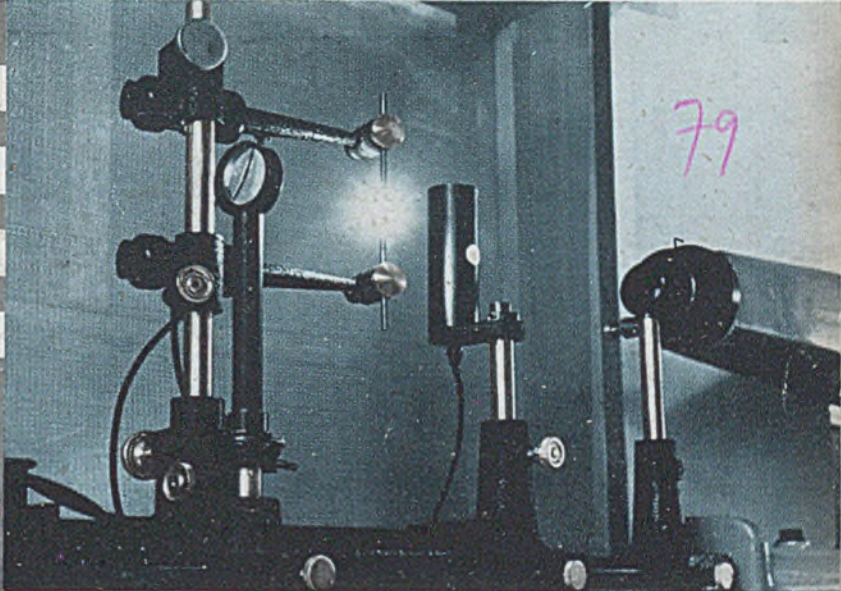
7.129/44

LIGHT METALS

AUGUST 1944

16

LIGHT
ALLOY
CASTING
TECHNIQUE



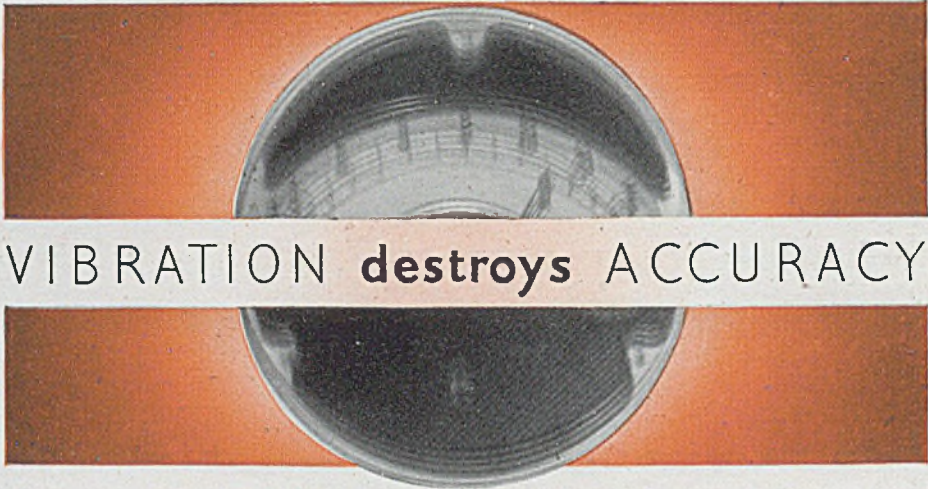
BIBLIOTEKA
POLITECHNIKI
KRAKOWSKIE

Production at Kent Alloys is founded on a basis of accurate laboratory control at every stage. It is the spectrographic control of alloys, the radiographic control of castings which, combined with certainty as to tensile strengths and hardness, ensure Consistency and Confidence.

Specialists in Light Metal Castings

KENT ALLOYS LTD.

HEAD OFFICES: COMMERCIAL ROAD, STROOD



VIBRATION **destroys** ACCURACY

Sensitive Instruments

are easily damaged by vibration. Sometimes the damage is not instantly destructive, but is in the form of accelerated wear which sets up extra friction, impairs accuracy, and reduces the value and reliability of the readings obtained.

The danger of vibration to aircraft instruments is well known—thousands of them are carried on Metalastik mountings.

But in the factory and the power-station, the effects of vibration are not so obvious—but often cause serious harm.

We maintain a full research staff with complete equipment, and can analyse vibration from any source and of any character, and design mountings to reduce or eliminate their harmful effects.

The small illustrations show three Metalastik instrument mountings, the low-frequency type, left, the cross-type, centre, and the stud-type, right.

Metalastik Ltd. Leicester



METALASTIK



NEW!

VICTOR *Supermix*

LIQUID

X-RAY FILM PROCESSING CHEMICALS



SUPERMIX PRICES

Developer :	
to make 1 gall.	6/6
" " 2 "	11/-
" " 5 "	27/-
Fixer :	
to make 1 gall.	5/6
" " 2 "	9/-
" " 5 "	23/-

.... it's as easy as that -

You simply pour these liquid concentrates into your tanks and add water no time lost in dissolving powders or adjusting solution temperatures. They will reveal in every film all the diagnostic qualities which your exposure makes possible, in contrast, density and detail.

.... and as economical as this -

With these longer-lasting Supermix solutions you can process up to 75% more films than with conventional processing chemicals. Unusual speed of developing (3 minutes at 68° F.) and fixing (less than 1 minute) will expedite your darkroom work; or, by developing 5 to 6 minutes you can reduce x-ray exposure 20% to 25% to economise in tube life. LONG-LIFE SPEED CONVENIENCE are the hallmarks of Victor SUPERMIX.



VICTOR X-RAY CORPORATION Ltd.

15-19 Cavendish Place, London, W.1 LANGHAM 4074
 BIRMINGHAM BRISTOL GLASGOW MANCHESTER DUBLIN
 BELFAST EXETER LEEDS SHEFFIELD NOTTINGHAM LIVERPOOL

ILFORD PLATES

for PHOTOMICROGRAPHY

ILFORD LIMITED manufacture a wide range of plates and films which adequately covers every requirement of the metallurgist whether for laboratory research or record purposes. Experience has proved that for the photomicrography of polished specimens there is no better plate than the Ilford Chromatic for general use where achromatic lenses are used in conjunction with deep yellow or green filters.

The Ilford booklet "Photography as an aid to Scientific Work" provides the research worker with a concise guide to the selection of photographic materials for every scientific purpose. A copy should be in every research laboratory.

ILFORD Process Plate

H. & D. 25 For all cases where high resolution is necessary.

ILFORD Chromatic Plate

H. & D. 135. For polished steel sections, in conjunction with a green filter.

ILFORD Rapid Process Panchromatic Plate

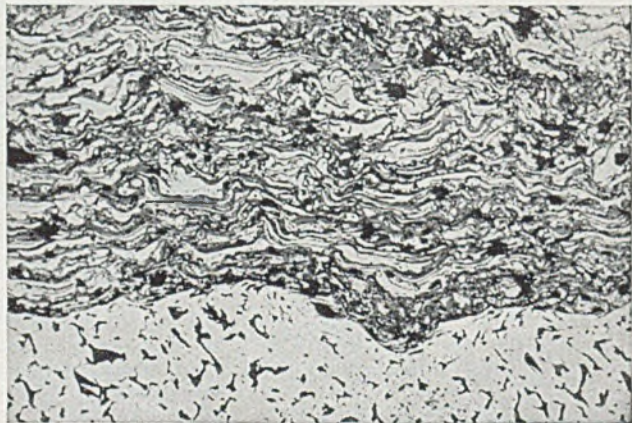
H. & D. 100. For specimens showing oxide or sulphur films but frequently used for all specimens.

ILFORD S.R. Panchromatic Plate

H. & D. 700. A faster plate.

ILFORD Hypersensitive Panchromatic Plate

H. & D. 3,500. For conditions of low intensity lighting, such as work with polarised light at high magnifications.



Mild steel sprayed on mild steel base by wire pistol process

Base Metal—ferrite (white), pearlite (half tone)
Sprayed Metal—1st phase (white), 2nd phase (half tone), pores (black)
(By courtesy of Messrs. Metallisation Ltd., Staffordshire Education Committee and H. A. MacColl, B.Sc.)

Technical Details

ETCHED—Picric Acid
MAGNIFICATION—X 150
OBJECTIVE—16 mm. achromat
N.A. O. 28
ILLUMINATION—Glass slip vertical illumination

EYEPIECE—X 6 compensating
LIGHT SOURCE—100 c.p. Pointolite D.C.
FILTER—Ilford Micro 3 (green)
PLATE—Ilford Chromatic
EXPOSURE—50 secs.

ILFORD LIMITED • ILFORD • LONDON

1825

First to prove the existence of a metal in alumina was Hans Christian Oersted, the Danish physicist, when, in 1825, he succeeded in isolating aluminium. Sir Humphry Davy had forecast its existence, but to Oersted belongs the credit of actual production of the metal.

Almost a hundred years were to pass before the widespread use of aluminium demonstrated the value of Oersted's discovery — today we look forward to a world in which aluminium will play an even greater part. The combined technical knowledge of the principal producers of aluminium alloys is at the service of all who seek to use their remarkable properties.

UNION CHAMBERS
63 TEMPLE ROW
BIRMINGHAM 2



WROUGHT LIGHT ALLOYS
DEVELOPMENT ASSOCIATION



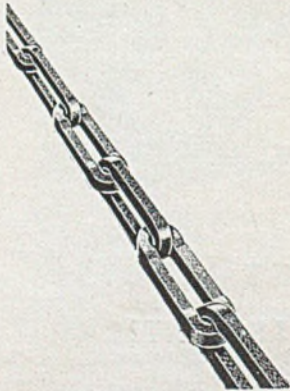
Mr. Huntsman pulls a tooth

BENJAMIN HUNTSMAN (1704-1776), the Inventor of Crucible Cast Steel in its present form, was a remarkably shrewd, observant and practical man. Starting as a Clockmaker and Mender in Doncaster, the constant breaking of English springs led him to manufacture his own steel, which later became his whole occupation. In addition, it is recorded of him that he practised Surgery with dexterity, and was held in special esteem as an Oculist; he was always ready to give advice in surgical cases, although he always declined payment. His skill was always at the disposal of his workpeople, and one may imagine that many an aching tooth was promptly disposed of.

BROCKHOUSE CASTINGS LIMITED produce steel castings to all commercial specifications, specialising in heat-resisting steels produced by the modern equivalent of the Huntsman process. Recent developments have led to the actual casting of Ships' Chains and Cable, an interesting casting technique which we shall be pleased to explain to you if you are interested.

CASTINGS in STEEL

BROCKHOUSE CASTINGS LTD.
WEDNESFIELD, WOLVERHAMPTON
Telephone - - - - - Fallings Park 31221



Ships' Cable cast in mild steel, proof load test of 134 tons, by BROCKHOUSE CASTINGS LIMITED.



JOHN DALE



ALUMINIUM
ALLOY
CASTINGS

PRESSURE TIGHT

We specialise in the manufacture of medium and high strength aluminium alloy castings to withstand high pressures, suitable for Pumps and connections in Hydraulic and Fuel Systems.

JOHN DALE LTD., BRUNSWICK PARK RD.,
NEW SOUTHGATE, LONDON, N.11

Telephone & Telegrams : LONDON—ENTerprise 1167-8-9

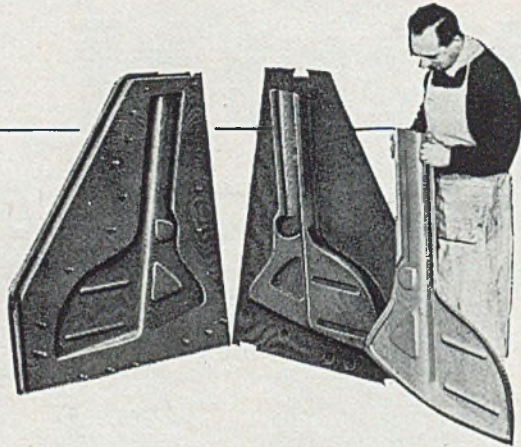
BIGGER*and BETTER tools...*

JABROC the improved Laminated Plastic Material is being used in ever-increasing volume for tools, jigs, templates, stretching blocks, etc.

INSUL-JABROC and fabric and paper based JABLIN are proving of vital importance where strength and electrical insulation are required.

JABLO PROPELLER BLADES as fitted to the majority of Spitfire, Hurricane, Beau-fighter and other leading Aircraft are proof of the high quality of this well-known family of Laminated Plastics.

Decades of experience and our highly specialised team of technicians will assist you with your current and post-war problems.



MOULDED COMPONENTS (JABLO) LTD.
The Pioneers of Laminated Plastics

11 OLD QUEEN ST., LONDON, S.W.1

**FOUNDRY PRACTICE**

A Pocket Journal for those who are interested in

BETTER CASTINGS AT LOWER COST

"Foundry Practice" is sent free on request to any Foundryman. It is to help the practical man overcome his difficulties.

The following articles appeared in recent numbers of "Foundry Practice":

Sand Casting DTD.424 ..	FP.59
Use of Chills in Sand Moulds ..	FP.60
Correct Cupola Operation ..	FP.60, 62
Sand Mixtures ..	FP.60
Deoxidation of Nickel Alloys ..	FP.61
War Emergency British Standards ..	FP.61
Runners and Gates ..	FP.63
Aluminium Gravity Diecasting ..	FP.64, 65
A.B.C. of Heat Treatment ..	FP.65
Cast Iron Liners, Cast Iron	
Pistons	FP.66, 67
L.33 Test Bars	FP.66
Magnesium - Moulding Methods,	
Specification	FP.67

Applicants will be put on the mailing list and posted back numbers, if still in print.

Write to:

FOUNDRY SERVICES LTD
285/7 Long Acre - Nechells - BIRMINGHAM 7

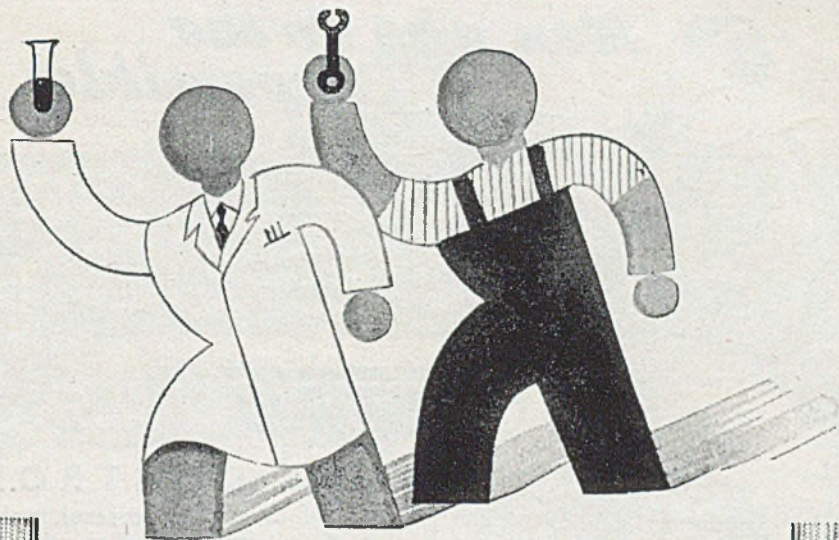
Is it

you want?
in BRASS, ALUMINIUM
or ALUMINIUM-BRONZE

- Owing to the restricted use of Aluminium, Dies for producing Aluminium Castings can be modified for Brass Production.
- Let us, as the Pioneers of Brass Gravity Die Casting, help you in your Technical Problems.
- Our Highly Skilled Technical Staff, Modern Foundries and many years' Experience are at Your Service.

**NON-FERROUS
DIE CASTING CO. LTD.**

North Circular Road, Cricklewood,
LONDON, N.W. Telephone: GLAdstone 6377



PRODUCTION FOLLOWS RESEARCH

Aluminium and its alloys have given immense service to the war effort, for production has followed research. Aluminium and its alloys have taken many shapes, and performed many tasks as a result of bold, inventive thinking that began in a laboratory. Research continues while production increases.

ALUMINIUM UNION LIMITED

GROSVENOR HOUSE, PARK LANE, LONDON, W.1



*Men who do the
impossible*

Shannon Systems

VISIBLE CONTROL

The greatest aid to business control is the system that gives instant access to all vital facts and figures relating to the business. Shannon Visible Control in fact. Let us send you details. To comply with regulations please send 1d. stamp.

THE
SHANNON LIMITED

IMPERIAL HOUSE, (Dept. E.5),
15-19, KINGSWAY, LONDON, W.C.2

And at Birmingham, Bristol, Liverpool,
Manchester, Newcastle, Glasgow (Agent)

“SUPINOL-N” SEMI-SOLID OIL

is a specialised new type of core
binder of particular service to

ALUMINIUM CASTINGS

because it has

IN THE GREEN STATE: All the working properties of a semi-solid
DURING CASTING: All the advantages of a high-grade oil

Our product gives freedom from

**NOXIOUS FUMES — METAL PENETRATION
KNOCKOUT DIFFICULTIES—METAL DISCOLORATION**

IN REGULAR USE BY LEADING ALUMINIUM FOUNDRIES

Manufactured by

F. & M. SUPPLIES LTD.

21/3, COLDHARBOUR, LONDON, E.14

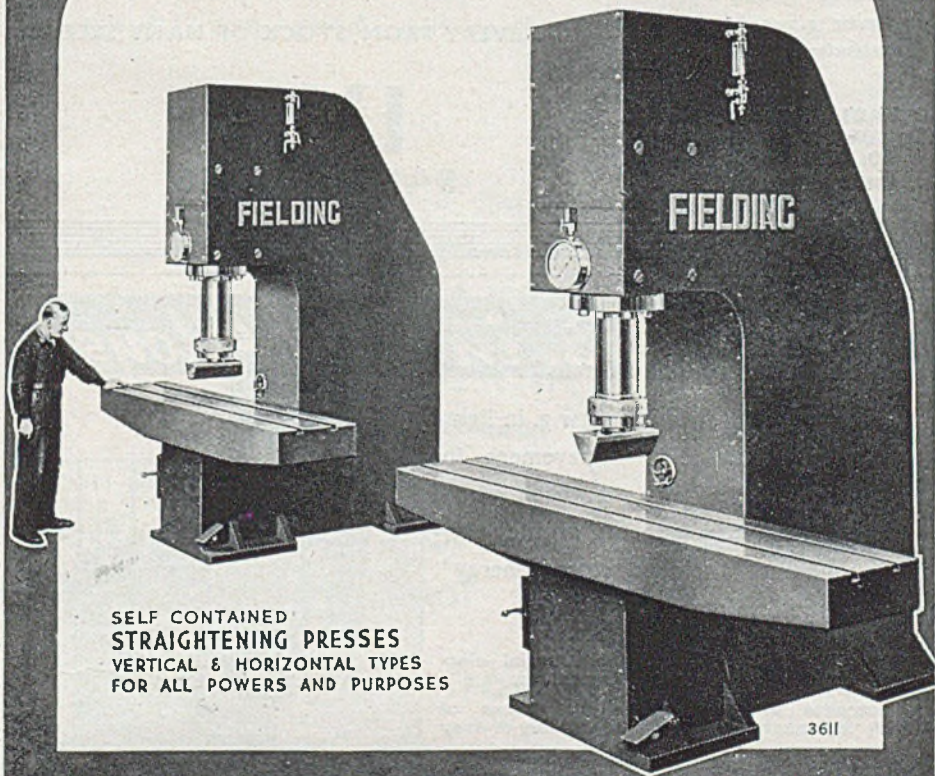
Also manufacturers of Degassers, Refiners and Covering Agents for Aluminium Alloys, Parting Powder, etc., of exceptional quality





FIELDING

PRESSES



SELF CONTAINED
STRAIGHTENING PRESSES
VERTICAL & HORIZONTAL TYPES
FOR ALL POWERS AND PURPOSES

FIELDING & PLATT LTD GLOUCESTER

3 DECISIVE ADVANTAGES

1. CONSISTENTLY HIGH EFFICIENCY
2. SIMPLICITY IN OPERATION
3. FUEL ECONOMY



IVO Salt Baths are A.I.D. approved and used by many of the leading aircraft manufacturers.

IVO ENGINEERING AND CONSTRUCTION CO., LTD.,
WOOD LANE, LONDON, W.12
Telephone - SHE. 4382/6

The low operating costs of IVO Salt Baths quickly repays the initial outlay. They can be fired by coal, gas or oil and the change-over takes about 30 minutes

DELIVERY FROM STOCK OF MANY SIZES

IVO

SALT BATHS

2 x 8 S.W.G. in Light Alloys!

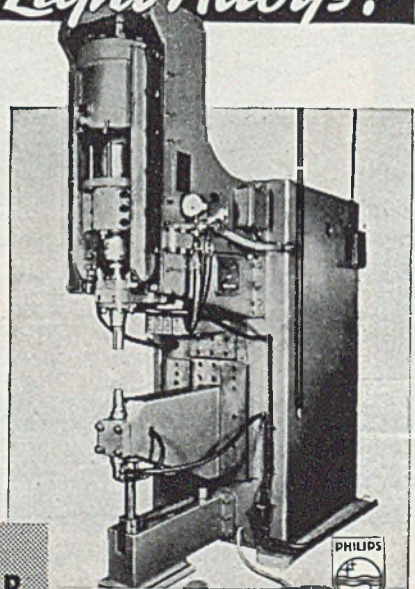
THE spot welding of 2 x 8 s.w.g. in light alloys is an outstanding achievement in resistance welding, which has been made possible by the development of the new Philips condenser discharge 'stored energy' welder — the E.1501.

★ Overall rigid construction and special electrode support by means of locating guides.

★ Electrodes are retractable by means of 'Hi-lift' mechanisms to facilitate welding of deep sections.

★ Bronze casting for lower part of upper arm reduces eddy current losses.

★ Maximum throat depth of 32" accommodates wide sections and special shapes.



PHILIPS *Hi-lift* **CONDENSER SPOT WELDERS**

PHILIPS INDUSTRIAL (PHILIPS LAMPS LTD.),
CENTURY HOUSE, SHAFESBURY AV., W.C.2
(57B)

Is there a Furnace in your Toolroom?

Gas flames, blacksmith's forges, even open fires will do for the hardening, annealing, tempering, etc., of steels. The results are good, quite often,

but

if you want to *know* that you are getting perfect results every time; to work by gauge instead of guesswork; to avoid scrap; to heat-treat to specification; to keep the shop cool and clean:

**then use an electric furnace —
— the precision tool for heat-treatment**

WRITE TO US FOR PARTICULARS TO-DAY

SIEMENS - SCHUCKERT (GREAT BRITAIN) LTD.
GREAT WEST ROAD BRENTFORD MIDDLESEX

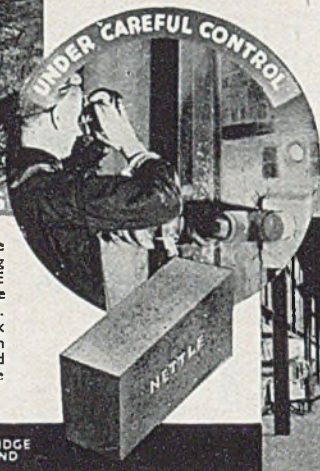
Tel.: EALING 1171-5

Grains: Siemensdyn, Brentford

Offices in London, Birmingham, Cardiff, Glasgow, Manchester, Newcastle and Sheffield

STEIN

Refractories



IN A MODERN PLANT



If a suitable design of burner is used, the trouble can usually be overcome by using a High Alumina Firebrick such as NETTLE (62.44% Alumina)—a point proved by the practical experience of several customers. An additional protection to the brickwork by washcoating with Maksicar II, or Stein Sillimanite Cement will often be found economic. Further information will be gladly supplied on request.

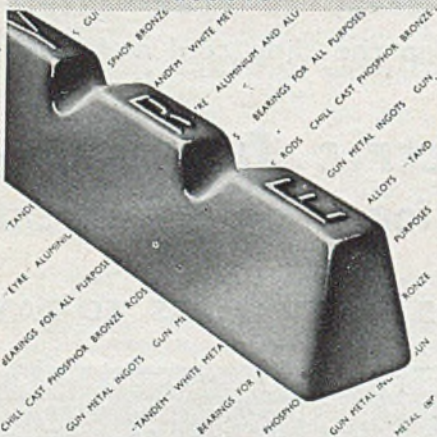
JOHN G. STEIN & CO LTD BONNYBRIDGE SCOTLAND

CREOSOTE-PITCH FIRING

A number of firms adopting this fuel have encountered new Refractory Problems caused by corrosion and Vitrification Spalling.

ALUMINIUM

ALLOYS



SWICH BRONZE
 WHITE MET
 LUMPHON AND ALU
 BEARINGS FOR ALL PURPOSES
 CHILL CAST PHOSPHOR BRONZE
 GUN METAL INGOTS
 GUN METAL INGOTS
 ALLOYS
 TAND
 PURPOSES
 HOUSE
 JUN
 METAL ING

Phosphor Bronze
 Tandem White Metal Alloys
 Eyre Aluminium and Aluminium Alloys

EYRE

Gun Metal Ingots
 Bearings for all purposes
 Chill Cast Phosphor Bronze Rods

SMELTING COMPANY LIMITED
TANDEM WORKS, MERTON ABBEY, S.W.19

Telephone: MITCHAM 2031 (4 lines)

PERFECT BLACK FINISHES

for ALUMINIUM and MAGNESIUM ALLOYS

• ANODIC • PHOTO-IMPREGNATION

for PANELS, DIALS & NAMEPLATES

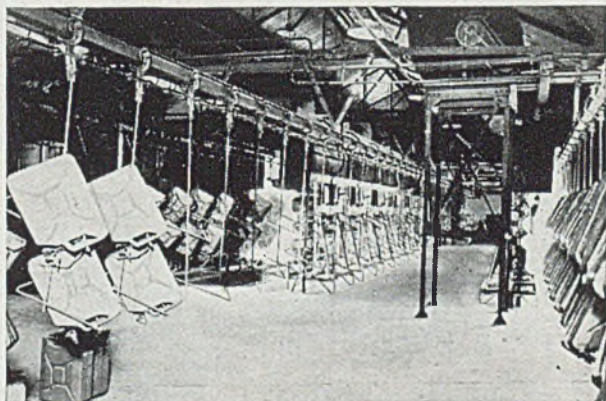
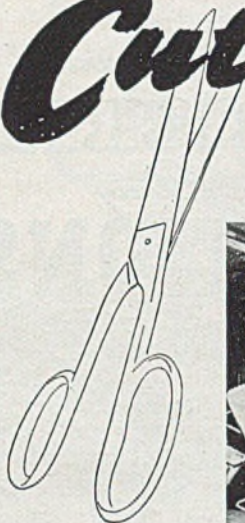
ALL NATURAL & COLOURED FINISHES TESTED & APPROVED.

THE RUSHTON ORGANISATION

173, CLARENCE GATE G'D'NS. LONDON. N.W.1.
 Phone: PAD. 1486. (P.B.X.)

LONDON, NEWBURY, BIRMINGHAM & WOLVERHAMPTON

Cut STOVING TIME by 90%



One of ten Terricon
paint drying installations
50 x kW using 2008 Osram
Infra-Red Industrial Lamps

G.E.C. INFRA-RED LAMP HEATING

WITH RHODIUM PLATED TROUGH REFLECTORS
and **Osram** Infra-Red Industrial Lamps

G.E.C. Infra-Red Lamp Heating may be employed for paint drying, coil drying, foundry mould drying, setting synthetic glues and softening plastics, etc. Operating times are drastically reduced and close control is obtained over quality. By incorporating the plant in the production line much handling is avoided, or it may be used in small units adjacent to individual machines.

G.E.C. Infra-Red Lamp Heating specialists are available for giving advice, and preparing schemes, for special requirements.

SAVES TIME

Paint drying times cut by 90%.

SAVES FUEL

Considerable fuel economy may be effected.

SAVES SPACE

Infra-Red Lamp Heating Plant is compact and occupies little floor space.

CONTROLS QUALITY

Consistent results obtained with unskilled labour.

SAVES HANDLING

G.E.C. Infra-Red Lamp Heating Plant may be inserted in the production line in large or small units.

"OSRAM" INFRA-RED INDUSTRIAL LAMPS

Of special robust construction.



ANTI-INVASION WEAPON 1535

Dangerous times these . . . when the gunner could never be sure whether the next charge would kill him or the enemy. And no wonder! The iron in these early breechloaders . . . crudely smelted, hammered, re-heated and shaped on the anvil . . . must have varied, not only from one batch to another, but in each separate cannon.

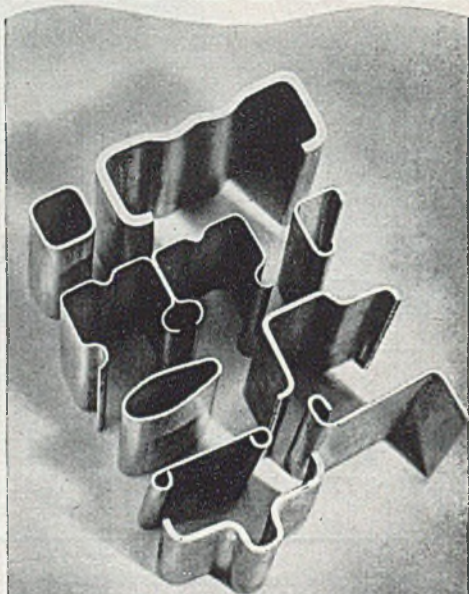
Today, when the making of even a small gun part demands rigid control of formula and temperatures, the Gas Industry is playing its part by supplying a fuel on tap, which meets the most exacting requirements of modern arms production. Definite temperatures, quickly reached and automatically controlled . . . uniform furnace atmospheres . . . reliability of supply . . . versatility, economy, cleanliness and ease of maintenance . . . these are some of the reasons for the wide use of Gas in nearly every process where heat and metal are brought together.

THE TWENTIETH-CENTURY INDUSTRIALIST KNOWS THE VALUE OF GAS

Gas equipment is still available for priority work. Wartime experience and achievement will benefit post-war planning.

BRITISH COMMERCIAL GAS ASSOCIATION
1 GROSVENOR PLACE, LONDON, S.W.1

Construct with
'WARICRIM'
High Duty
SECTIONS



Lengths in all metals up to 20 feet



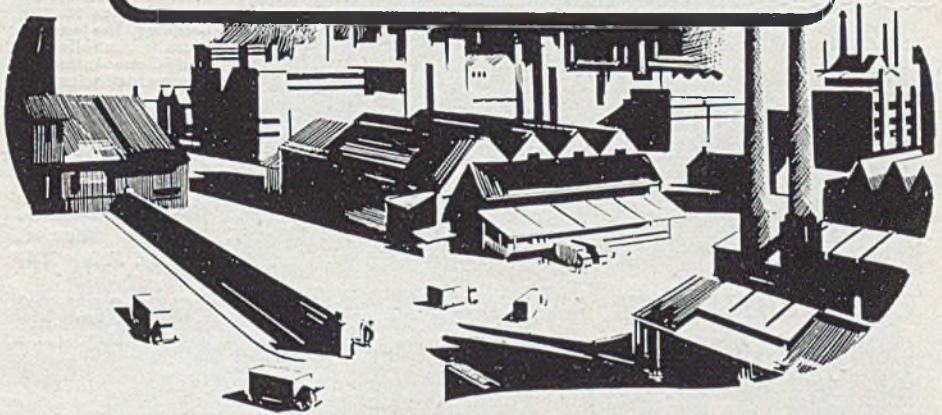
*Sections supplied to the Aircraft,
Automobile, Textile, Coachbuilding,
Railway, Shipbuilding, Architectural
Industries, etc., etc.*

WARWICK RIM & SECTIONING CO. LTD.
GOLDS GREEN, WEST BROMWICH, ENGLAND

London Agents:—
Murwood Ltd., 24 Grosvenor Gardens, LONDON, S.W.1

Let 'WARICRIM' Sections take the strain

Quick Facts for the X-Ray Dept.



1

For the routine inspection of light metal and alloy castings and for general crystallography use Ensign Mettaray Industrial X-Ray Film.

This is a fast non-screen X-Ray film of very fine definition and well-balanced contrast designed to produce radiographs of maximum detail with minimum exposures.

For the critical inspection of heavy castings and welds by X-Rays or Gamma-Rays when the use of lead screens is justified, Ensign Mettaray is the correct film to use.

2

For the radiographic inspection of heavier types of metals use Ensign Mettascreen Industrial X-Ray Film with intensifying screens. Mettascreen is particularly well suited for this purpose because its high speed permits the exposure time to be reduced to a minimum, and, since it maintains a well-balanced contrast throughout the whole exposure-range, flaw-detection is greatly facilitated.

Mettascreen used without screens is recommended for the radiography of subjects having a wide range of thickness.

... use **METTARAY**

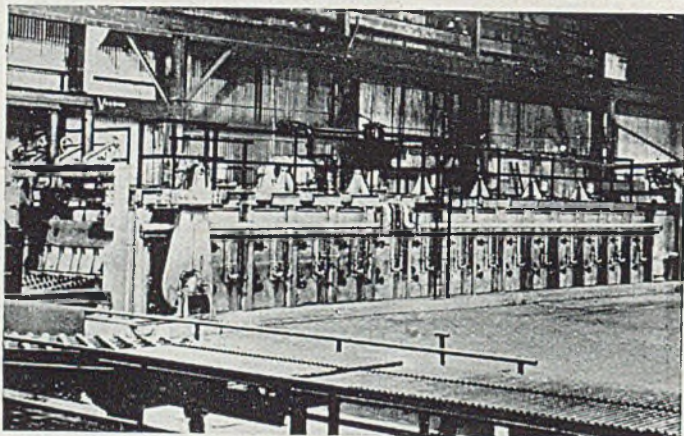
... use **METTASCREEN**

*An
Invitation*

The services of the Ensign Technical Department are available to deal with enquiries regarding Ensign Industrial X-Ray Films. Firms are invited to communicate with AUSTIN EDWARDS LTD., ENSIGN FILM WORKS, WARWICK (Manufacturers of X-Ray Films for nearly 30 years).

X-RAY IT ON *Ensign*

ALUMINIUM & ALLOY RE-HEATING FURNACES



The Furnace illustrated is heated by a series of Gas Fired Radiants. The waste gases from the radiants can be diverted either into the heating chamber in contact with the product, or can be evacuated direct to the chimney. The temperature is controlled by Multi-Zone Automatic Pyrometric Equipment, which together with the Gibbons' System of Heating and Fan Re-circulation ensures close temperature control.

Gibbons Bros. Ltd.,
Dibdale Works,
Dudley. Phone 3141

FOR ALUMINIUM AND ALLOY BILLETS OR SLABS

GIBBONS RE-HEATING FURNACES

M.W. 79

For anodising of Aluminium and its alloys; Chromating of Magnesium; Zinc & Cadmium Plating; El-Tin, etc., to A.I.D. specifications. We are specially equipped with large up to date plant capable of handling bulk work at speed. Also HEAVY NICKEL and Hard Chrome available at short notice.

**DAY &
NIGHT**

SERVICE
AVAILABLE

ANODISING
AND PLATINGS LTD
HOLLAND STREET, RADCLIFFE, LANC.

URGENT WORK HANDLED
IMMEDIATELY
RADCLIFFE 2637-B

TELEPHONE

dm 1030

Aluminium Corporation Limited

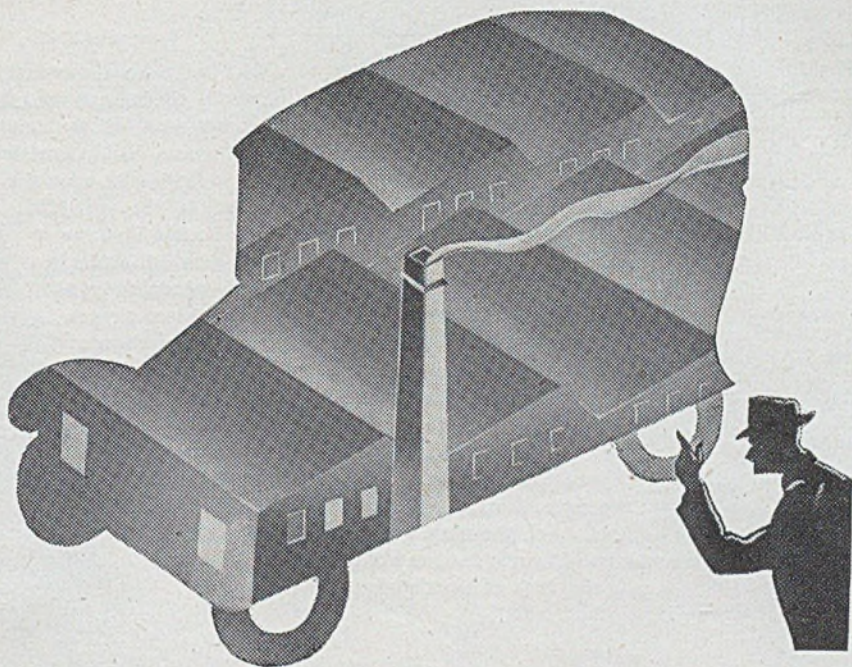
Suppliers to
A.I.D., Admiralty
and War Office
Specifications

Temporary Head Office:

Dolgarrog, Conway,
Caernarvonshire

Telephone:
Dolgarrog 211

Telegrams:
Fluxode, Dolgarrog



machine for hire

After the war we shall have a complete production machine for hire—planners, office organisation, engineering plant, a thousand skilled hands—all directed by practical men who have really been through the mill. What are your post-war production problems likely to be? We can turn out anything from small parts to large assemblies. Talk it over with us. We like difficulties!

EVANS the engineers who can
take their coats off

J. EVANS & SON (Portsmouth) LTD.

REGISTERED OFFICE : 102, VICTORIA ROAD NORTH, SOUTHSEA, HANTS

Do you know?



CRYOLITE was the crystal key, unlocking the door to the industrial production of aluminium.

The two pioneers, Hall in America and Heroult in France, hit upon the use of this flux in the year 1886.

CRYOLITE is a double fluoride of aluminium and sodium which occurs in

Nature, but is now produced synthetically. To split alumina into oxygen and aluminium needs a heavy electric current, and the alumina must be molten.

Alumina melts at over 2000°C., but a 10 per cent. mixture of alumina in cryolite melts at under 1000°C., and the passage of an electric current through such a mixture throws out the oxygen, leaving the molten aluminium at the bottom of the bath. With detail refinements the Hall/Heroult discovery of the value of cryolite is still the basis of aluminium production to-day.

THE CRYSTAL KEY



THE

British Aluminium

CO. LTD

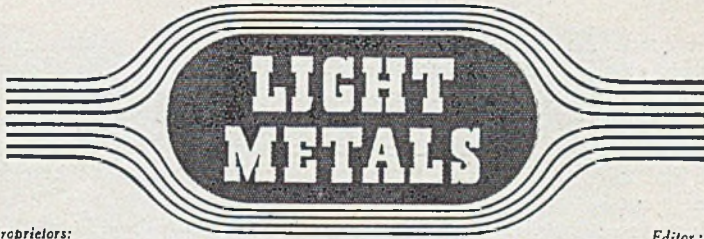
Temporary Head Office:

SALISBURY HOUSE, LONDON WALL, LONDON, E.C.2

Telephone: CLERkenwell 3494

Telegrams: Cryolite, Ave, London



*Proprietors:*

TEMPLE PRESS LTD.

Managing Director:

ROLAND E. DANGERFIELD

*Dealing Authoritatively
with the Production, Uses
and Potentialities of
Light Metals and
their Alloys*

Editor:

E. J. GROOM, M.Inst.MET.

*Offices:*BOWLING GREEN LANE,
LONDON, E.C.1

EDITORIAL OPINION

The Cobbler Leaves His Last

CONVENTION in technical journalism dictates that; in the main, there shall, mutually, be no transgression of territory by editorial and advertising departments. In a mild way, we defy this unwritten law in the present issue of "Light Metals" and venture to publish comments from various interests regarding current trends in advertising styles.

To state the case more clearly, some degree of controversy has arisen as to the suitability or otherwise of the indirect appeal, whether it takes the form of straightforward humour or highly artistic presentation in colour. The groups most nearly concerned in the matter comprise, first, potential customers, the attention of whom the advertiser always desires to attract. This section may be subdivided into technical and non-technical personnel. Secondly come the publicity of specialists, who, it is to be presumed, are masters of their own art and, therefore, competent to decide the best mode of appeal. Thirdly, there are the merchanting organizations, who, whilst not being buyers in the true sense, nevertheless, rely for their daily bread on markets fostered by wisely handled publicity (exporting houses are of particular interest in this group). Fourth in the list is the industrial technologist, who, in general, if not to be considered directly as a purchaser, may greatly influence decisions as to whether or not a certain commodity or item shall be bought. Finally, there is the general reader—a technologist, maybe, but not specifically bound to the industry represented by the periodical concerned.

It would seem that there are available few data regarding the habits of these groups so far as the advertisement pages of their particular periodicals are concerned. We are sure to find the buyer, professionally, scanning not only display pages but also "small ads.," no matter what journal he may pick up during his working hours. Technical personnel, having digested the editorial pages of their appropriate publication, will, almost assuredly, run an eye over display pages, although whether classified items occupying only a few lines of minute type will receive equal attention is to be doubted unless any specific item is to be sought. In quite a large number of cases publicity personnel do little

more than count the number of advertisement pages in a journal, indicating, thereby, very clearly, that they consider the outward and visible effects of mass appeal of somewhat greater importance than the exercise of individual judgment.

This facet of the problem we are here discussing is significant, for, if factual advertising is likely to appeal to only a minority of readers (no matter how important that minority may be), there is obviously something to be said for the non-factual sensation-perception type.

In the course of a series of private discussions recently held in the Midlands, a curious state of affairs was revealed. Business representatives, including those claiming no technical knowledge at all, and those possessing but a slight degree of insight, voted unanimously against what was termed non-informative advertising. They frowned most severely on all efforts at humour. Unequivocally, too, the representative of an exporting house denounced this class of publicity, giving as his reasons, first, that what constitutes humour in this country will almost certainly fail to strike a funny note abroad, and, secondly, that indirect appeal, even of the highest artistic merit, could hardly be expected to strike a chord in the heart of a foreigner ignorant alike of the English tongue and of the nature of the advertiser's products. Two technical representatives of a large concern specializing in cutting fluids and quenching alloys were also very averse to non-informative publicity, especially that of the humorous variety. Throughout a desire was expressed for advertisements providing positive data in a form capable of assimilation, for example, by buyers of limited technical knowledge.

Now it must be understood at once that the opinions recorded here are not the result of a detailed or nation-wide survey. Whether or not they are shared equally amongst all the engineering and allied industries in different parts of the country has yet to be demonstrated. It is quite certain, however, that, on the technical side of industry, the same objections do not hold good. Even in the purely scientific sphere (in so far as it is interested in technical periodicals), some degree of support has been found for fine colour work and well-thought-out humour.

No simple issue is at stake here. Probably it is fallacious to lump all technical periodicals together under that one common heading; tastes will differ in different industries. Shipbuilders, we are told, find comic advertising most repugnant.

So far we have omitted to express our own ideas on the subject. Well, we find ourselves laughing at nicely timed fun when we come across it in the advertisement pages and we enjoy works of art even if they forget to tell us that John Jones, Ltd., does, in fact, manufacture aluminium gas holders.

Contents

	Page		Page
SPECIAL ARTICLES		REGULAR FEATURES	
Post-war Buildings	361	Editorial Opinion	359
Radiography of Light-alloy Castings	375	News—General, Technical, Commercial	369
Precipitation from Super-saturated Solid Solutions ..	383	Book Reviews	410

THE FACT that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

SAVE PAPER.—More than ever is paper waste required for our war industries. Waste paper makes munitions in a hundred forms—from shell cases to aeroplane parts.



Fig. 1.—View of part of roof of L.C.C. Hospital, Ducane Road, Hammersmith, showing aluminium glazing bars in lantern lights. These bars have been in position for nine years and, although provided with no protective coating of any sort, are still in excellent condition.

POST-WAR BUILDINGS

Discussing the Theory and Practice of the Utilization of Aluminium Alloys in Post-war Building Construction. (Paper Read Before the Incorporated Association of Architects and Surveyors, on June 14, in London)

By
Dr. E. G. West
and
D. V. Pike, A.M.Inst.C.E.

IN an earlier paper¹ the authors discussed in general the possibilities of using aluminium alloys for many of the elements comprising modern buildings. Existing examples were quoted and probable and possible applications with an emphasis on prefabrication were suggested. The steady pre-war developments which brought about certain applications in the architectural field here and also in the structural field in other countries; the tremendous increases in plant and labour necessary in all branches of the industry during the war directed to the production of aircraft; and the great potential field of post-war applications resulting from advances in our knowledge of the properties, production and fabrication of the alloys indicate that they will be able to play an important part in post-war reconstruction.

Information has been given previously concerning the production of aluminium alloys and their constitution,^{1,2} the methods employed for their manufacture in forms suitable for fabrication; the differences between the non-heat-treatable and heat-treatable alloys; the comprehensive range of available alloys and their physical, mechanical and chemical properties.

The present paper attempts to reflect the trend which now appears to be shaping in projected applications, and whilst only a few

components will be discussed at length, reference will be made to many other building applications.

The Special Position of Aluminium Alloys in Post-war Building

The provision of sufficient houses after the war is now recognized as one of the most serious questions for which a solution must be found. Whether the conventional building materials will be available in sufficiency for the required programme is apparently uncertain, but it appears that lack of building personnel will, in any case, prevent its fulfilment by old-established methods.

In contrast to this the conditions in other industries will be very different and, with wartime requirements ended, other outlets for their expanded production will be sought to avoid the immediate unemployment of trained personnel.

These considerations have given great impetus to investigations into factory production of houses, schools, etc., and such methods which

(1) "Wrought Aluminium Alloys in Post-War Building." Paper read to the Association of Building Technicians on November 12, 1943, by Dr. E. G. West; see "Light Metals," January, 1944, (72) p. 11-19.

(2) W.L.A.D.A. Information Bulletins, Nos. 2, 3, 5, and 6.

have been steadily progressing since the 1914-1918 war are concerned, not necessarily with houses of a limited length of life, but also permanent dwellings.

The properties of aluminium alloys of which the most noteworthy are low weight (approximately one-third that of steel), high resistance to corrosion, great strength and pleasing appearance, have appealed to many authorities as being especially valuable in a material for prefabricated units.

The probable extent of their application varies; some envisage an almost completely aluminium-alloy building, whilst others have hitherto considered the light alloys as suitable for small components only. It must be emphasized that aluminium alloys are suitable for use in permanent buildings of all kinds—indeed, their pre-war application in building has been confined almost exclusively to high-class office blocks, hotels, civic and other public buildings, luxury flats, shops, hospitals and the interiors of ocean liners. There is no doubt that the employment of aluminium by discerning architects will continue to increase for such buildings and, furthermore, expansion into the field of housing will certainly occur.

Past attempts in the prefabrication of houses have indicated that commercial success depends on mass production being possible, the cost per house falling as the number made increases. This is fully recognized, and one of the chief problems which is seriously engaging the architect is how to arrange for maximum flexibility in design to be obtained whilst keeping the number of components to a minimum. They must be suitable for simple repetition manufacture on a large scale, and at the same time provide dwellings of a pleasing character.

Another very important factor is that erection must be speedy and require only unskilled or semi-skilled building labour. In this connection much attention has been given to the possibility of manufacturing large units such as complete walls, roofs and floors in the workshop and erecting them by a small crane.

Here, the proper use of aluminium enables large units to be handled with comparative ease through all the stages of manufacture, transportation and erection. It should be emphasized that another great advantage in manufacturing large units is that site jointing can be reduced; jointing is much more efficiently dealt with in the workshop where methods may be employed which would be impracticable or uneconomic at site (e.g., spot welding).

It is emphasized that, in the view of the authors, the post-war application of aluminium alloys in building will be governed by their properties, which unfortunately are not yet familiar to a great many engineers, architects and designers. They are summarized in the Appendix to this paper and it is now proposed to discuss a number of applications based on their favourable characteristics.

Structural Systems

Wholly prefabricated house systems appear to fall into two main groups—one in which complete rooms or portions of rooms are factory made in their entirety for assembly on the site, and one in which the walls, roofs, floors, etc., are transported as flat panels to the site. In each case the panels may be composed either of

skeleton structural framing and infilling or of panels only, capable of carrying sufficient load to dispense with framing. The procedure of first raising the complete roof sufficiently for the walls above first floor to be connected to it and the first floor to be connected to the walls, then raising this construction to its final position and finally adding walls from ground to first floor, together with variations of this general method, has been studied at some length. The adoption of aluminium alloys would help to bring such schemes within the range of practicability.

The patented systems employing metals as the basis of their construction even in pre-war days would require a volume to describe, and during the war their number has increased. There is little technical reason why aluminium alloys could not, with very little change, be used in all of them, but, by so doing, it is probable that the advantageous properties of the alloys would not be used to greatest advantage. It is by exploiting their characteristics of lightness, strength, corrosion-resistance, unlimited range of section shapes possible by the extrusion process, workability, finish, etc., that the most successful system of construction will result, rather than by merely substituting aluminium alloys for other metals.

Suitable Alloys for Structures

In considering the most suitable aluminium alloys for house construction it is found that in many cases practical considerations govern the dimensions of the sections and that aluminium alloys of the non-heat-treatable type usually provide sufficient strength.

The maximum strength obtainable in this group is over 20 tons/sq. in. against an ultimate strength exceeding 35 tons/sq. in. in the heat-treatable group. In order to use the most suitable alloy of the many available for specific conditions it is advisable to obtain advice from the W.L.A.D.A. or the manufacturers.

At present all aluminium alloys are covered by specifications for aircraft purposes, but British standards for aluminium alloys suitable for building and general engineering purposes will be available shortly. The range of alloys to hand is adequately exemplified in a table accompanying B.S. 1161.

Group	0.1% proof stress (tons/sq. in.)	Tensile stress (tons/sq. in.)	Elongation on 2-in. (per cent.)
1	4.0	11.0	15.0
2	7.0	15.0	15.0
3	14.0	18.0	10.0
4	10.0	20.0	15.0
5	17.0	22.0	10.0
6	15.0	25.0	15.0
7	21.0	27.0	10.0
8	26.0	30.0	8.0
9	27.0	33.0	8.0

Importance of Young's Modulus

The value of Young's Modulus for aluminium being 10×10^6 lb./sq. in. against 30×10^6 lb./sq. in. for steel, means that for geometric-

ally similar sections an aluminium alloy member deflects three times as much as steel. That is, the resilience of the aluminium alloy is greater and offers better resistance to impact stresses. The difference in modulus also suggests that continuity in construction is even more important in the case of aluminium alloys than steel. The deflection of a beam with fixed ends, for instance, is only one-fifth of that which would occur if it had pin ends. An intermediate state between these two conditions may be fairly easily accomplished and in fact is more desirable than full fixity for, in addition to reducing deflection, such partial fixity may produce positive and negative bending moments nearer to each other in magnitude than with completely fixed ends. That is, the ideal state gives equal positive and negative bending moments of $\frac{WL}{16}$ when ends have a certain measure of restraint, whilst with ends fully fixed a negative bending moment of $\frac{WL}{12}$ occurs over supports, with a positive bending moment of $\frac{WL}{24}$ at the centre of beam.

The most desirable amount of "give" in a floor may well receive consideration. Certain regulations specify maximum deflection for beams, but these have been made primarily to avoid cracking of plaster ceilings rather than out of regard for persons using the floor. It may well be that more springiness than that afforded by such regulations is desirable, for it is well known that personal fatigue is greater when walking over a solid ground floor than over suspended floors, the deflection of which reduces the impact on the feet.

Roofs

The use of aluminium alloys for roofing purposes is not a new development, for a very successful roof of aluminium corrugated sheets was used on a Government building in New South Wales before the end of the last century. When examined some 40 years later the metal was in excellent condition except where copper fixing nails were wrongly used.

Aluminium alloys may be employed to-day for tiles, for seamed sheet roofs (flat, domed or pitched) and, for composite roofing, slabs or boards. A great deal of attention has recently been devoted to each of these systems, and roofs have also been designed in which aluminium alloys were used for the structure as well as the weather-resistant covering.

Several schemes of this kind can be mentioned. In one, light frames, at 2-ft. 6-in. centres, with members extruded to the required sections, and roof panels composed of aluminium alloy, joined by an adhesive to insulating material and prepared to accommodate ceiling panels, were used. In another, beams at 2-ft. 6-in. centres were adapted to flat roof construction with the ceiling slung below. A central longitudinal lattice girder supporting ribs at about 2-ft. 6-in. centres, with roof panels and suspended ceiling as above, was a feature of a third design. In a fourth use was made of two longitudinal girders which formed a flat between their top booms and a pitched roof from top booms to eaves, the covering being

of aluminium alloy troughing on which rested insulation boards with weather-resistant aluminium-faced surfaces. These represent only a few of the ideas which have been analysed and in which the advantages of lightness, heat insulation, finish and corrosion resistance have been exploited. The question of the transport of the roof fully fabricated and ready for lifting by a light crane, in sections as large as transport facilities permit, or in panels and pieces, has received a great deal of thought.

These roof systems have been considered primarily in conjunction with brick walls but may be incorporated in wholly prefabricated buildings. It appears preferable, however, to work out special designs in the latter case where roof and walls may be considered in combination.

Flat Roofs

Flat roof construction seems to be distinctly attractive to many architects on both æsthetic and economic grounds. As mentioned above, troughing of aluminium alloys may be used to provide the required rigidity, but there are many other structural forms possible, e.g., box sections. Weathering may be of aluminium alloys either spot welded or welded in the conventional manner; insulation may be considered sufficient if a hardboard ceiling is connected to the underside but, if desired, further insulation may be added by insulation boards between weathering skin and troughing, etc., or by aluminium alloy foil inside the boxes. A composite slab consisting of aluminium alloy filled with an inexpensive insulator such as sawdust or sawdust concrete may find very useful adaptation here or in the construction of floors.

For roofs of comparatively small span ribs or trusses may be dispensed with if the roof is broken up into self-supporting panels. In the case of pitched roofs the walls may be capable of providing the horizontal reactions, or alternatives such as tie bars introduced at suitable spacings.

The facts that aluminium-alloy sheets may be obtained pressed or corrugated to any pattern and that they possess great ductility so that they can be bent and shaped, ensure a wide scope to the designer. As with other ductile metals, joints may be welded when employing flat sheets, but less expensive methods are possible, such as lapping the ends and sides, turning the sides up and providing special cover junction strips or turning the sides down into a channel formed in the aluminium alloy extruded support and filling up the channel with a bituminous material. The use of plastics for jointing is also worthy of exploration.

The extrusion of special aluminium alloy sections having thin outstanding arms which may be easily bent down over the bent-up edge of sheeting so that a sound joint is provided, should be noted. This system is applicable where aluminium alloy sheets are used to cover roofs of any material. The junction sections are first connected to the base material by plugs or screws, then the sheets with sides turned up are laid, and finally the thin lapping portions of the extrusion bent over. This idea may be extended and the extrusion used structurally, e.g., as the rafter of the aforementioned

ribs spaced 2 ft. 6 ins. apart. Here again may be emphasized the great advantage to be gained for the manufacture of units covering as wide an area as possible, so that site joints, always a source of concern, may be eliminated.

Gutters and Spouting

Rainwater goods are preferably of aluminium alloy where this material is used for the roof. Aluminium gutters and down-pipes may be manufactured in the same manner as with other metals, but greater length may be readily handled. Maintenance is lower than with ferrous materials and there is no risk of staining due to corrosion products.

Partitions

The application of aluminium alloys to partitions has not, as yet, been made to any great extent, although decorative aluminium panels

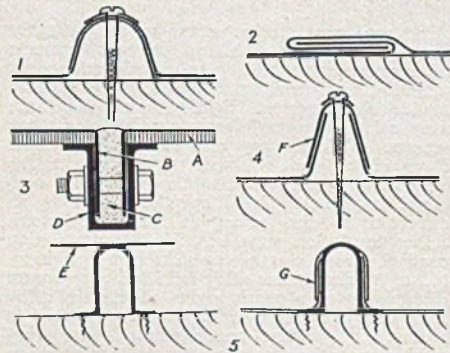


Fig. 2.—Five types of roof joint for aluminium sheeting: 1, single roof lap; 2, interlocking lap; 3, rib and panel joint (A—sheet metal panels on fibre board, B—panel flanges, C—mastic filling, D—rib section); 4, cover strip joint (F—cover strip forced over sheet upstands); 5, extruded joint section. Diagram at left illustrates form of section before laying roof sheets (E—flanges as extruded). Diagram at right shows form of section after laying roof sheets (G—flanges turned down over sheet upstands).

and other fixtures have been used for many years. The chief reason for this is that detailed information has been lacking, whilst price considerations have hitherto militated against such applications.

For partitions which may be removed and re-used elsewhere, and for sliding partitions, the low weight of aluminium alloys suggests their extensive application. The weight of aluminium alloy partitions would be so small that in rooms of the average height it would probably be permissible to omit allowance for them when designing the floor and they may be safely introduced to floors which would not have the necessary safety margin to carry heavier partitions.

They may be designed to act as load-carrying members forming part of the structural scheme, in which case the heat-treatable alloys would be used to provide maximum stress-resistance

properties. Suitable alloys are available in a range of ultimate strengths from 22 tons per sq. in. to at least 30 tons per sq. in.

The aluminium alloys suggested for non-load-carrying partitions, including panelling, are of the magnesium-aluminium non-heat-treatable type which may be readily welded by the electric arc, gas and spot methods. The weight of such partitions constructed wholly of aluminium alloys should not exceed 2 lb. per sq. ft.

Plastics for jointing may be particularly suitable for use in aluminium alloy partitions and one partition system, lately evolved, comprises aluminium alloy facing sheets about 3 ins. apart, connected by an internal troughed sheet, the joining of this internal trough and the external sheets being by a plastic compound.

The high thermal insulation of aluminium alloys is advantageous here and it could be further improved by filling the panels with an insulating material such as cork or arranging aluminium foil inside the panels; the polished foil may be stapled to wood battens connected to the inside of one of the aluminium sheets by an adhesive.

Services may be accommodated within the panels and hollow parts. Features such as skirting, dado, cornice, etc., may be arranged by shaping sheets or strip as required.

Periodic cleaning with warm soapy water is sufficient to maintain aluminium alloy surfaces in an unimpaired condition for an indefinite period except for the possible fading of dyed anodic coatings. The control of tints obtained by anodizing and dyeing is not always perfect and some slight variation between individual sheets may occur. This variation would not be noticeable in partitions in which the area is broken up into panels with thin cover strips of a contrasting colour.

The decorative scheme may be arranged to satisfy almost any taste, using metal alone or combined with other materials. Panelling or coverings, such as plasterboard, glass, plastics, etc., may be used with aluminium alloy framing, or, alternatively, aluminium-alloy panels or covering may be used with framing of other materials.

That the aluminium alloys are non-inflammable is sufficient to allow the general installation of aluminium alloy partitions, but as the melting points of these alloys range between 530 degrees C. and 640 degrees C. should special circumstances require it a fire-resisting material such as asbestos may be incorporated inside the components.

Sliding Partitions

Sliding partitions may be formed of panels generally similar to those of fixed partitions. Aluminium alloys appear to be ideal materials for such construction to ensure maximum ease of opening and minimum impact on walls, thus conferring maximum life to the fittings, especially those bearing on the guide and runner bars. Bottom sills, covers to top track and wall posts may also be constructed of aluminium alloys to match with the partition.

Doors

Doors may range in size up to those which are fitted to airship hangars, and with their increase in size the difficulty of opening and closing increases. It is recognized, therefore,

that simplification follows the use of aluminium alloys for the large type of door, for a reduction of 50-60 per cent. of the work required to operate such doors could be obtained. In the case of sliding doors the reduction in weight enables the section of the supporting structure from which they hang to be proportionally reduced in size.

In cases where a considerable span is required, as for a level crossing, the forces in the bars of the gate itself would be reduced by using aluminium alloys.

It follows from the foregoing that this advantage of the lighter material is cumulative and it may well be that doors may be constructed of aluminium alloys of a size which would otherwise be prohibitive. The corrosion-resisting properties of aluminium alloy are also of great advantage where maintenance is difficult, as may be the case with large sliding doors.

Smaller doors would also benefit by using aluminium alloys on account of ease of opening, resistance to corrosion and the fine finish possible. Hinged doors may be of hollow construction with features formed by pressing and the space inside filled with an insulating material. Each side of the door may be pressed from a single sheet, their edges bent and welded edge to edge forming the thickness of the door.

A great many glazed doors of aluminium alloy have been made for shops, restaurants, hotels, etc., and particularly good examples are swing doors which weigh considerably less than those of similar type in wood.

Glazing Bars and Windows

Aluminium-alloy glazing bars were in use over 14 years ago and competed successfully with bars of other metals. The effect of weathering on many of these installations has recently been investigated and in all cases the findings have been considered very satisfactory.

Examples of Glazing Bars

A good example is the aluminium alloy glazing bar used in the Dudley Zoo Bird House, a circular building some 40 ft. in diameter lit from above by means of a complete circle of roof glazing. It was found that the only effect from six years of exposure to the weather outside and the internal atmosphere peculiar to such a place was that externally the bars had acquired a dull grey colour but were otherwise in perfect condition, with the single exception of one bar, part of the flange of which showed some signs of corrosion at one end. Internally the bottom surface of all bars was covered with a fine scaly film, but by rubbing with a damp cloth a bright surface was obtained.

Although six years cannot be regarded as a satisfactory test period for roofing materials, the exposure for this period of a material in its unprotected condition must be regarded as highly encouraging.

Another report on the examination of aluminium alloy glazing bars in lantern lights at Hammersmith L.C.C. Hospital shows that although the bars have received no protective coating and have been in position nine years they are in excellent condition. A slight coating of soot covered the bars and the conditions are urban with a moderate degree of industrial

pollution from heavily built-up surrounding zones and a railway in the vicinity, but neither uniform surface corrosion nor pitting are visible. It is concluded that such bars may be exposed for many years in polluted urban atmospheres without any form of protection and remain free from attack.

The fact that by the extrusion process shapes too complicated for rolling may be obtained is a great asset to the design of suitable glazing bars. Apart from the good appearance of aluminium alloy bars their weight is low; hence it is often possible to reduce sections of the supporting structure.

A very fine example of the use of aluminium in connection with glazing may be found in the conservatory in the Botanical Gardens, Washington, U.S.A., where the alloys have been used to a considerable extent for the main structure in addition to glazing bars.

Windows

Penetration in aluminium alloys before the war received considerable attention and the following applications may be noted:—Civic



Fig. 3.—Aluminium wash-basin as used on air liners prior to the outbreak of war.

Hall, Wolverhampton; Hickman and Mould Dairies, Wolverhampton; Cambridge University Library; Arlington House, St. James's, London; Threshers, Ltd., Conduit Street, London; Bodleian Library, Oxford.

For some years prior to the war aluminium alloys were used for windows in many notable buildings and recent examinations of them have encouraged the extension of their application to all types.

The maintenance of aluminium-alloy windows is low, even in the presence of a very damp or polluted atmosphere. If it is considered that the alloy window frames should have some further protection than that afforded by the protective film which forms on exposure, anodizing or chemical oxidation may be specified or the metal may be painted.

Sea-air conditions are dangerous to most metals, but the aluminium alloys of the magnesium-bearing type are highly resistant to marine conditions and it is probable that alloys of this type will be widely used for all aluminium alloy frames.

Sliding windows and sashes in which lightness is desirable call for the application of aluminium alloys; this type of window appears to be exceedingly popular and easier manipulation would ensure still wider adoption. Further detailed design work is necessary on this aspect, however.

Extruded aluminium-alloy sections have been exclusively used heretofore, the corners of the frame being welded, and it appears that such construction may predominate in the future, especially in view of probable improvements in welding. Experimental work has been carried out on the manufacture of pressed aluminium



Fig. 4.—Further example of the application of light-metal glazing bars (Westminster Central Depot).

alloy and cast aluminium alloy frames and it appears probable that these methods will provide competition, especially for the smaller windows.

Canopies

Canopies provide an instance where four properties of aluminium alloys—high strength, high corrosion resistance, pleasing appearance and ability to extrude almost any section—may be used to great advantage.

These qualities are found together in no other material used in canopies, consequently either the conventionally shaped structural members are exposed from below, camouflaged by some form of decorative treatment, or the whole of the structure is encased with a decorative and protective covering.

This cover is usually of sheet steel and it is well recognized that its maintenance is a continuous heavy liability, and so rapid is the corrosion that it has been said by the architect of a concern owning many buildings equipped

with such canopies that inspection for corrosion must start immediately after fixing.

When using aluminium alloys, no added covering to the structure is required, the structure, roof covering and all other features being combined and treated homogeneously. The reactions of such cantilevered canopies in aluminium alloys are, of course, considerably reduced on account of the much lower weights involved.

Kitchens and Bathrooms

Parallel with the tremendous interest lately concentrated on the construction of houses of the future has developed a keen sense of the importance of the amenities desirable within a house in order that it may provide a reasonable standard of working conditions.

At present many kitchen schemes are being designed and the new materials are being critically reviewed. In these investigations aluminium alloys are receiving much consideration, and although it is not suggested that an all-aluminium kitchen would be ideal, it is certain that aluminium alloys fulfil most of the kitchen designer's requirements admirably.

Lockers and cupboards in aluminium alloys were adopted before the war by at least one very well-known multiple caterer and received great approval. The metal is non-toxic (hence its great application in dairies, breweries, etc.) and food may be stored with absolute safety. Such cupboards are easily kept perfectly clean, whether the metal be anodized or is untreated. Other advantages are that they may be easily moved, are vermin-proof and present an impeccable exterior.

Construction may be on the basis of using sheet aluminium of requisite stiffness pressed and stretched to the required contours with stiffening ribs incorporated or of a sandwich board made up of a core of material acting as a base, such as plywood, plastics, cork, etc., with surface facing both sides of aluminium alloy.

The application of aluminium alloys to refrigerators appears to offer success, for here the insulation properties of the material may be utilized. Suitable alloys resist corrosion by most of the refrigerants.

Aluminium covering, applied to table and counter tops, has been used for some years and an extension of application is here being pursued by considering the table as mainly constructed of the metal. The surface may be easily kept clean and shows no staining, its appearance is pleasing and the lighter weight would be an asset.

Wall and ceiling panelling to kitchens may be treated very successfully by facing with aluminium alloys. Its use for such features as mouldings, junction strips, etc., has long been appreciated.

Many kitchen fittings and utensils, such as door furniture, lampshades, pots and pans, etc., are too well known further to discuss.

Bathrooms

In the bathroom the application of aluminium alloys to the walls and ceiling are attractive. This is encouraged by the variety of finishes possible and the ease with which the surfaces may be cleaned.

Baths in aluminium alloys have been experi-

mented with in pre-war days, but the cost then prohibited any serious attempt to interest the public. Further investigations are required on this and similar items such as washing basins.

Shower Bath Cubicles and Swimming Bath Fittings

It has been found that the application of aluminium alloys for the facing of shower bath cubicles, enabling easy cleaning and tidying, is very successful. They have also found very useful service for swimming bath fittings.

Insulation

Great interest has been taken recently in the insulation of buildings, and it came as a surprise to many people to learn that the Portal factory-made house was insulated with aluminium foil.

Although the heat conductivity of aluminium alloys is twice that of steel its value as an insulator is notably high on account of the high percentage of radiant heat which is reflected. The thermal and optical reflectivity of the alloys "as produced" is high, and although if used externally weathering reduces the reflection value somewhat, the inner surface retains its original condition.

Insulation by using a material of low conduction is widely appreciated, but the control of radiant heat has been given less attention. Some idea of the importance of the latter may be noted from the heating of rooms by open fires. The heat rays are projected to the surrounding walls, furniture and air. Air is a poor conductor but carries heat by circulation, and of the heat projected by the fire the greater portion reaches the surrounding walls as radiant heat.

The absorption of these rays varies from 100 per cent. in the case of a completely black surface to nil for a perfect reflector. In insulating against external heat or cold, consideration of radiation is of first importance. In tropical countries the value of a covering which will reflect most of the heat rays is well known; this has been exemplified in the case of oil storage tanks, which lose a considerable fraction of their contents per day by evaporation, but when covered with aluminium foil the loss is greatly reduced.

As a good reflector is a bad radiator, aluminium when used for exterior cladding in cold atmospheres retards the flow of heat from the building.

Where heat insulation without strength is wanted aluminium foil has been found remarkably effective and cheap. It is inserted in an air space inside the wall or roof panels and typical figures for insulation are given below:—

Blu/sq. ft./hour for 1 in. thickness and 1 degree F. difference in temperature

Slab Cork	0.3 average
Slag Wool	0.35
Glass Silk	0.2 to 0.3
Cellular Rubber	0.3 to 0.4
Fel Grass	0.31 to 0.34
Cellular Concrete	0.49 to 0.9
Common Timbers	0.81 to 1.11
Asbestos Slabs	0.33 to 0.37
Wood Fibre Board	0.38 to 0.41
Plaster Board	1.1
Asbestos Cement Sheeting	2.0

Concrete with Gravel aggregate	6.7
Do. with light weight aggregates	1.1 to 2.3
Single layer Aluminium Foil in 1-in. air space ..	0.25

Other Applications in General Building Construction

The following represents a summary of building applications other than mentioned already. These applications are typical and the list is by no means complete.

Grilles, balustrading, handrails, shop fronts and general architectural metalwork have become fairly commonplace in aluminium alloys and many interesting examples may be quoted of which the following are typical:— Westminster Central Depot, London; Threshers, Conduit Street, London; Woolwich Electricity Showrooms, Woolwich; Messrs. Redmayne's, Ltd., and Jean Palma, Oxford Street, London; Wolverhampton Civic Hall; Bexhill Pavilion; Mount Royal Flats; S.S. "Orcaes."

Other countries, especially U.S.A. and Germany, were far ahead of Great Britain before the war in the application of aluminium alloys and it is possible to note some interesting examples and to profit from their experience.

Lifts comprising a big percentage of aluminium have been installed in Paris, Chicago and New York. It has been possible to reduce the weight of the lifts by up to 50 per cent. with such application. Less counterweighting is required; less power is necessary; acceleration and deceleration may be easier accomplished. It may be added that collapsible lift gates in aluminium alloys are remarkably easy in operation. In this country a lift in which is used a high percentage of aluminium alloys may be seen at Unilever House, London, whilst another British example is that of the lifts in the "Queen Mary."

Roller shutters, fire escapes, roof walkways, chimney cowl, copings, sill flashings, ventilating systems are other instances where aluminium alloys have been used.

Escalators wholly of aluminium alloys have been built in this country for Messrs. Simpsons of Toronto and a good example of facings and mouldings may be seen in the escalator at Messrs. Harrods of Kensington. There appears to be no reason why escalator treads and risers should not be made of aluminium alloys instead of wood, for here lightness is desirable and length of service is considerably greater.

A use of aluminium already followed in this country, but particularly in the U.S.A., is for wall-facing or cladding in the form of spandrels, pier casing and panels. The chief advantage of the use of the metal is the great reduction in dead-weight of walls, this being considerable in multi-storey buildings.

Spandrels are often cast, the technique affording good opportunity for intricate detail at little extra cost, though solidly backed sheet can be used equally well, this type being the lightest in weight. Pier castings are generally extruded and where one section may not be sufficiently wide the whole can be built up from a number of extrusions. Panels are generally of a thin gauge sheet solidly backed (fibreboard, plywood, etc.) and fixed to framed walls and partitions as mentioned elsewhere.

Solid backing is necessary to obtain rigidity and freedom from an appearance of waviness, this being particularly noticeable when a high specular finish has been specified.

Conclusion

It is now generally accepted that new methods of building will be employed extensively after the war, and the materials new to building will also be applied on a considerable scale. Before any new material can be accepted it must be shown that its employment is technically sound and also economically practicable. In so far as the aluminium alloys are concerned, past experience and more recent investigations have shown that there are valid technical reasons for their use in a number of applications, but there is as yet little definite indication of the post-war price level of this group of materials.

In this connection, however, it should be noted that fundamental changes have taken place during the war, of which the most important are:—

- (i) World capacity for producing aluminium at the end of the war has been estimated six times the 1935 tonnage, at least.
- (ii) There will be large stocks of both virgin and secondary metal throughout the world.
- (iii) There will be a considerable increase in the amount of plant available for the production and fabrication of the aluminium alloys, together with very large numbers of workmen skilled in the working, joining and finishing of these materials. It is apparent, therefore, that the cost of finished articles of aluminium alloy will tend to be reduced, to the benefit of the consumer.

Immediately prior to the war the price range of the light alloys, volume for volume, was approximately in line with that of copper and the alloy steels. Aluminium alloys were rather more costly than lead, zinc, and the cheaper brasses, and considerably more costly than iron or mild steel. Post-war re-orientation of the prices of the common metals is likely to show a change of position, although it is too early as yet to forecast what the relative prices will be. Full account of this trend must be taken, however, in planning the post-war utilization of the various materials now available for building.

APPENDIX

Summary of Properties of Aluminium and its Alloys

Although the properties of these alloys have been discussed previously² it is advisable to summarize again their principal characteristics of interest in building. The outstanding point is the exceptionally wide range of properties obtainable over the whole range of the light alloys—it is certain that there are very few items in normal buildings for which one of the aluminium-base materials cannot be successfully used.

Low Weight.—The outstanding property of aluminium and its alloys is, of course, their low density which ranges from 2.63 to 2.82, compared with 7.8 for steel, 8.9 for copper, 7.1 for zinc and 11.3 for lead. A cubic ft. of

aluminium alloy weighs approximately 172 lb. as against 486 lb. for steel, about 112 lb. for brickwork and about 140 lb. for concrete.

Resistance to Corrosion.—Aluminium and its alloys do not rust or corrode in any way similar to ordinary steel, and practical examples of their high resistance to corrosion are mentioned in the body of the paper, and a great deal of other information is available. Their resistance varies somewhat according to the composition of the alloy, those containing copper being rather poorer than those which are copper-free. Particular note should be made of the aluminium-magnesium series, containing from 2 to 7 per cent. magnesium, as they are especially resistant to marine atmospheres and are not heat-treatable. Another important point to be mentioned is the effect of electrolytic corrosion, which occurs when any two metals are in contact, one of them being preferentially attacked. The degree of corrosion when aluminium alloys are in contact with zinc, cadmium and steel (especially stainless steel) is very small, but increases when the second metal is copper or nickel. Maximum resistance to corrosion, combined with highest mechanical strength, is obtained by cladding a high strength heat-treatable alloy with pure aluminium ("Alclad"), this being used extensively in aircraft.

The resistance to attack can also be greatly improved by anodic oxidation by which process the natural film of impervious oxide is increased in thickness from a few molecules to as much as 0.001 in. This is a most valuable property possessed by no other metal, especially as the film can be coloured in a variety of tints.

Conductivity.—The electrical and thermal conductivities of aluminium rank next to that of copper and the alloys also possess high conductivity.

Mechanical Properties.— Ultimate tensile strengths range from about 5 tons/sq. in. for the pure metal to over 33 tons/sq. in. for some of the heat-treatable alloys—every possible use in building being adequately covered. Ductility and toughness are also good.

Mechanical Constants.—The values of the mechanical constants are:—

Modulus of Elasticity (E)	= 10×10^6 lb./sq. in.
Torsion Modulus	= 3.9×10^6 lb./sq. in.
Poissons Ratio	= 0.36.

Forming and Machining.—The aluminium alloys can be formed and machined readily and there exists a tremendous reserve of plant and skill for all necessary operations.

Joining.—The pure metal and soft alloys are easily joined by gas and spot welding, whilst riveting and spot welding are usually employed for the alloys of highest strength. Newly developed methods of joining by means of plastic adhesives are promising.

Reflectivity.—To this property detailed reference has been made.

Appearance.—The self colour of aluminium alloys is generally pleasing to most architects and the range of finishes, including anodized and surfaces dyed to any colour, is welcomed as allowing maximum expression and minimum of constraint. The warning that dyes vary in permanency must be made; the fading is similar to that of any other dyed materials.

NEWS — General, Technical and Commercial

Art of Advertising

CORRESPONDENCE reproduced here results from recent private discussions on the place of pure art and humour in technical publicity. Opinion, in the main, favours straightforward factual advertising. With this viewpoint we and our first correspondent are not in entire agreement.

Humour? Why Not?

"The increasing tendency to introduce the humorous element into technical advertisements appears in some quarters to be meeting with a certain amount of criticism.

"Perhaps this humorous element will appear in its proper perspective, namely, neither better nor worse than any other subterfuge to seduce the reader from the text, if true appreciation be made of the ultimate objects of advertising. This science fulfils two main functions. The first and more obvious one is to acquaint the prospective buyer with the nature and use of various products, what they cost and from what producers they may be obtained. This function, which assumes the existence of prospective buyers, seeks merely to effect a connection between them and the source of supply, and is best served by the purely factual statement, such as may be inserted under classified small 'ads.'

"It is ludicrous to tempt a producer to take full-page advertisements in a national daily paper if the same purpose can be served by the insertion of a few lines in the appropriate columns of a dozen magazines. Nevertheless, it frequently occurs that a situation of this kind arises, and the reason is to be sought in the second main function of an advertisement, namely, the desire to acquaint those who are not prospective buyers with the fact that such-and-such a product would be of benefit to them in their homes, in their businesses or where you will.

"This branching out from the assumed prospective buyer to embrace all and sundry calls for an entirely different technique.

"Some of the American publications devote something like 90 per cent. of their available space to the reproduction of a work of art and a comment on it, finally adding a very short note on the products advertised and leaving it to the reader to assume that there is a similar degree of excellence in both. Now this is, in fact, a trick, yet statistics show that, of all publicity, this type is the most popular and returns the biggest dividends in increased trade.

"The argument may well be advanced that, in the technical world, we are not in the mood to have 'giggling girls' camouflaging ball-bearings. The submission is, however, that this argument is fallacious, as if to a given reader the problem as to how and from whom ball-bearings may be bought is so serious, then that reader probably belongs to the class of prospective buyers and would read any pertinent advertisement, whether serious or otherwise, be it a full-page job in three colours, or a three-line job in the classified ads.

"Summing up, therefore, it seems that there can be no fundamental objection to humorous advertisements. Finally, can it be that our technical men are so devoid of the human touch that they either miss the humour altogether or, seeing it, skip an extremely important advertisement?"—Technologist.

It's Not Funny in China!

"With the end of the war drawing near, we are all concerned with getting ready to serve, once again, the old and, perhaps, to find new markets for our products. But, besides providing the right goods, it is essential to bring them to the knowledge of the respective buyers abroad; for many reasons travelling in the post-war period will still be difficult, so that one of the few means of doing this will be to make use of the advertising pages of our various technical publications.

"To my great surprise I find that we are not paying enough attention to the manner in which this publicity is carried out, and often see advertisements in technical papers which might well convey to readers abroad, not familiar enough with the English language, the impression that the paper concerned is not a specialized periodical, but one of general interest, rapping from poultry-keeping to landscape gardening. Surely, it is better to concentrate on the subject of one's products and to bring these to the notice of the respective buyer, rather than indulge in flights into the higher realms of artistic creativeness?

"For instance, if one wishes to sell oil filters, bolts or nuts, let the article be shown.

"Designers of advertisements need to realize, too, that not everyone abroad has the same sense of humour as ourselves. The foreigner, with little knowledge of English, must, by looking through the advertising pages, be able at all times to see rather than read what the manufacturer in the United Kingdom has to offer.

"I know, from my own experience, that the engineering buyer overseas does not respond well to humorous advertising. In many cases, the impression created by such publicity is a poor one, and the prestige of the firm concerned, far from being enhanced, is frequently lowered by appeals of this type to overseas markets."—Export Merchant.

Different People, Different Appeals

"Without wishing to suggest that advertising is a deep mystery, whose secrets are only known to the initiates, it has, I think, been demonstrated conclusively that one needs to advertise differently to different types of people, and that the same type of advertising which has been successful in the daily Press will not necessarily be successful if repeated in the technical Press. In fact, in my experience, the odds are that it will fail completely.

"The reason for this is, I suggest, that we are different people in our different capacities.

Mr. Smith, architect, is just plain Mr. Smith when he is thinking of buying a shirt, but he is a technician when he is detailing the construction of a staircase and specifying materials for it. Therefore, as his approach is different to the two different problems, so must the approach of the advertising be different in both instances.

"Yet, in both cases, Mr. Smith wants information, either implied or stated. In the first case, he wants to be assured that the shirts will fit him; that the material is good for the price he is asked to pay; that the colour is pleasing. But in the second case he requires much more detailed information; if he contemplates designing wooden balustrading he wants to know whether the timber that he thinks of using will turn easily without chipping; will take stain and polish, and will be strong enough to bear weights that may be thrown upon it. If he contemplates light metal capping or hand-rail, he wants to know sections of extrusions obtainable; possibilities of fixing; oxidization and loss of colour; price, and a whole host of other data.

"In fact, he wants to know much more than when he is buying a shirt, and an advertiser is faced with the problem of conveying all this information to the technician without loading or over-loading his page or half-page advertisement.

"The only way to accomplish this is to induce the technician to ask for more information than one can possibly give in an advertisement. In other words, you stimulate his curiosity by either stressing one point, or by touching on all the points, so that he will ask for the rest, which can then be conveyed by catalogue or brochure.

"But the point to be remembered is that the technician wants information that will help him in his job, and these words 'in his job' really connote the difference between technical advertising and what I will call ordinary human advertising. Where many advertisers, however, go wrong, in my mind, is that they recognize the axiom that all advertising must attract attention, and in technical advertising are apt to over-stress this, thinking that if they draw a funny picture of a boy standing on his head wagging his heels in the air, which is likely to attract attention, they have done their job thoroughly; but I submit that having attracted attention they have then got to stimulate curiosity, which the form of advertising I have instanced fails to do.

"This concentration on attraction is carried by many advertisers beyond Press advertising, into their brochures and booklets, which is a very sad mistake. I have recently had occasion to go through the catalogues and brochures which a number of architects have retained in their files, amounting to some hundreds. Ninety-eight per cent. of those retained are informative copies, kept for reference purposes. Only about 2 per cent. of the 'pretty picture' type have been kept, and these only for special individual reasons.

"All architects, however, will tell you that the majority of the circulars, brochures, and so on which they received in peace time were of the pretty-picture, attractive nature, and these went straight into the waste-paper basket.

"Let it not be thought that I decry attractiveness. I decry it as an end, but not as a

means, and it is perfectly simple—once you have the knack of it—to set out informative matter attractively, but it does not demand a knack almost amounting to making it a specialist's job."—N. C. STONEHAM.

Advertising Trends and Values

"The following account was written as a result of a discussion between the editor of 'Light Metals' and a buyer in a large modern plant engaged in the production of light alloys. It is published, not to give rise to any controversy as to what is, or what is not, good and appealing advertisement matter, but merely as the reaction of one by whom, presumably, advertisements are meant to be studied, borne in mind, and used when occasion demands.

"Primarily, it may be supposed, advertisements are intended to be read by buyers and engineers of concerns which, possibly, use, or may be called upon to use, the products described, and which, at the moment, either do not employ such products, or which use similar goods made by a competitive firm.

"As regards bodies already using the products which are the subject of any advertisement, it may be assumed that buyers and engineers are, in general, immunized against the intended appeal because of an already established knowledge of their requirements and existing connections with the several manufacturers. Publicity, therefore, if it is to be effective, must appeal to and be directed at prospective new clients.

"Until a few years ago advertising followed, as a rule, more or less orthodox lines, inasmuch as the name of the appellant company appeared prominently, together with more or less written details of what was manufactured or sold. Such publicity was adorned with established and possibly well-known trade marks; in many cases pictorial presentation of the articles manufactured was also attempted. Such propaganda, it is safe to say, merely intimated to prospective buyers that such and such a concern or corporation made goods which the buyer required for the first time, and his reaction was a general inquiry to those bodies, the advertisements on behalf of which appeared to give an indication of experience and solidarity.

"Recent trends, however, seem to be towards pseudo-humorous, or highly coloured and pictorial matter which, in itself, conveys little impression to the buyer as to the prestige of a concern, or to the nature of the goods it wishes to sell. Unlike the older type of advertisement, it tends to leave him guessing as to the technical and business standing of the manufacturer.

"It seems, therefore, to the writer, as one of many buyers with limited time under present conditions for studying advertisements and semi-technical matter, that much publicity of the type mentioned represents merely a waste of time and paper, because it does not 'put over' the requisite information and the standing of the advertiser—factors of so much importance to a buyer on first approach to a new requirement.

"To the engineer (whose first considerations are, presumably, technical and mechanical data regarding the article he requires), recent types of humorous or highly coloured futuristic design in propaganda are likely, one would imagine, to convey no favourable impression. Solid tech-

ANNOUNCEMENT



THE SIGNIFICANCE OF HIDUMINIUM[★] TO YOUR INDUSTRY

THE characteristics of light metals impel imaginative thinking. Whatever you manufacture—aeroplanes, ships, road transport vehicles, railway rolling stock, machinery or household appliances, building or electrical equipment—HIDUMINIUM aluminium alloys will play an indispensable part in solving the mechanical and structural problems of the future. A new Company—Hiduminium Applications Ltd.—has been formed to collaborate with designers and constructors in every industry to secure the best use of Hiduminium alloys. Further information will be sent on request.

★ *Light weight and high strength · high thermal and electrical conductivity · high resistance to corrosion · workability, ease of fabrication · non-toxic and non-magnetic · excellent appearance.*



HIDUMINIUM APPLICATIONS LTD.
ALUMINIUM ALLOYS · FARNHAM ROAD · SLOUGH · BUCKS.

NICH DUTY ALLOYS LTD. · REYNOLDS TUBE CO LTD. · REYNOLDS ROLLING MILLS LTD.



"...and a smile on the face of the tiger."



Photograph: Fox Photos.

Industry everywhere is beginning to realise that it has, for too long, been somewhat like "the young lady of Riga."

It has ridden rather "expensively." Metals hitherto employed have had "a short life and a gay one." It is recognising how much machine-energy can be eaten up by deadweight—a rapacious devourer.

In other instances—metals are eaten into—and profits too, by gulps.

It is therefore not surprising to realise the welcome awaiting Reynolds' Strong, Light, and non-corrodible Alloy Products immediately on their release from work of National importance.



REYNOLDS

TUBES • RODS • SECTIONS • SHEET • STRIP IN
"DURALUMINUM" ALUMINIUM ALLOYS

REYNOLDS TUBE CO. LTD. & REYNOLDS ROLLING MILLS LTD. BIRMINGHAM, II.

nical achievement, on the other hand, as evidenced by some degree of development in a product or machine with which the engineer is already partly acquainted, will infallibly arouse that first spark of vital interest, and provoke him to probe deeper into the matter by contacting the advertiser concerned.

"Requirements for concerns such as that with which the writer is connected, may cover a diversity of goods, including light metals and heavy metals, machine tools and working equipment of every sort. Buyers in such concerns are, it is granted, essentially commercially minded, but enterprise and progress demand that they keep a constant eye on primary technical developments connected with their current and probable future requirements; the modern trend of advertising design, it seems, does not further this aim and fails to strike the right note of first appeal.

"It is realized that it is difficult for those responsible for drawing up publicity to decide just what and how much of the various matter appertaining to the advertisement shall be made public in the form of 'copy' or illustration; particularly is this so at the present time, when

so much developmental work must, for obvious reasons, not be disclosed. In addition, one single type of advertisement cannot be expected to exert a maximum appeal upon each and every engineer or buyer whose attention it is desired to attract.

"Both at home and abroad post-war industry will make numerous demands upon suppliers of raw materials and semi-finished forms. A common thought in the minds of all engineers embraces the numerous developments, improvements and alterations in existing materials and plant, which must be reckoned with in formulating peace-time programmes. To serve its purpose publicity which will strike home at first glance must, it seems, therefore, lie somewhere between the old, dry factual type, and the very new forms of which the writer complains.

"Business solidarity and technical confidence must be indicated, together with just sufficient information of that type which the buyer can at once appreciate and absorb, and which will either remain standing in his mind to be called on when required, or be sufficiently impressive to be recorded for future reference."—BUYER.

DETERMINATION OF ZINC IN LIGHT ALLOYS

IT is to be regretted that, in the paper "Determination of Zinc and Aluminium Alloys," by W. Stross and G. H. Osborn, published in the July issue of "Light Metals" (p. 323), numerous errors occurred in reproduction of the original copy. Those interested may obtain corrected copies by applying to the authors.

Further to the comment contributed by Roberts on this paper ("Light Metals," 1944/7/327) the following letter has been received:—

"The question of what accuracy really means will no doubt continue to worry many industrialists. It is of little use weighing to four decimal places, using a chemical process that may entail much more serious inaccuracies. We may instance as extreme examples, say, the well-known Conradson fixed carbon test for oils which while not an analytical method is an extremely important control. Here much depends on the individual and the method of burning. One would not introduce accurate weighing since the process may entail an

inaccuracy of 10 per cent. Another example that might be cited is, say, the estimation of cobalt in metallo-organic compounds. Most workers use a preliminary ashing and differences of results by different workers have often been as much as 7 per cent. and 8 per cent. Some consider, not without good reason, that inexact results in industry are not disastrous so long as the inexactitude is known. Thus it is often better to rely on one careful worker who works consistently inaccurately (not carelessly). At judicious periods truly accurate analyses may be made to keep a check on the actual inaccuracy. This applies also to colorimetric work—one constantly inaccurate but careful worker is often worth more than a pedantically accurate but partially colour-blind worker. By and large, one finally gets sufficient accuracy and certainly speed.

On the whole one welcomes the introduction of any physical instrument to eliminate many chemical analytical methods, so long as they do not introduce other chemical discrepancies. —M. D. CURWEN.

ACCELERATED ANODIZING: Commentary

THE work of Akimoff* and his colleagues gives a fair picture of the quantitative aspect of anodic oxidation and, as such, serves to remind readers of the chemical principles involved in the many possible variations of anodizing conditions. It should be appreciated, however, that the bulk of the information given appears to comprise a summary of British, American and German work carried out during the past 15 years. The correctness of some of the facts is open to criticism and the following commentary is intended to present other aspects

which the author appears to have overlooked. In view of a scattered literature and the lack of published information of a concise nature, it is not surprising that some points have been overlooked or misinterpreted.

The comparisons drawn between the sulphuric and chromic acid films are in some cases at variance with established views. viz.:—

(a) The protective properties of the film produced by the usual sulphuric acid pro-

* See "Light Metals," 1944/7/311.

cess (DTD.910B) and the chromic acid process are approximately equal in so far as resistance to corrosion is concerned. This statement is based on extensive visual and mechanical assessment carried out by the R.A.E. and other test houses. The resistance of the sulphuric acid film to mechanical wear is of the same order as that of the chromic acid film for equal film thickness, but the former process is one that lends itself to the production of films having thicknesses far in excess of those produced by the latter method. For this reason it is often possible to rely on the combined resistance to corrosion and mechanical wear of the sulphuric acid film plus a chemical sealing process to simplify or eliminate the subsequent painting system although British aircraft constructors have been slow to appreciate this point.

(b) The chromic acid process can readily be applied to duralumin, and, indeed, this alloy is probably anodized in larger quantities in this country than any other alloy. The process can also be applied to aluminium castings, containing less than 5 per cent. copper or to higher copper alloys if the operating conditions be modified. Chromic acid trapped in porous castings is less likely to give rise to corrosion trouble than sulphuric acid and, for this reason, those aluminium alloys that are difficult to anodize in chromic acid and which must be treated in sulphuric acid are best given a sealing operation in potassium dichromate solution so as to introduce chromate into the pores in partial or whole replacement of any trapped sulphates.

(c) The statement that the adhesion of sulphuric acid film is greater than that of chromic acid film is peculiar and if intended to apply to the adhesion between film and base metal is difficult to believe. The authors may have in mind the adhesion of paints to the anodic film, in which case the statement is correct. It is not generally appreciated in this country that certain types of sulphuric acid films give better paint adhesion than any other known method of preparing light-alloy surfaces, including pickling, chemical oxidation, chromic acid anodizing, etc.

(d) Although the use of chromic acid necessitates compliance with special health precautions, it is also desirable, but not essential, to exhaust sulphuric acid spray. Even if operators are acclimatized to the sulphuric acid spray, structural steel work and other steel plant in the vicinity suffers very rapid corrosion.

(e) The danger of damage to aluminium articles due to current interruption during anodic treatment in sulphuric acid has been greatly exaggerated. The maximum time of immersion is 20 minutes and only alloys containing high copper or zinc are likely to be affected.

(f) With the exception mentioned under section (b) above it is not essential to seal the sulphuric acid films in a chromate solution, particularly if painting is to follow;

indeed, the sealing operation decreases the paint adhesion to a slight extent. Of course, if painting is to be omitted and if the yellow colour of the chromate-sealed coating is not objectionable there is ample evidence that this sealing process considerably increases the corrosion resistance of the film.

(g) The time of treatment for sulphuric acid films recommended by the Russians exceeds that usually used in this country (15 minutes). The additional process of sealing merely delays the time taken to turn out the first batch of work; all subsequent batches arrive at 15-minute intervals—a rather different state of affairs from that arising where the anodizing process, taking 35 minutes, is used. (Modified chromic acid.)

(h) The figure given for the quantity of electricity used in the standard sulphuric acid process adopted by the Russian Research Institute of Aircraft Materials differs so greatly from the average figures in this country that it is possible that some error of translation has occurred. The current consumption of 200 A.secs./dm.² is equivalent to 1855 A. secs./sq. ft. or approximately 0.5 A.hrs./sq. ft. The typical British process operates at a current density of 20 amps./sq. ft. for a period of quarter of an hour which is equivalent to 5 amp. hrs./sq. ft. If the error be one of translation involving the misplacement of a decimal point, it is probable that the current-consumption figures are precisely similar in both countries.

(i) The authors make the startling statement that a reduction of film thickness decreases elasticity. This is contrary to general experience as most thin films will stand more mechanical deformation than thick films formed in the same electrolyte. In any case, it is difficult to appreciate why lack of elasticity should be objectionable, assuming that, as in this country, mechanical processes involving bending, etc., precede anodic treatment. In the section dealing with elasticity it is said, in contradiction to an earlier statement, that visible crazing of the film occurs earlier on thick films than on thin films.

(j) The authors draw attention to the accumulation of aluminium sulphate during the operation of sulphuric acid anodizing baths, and the figures of permissible concentration of aluminium are similar to those specified in this country, but it has been found that the life of a sulphuric acid anodizing plant can be prolonged by operating at such a voltage that the current density obtained in a fresh bath is maintained. This involves operating at, say, 14-15 volts instead of 12-13 volts when the bath is nearing the end of its useful life. Determinations have been made of the increase in weight of pure aluminium anodes together with a note of the coat thickness and loss of metal section, and it would appear that providing the same current density is employed both in the old and new baths all the other properties of the film

remain similar within the limits of commercial requirements. A stage is reached when the amount of aluminium sulphate is such that crystallization tends to occur when the bath cools overnight and at this stage it is more economical to dispose of the bath than to attempt filtration.

(k) The protection property test is

definitely a rough-and-ready method, but it is quicker in operation than separate tests for porosity and film thickness. The test assumes that porosity and film thickness are of approximately equal importance whereas it might be held that porosity is the more objectionable factor as its presence is detrimental even in thick films.—V.F.H.

MAGNESIUM IN POST-WAR U.S.A.

THE United States Department of Labour (Bureau of Labor Statistics) has recently issued, under the title "Impact of the War on Clark County, Nevada (the Las Vegas magnesium area)," a further addition to its series of working notebooks for use by local groups studying current economic developments assisting in the formulation of plans for the post-war period.

The scope and purpose of this report is best summed up in the words of the first paragraph of the introduction: "This study is one of a series of industrial area reports which the Bureau of Labor Statistics is preparing as a service to local civic, labor and business groups and as a means of developing a panoramic background of local conditions against which proposed Federal policies for the post-war period can be more realistically appraised." The introduction goes on to say that: "The series will cover as many as possible of the 300 main industrial centres of the nation which even before the war contained three-fifths of our total population and four-fifths of our factory workers and miners. In general these are the communities which have been most changed and expanded by the war and which will later face the most serious problem of reconversion, re-employment and industrial adjustments. The job of developing a sound program for demobilization and sustained business activity after the war is big and difficult. It will require the best efforts of many groups and individuals. Moreover, no one knows how soon we may be confronted with the need for immediate action."

Although referring purely to local situations in the United States, the manner of approach adopted in this report is worthy of serious consideration by interested parties in this country, where, as in U.S.A., "Disagreements on important economic problems continue to exist, as is to be expected in a democracy."

The hope is expressed that in the U.S.A. "there is a substantial and growing recognition on the part of all major groups that American economy after the war must be made to operate on a high level of production, income and employment"—this outlook we hope is echoed in Great Britain.

The contents page of the report illustrates how thoroughly the position has been surveyed. Under six headings the following points are dealt with:—

1. Labour force, employment and developments in industry.
2. Natural resources, transportation, public utilities, climate.
3. Total population, urban and rural population, race and nativity, age distribution.

4. Local government, education, health facilities, housing, income tax.
5. Expansion of war plant facilities, war production, employment, labour supply, current construction of civil plants.
6. Post-war outlook for magnesium, other industries, public works.

The section dealing with the post-war outlook for magnesium deals, rather naturally, principally with estimates of post-war trends based on established pre-war data. In 1939 65 per cent. of magnesium consumed in U.S.A. went into fabricated parts, primarily sand and die-castings, extrusions and rolled sheet. Of this item of production 80 per cent. went into aircraft, mostly into engines, the balance being consumed in air-frames and wheels; the remainder was largely consumed in the manufacture of automobiles and 30 per cent. of magnesium metal output was consumed as an alloying addition for aluminium and other alloys, mainly zinc. Five per cent. of the magnesium output was employed as a scavenging or deoxidizing agent, pyrotechnic compositions, tracer bullet chemicals and other products. Speaking of post-war prospects of the metal the report goes on: "Its potential uses are numerous. European automobiles have always contained much more magnesium than those manufactured in America. Germany and Japan, lacking other metals, are probably effectively using magnesium alloys as substitutes. Report tells of German use of magnesium in telephone switch parts and busbars, blanks for process engraving and instruments, portable high-speed tools and equipment.

"However, prospects for magnesium in the immediate post-war period rest chiefly with the aircraft industry. No other industry can furnish a demand immediately after the war large enough to absorb the enormously expanded production capacity. Use of magnesium is increasing within the airplane industry. Magnesium alloy sheet was produced for the first time in 1939 for use in the interior of airplanes for walls, seats, berth members and partitions, doors and other secondary structures.

"The eventual demand for magnesium is not the only factor to be taken into account. For when the present demand for magnesium in military aircraft production comes to an end, some time will elapse before civilian requirements mount to that high level. During that waiting period the demand for magnesium must inevitably slacken and employment decline. This possibility might be countered if an energetic and optimistic management produced for stock in the expectation of civilian markets and in the hope of being first in those markets."

U.S.A. Aluminium Production

THE American Chemical Society's "News-Letter" for December 10, 1943, published an interesting article by Francis C. Frary of the Aluminum Co. of America, entitled "Aluminum in War." The report is largely on the aspect of production of America's wartime demands for light metal.

Considerable work has been done on the utilization of low-grade native bauxites and clays, work which was initiated before World War I and intensified during the past six years. According to Frary, it is, however, only under exceptional circumstances that low-grade ores can compete with high-purity bauxites.

Voice of the Factory

ISSUED by the Austin Motor Co., Ltd., is a manual entitled the "Voice of the Factory."

Summarizing the aims of and lessons learned from an exhibition entitled "Tell the War Worker," which was organized by the Austin Motor Co., Ltd., in collaboration with other leading firms in the Birmingham area, this publication, which is available at 2s. 6d. (postage 4d.), is excellently printed and well illustrated. Defined on the title page as "A Manual of Works Relations," it is by J. F. Bramley, Safety and Welfare Superintendent to the Austin Motor Co., Ltd.

The Missing Technician

UNDER the title "The Missing Technician in Industrial Production," John Gloag has presented us with a most refreshing booklet.

Within the scope of 100 pages, the author sets out to prove that good industrial design pays hand over fist. It might be said that the moral of the work lies in its common-sense attitude in relationship to the services which industry must render to those it serves. Naturally enough, the role of aluminium and plastics in the future progress of industrial design is indicated.

Metallic Hearths for Furnaces

WE have received from the Incandescent Heat Co. a pamphlet entitled "Distortion-free Metallic Hearths." In design, these hearths consist of an assembly of specially designed small tiles and are applicable for heat treatment, carburizing and annealing furnaces up to temperatures of about 1,000 degrees C.

Midland Post-war Production

ON Friday, May 12, at the Abbey Hotel, Kenilworth, some 50 Midland manufacturers, directors and members of their administrative and technical staffs gathered at the invitation of Mr. Louis E. Dickens, of the Louis Dickens Co., the Coventry Engineering Sales Agents, to review the possibilities and problems of post-war industry in general, and in particular as regards new developments relating to moulded plastics, non-ferrous castings, piston rings and precision springs.

These subjects were covered in an informative manner by Mr. K. R. Dodd, sales manager of United Ebonite and Lorival, Ltd. (Plastics), Mr. G. W. Littlewood, general manager of the

Sandwell Casting Co., Mr. R. H. Hainsworth, technical manager of the Aero Piston Ring Co., Ltd., and Mr. F. C. A. Skelding, director of Skeldings, Ltd. (Springs). A useful discussion took place and many questions were raised by the large company present, which included Messrs. A. G. Booth, L. Cowland, G. Chadwick, W. A. Dobson, J. Heritage-Peters, J. E. Johnson, T. L. Jump, E. W. Martin, K. J. Palmer, H. J. Satchwell, Geoffrey H. Savage, and numerous other gentlemen well known in Coventry engineering circles.

Future industrial developments in Coventry and district were also discussed, following speeches by Mr. Harry Weston (Modern Machine Tools, Ltd.), Mr. J. Heritage-Peters (Advertising and Sales Consultant) and Mr. James Taylor (City Development Officer).

Patent-Office Metallurgy

THOSE who sponsor the need for a revision of our patent law will, we believe, find ample support for their claims in B.P. 560410. With the soundness of the invention we do not quarrel; the phraseology, however, borders on the fantastic.

Society of Instrument Technology

THE Society of Instrument Technology has been formed for those interested in the design, manufacture, use and maintenance of scientific instruments. Its objects are:—

(a) The advancement of instrument technology by the dissemination and co-ordination of information relating to the design, application and maintenance of instruments. (b) The provision of opportunities for discussion, particularly between the designers and manufacturers on the one side, and the users on the other. (c) The provision of opportunities for discussion and collaboration between the society and other associations. (d) The encouragement of technical education for persons who wish to enter, or are already in, the industry dealing with instrument research, design, manufacture or use. (e) The encouragement of research into problems relating to instrument technology. (f) To encourage the standardization of instruments and accessories by collaboration between manufacturers and users. (g) The determination of a commonly acceptable terminology. (h) Enhancing the status and prestige of those employed in the industry.

Members of council and officers are:—President, Sir G. P. Thomson, M.A., F.R.S.; members of council, Dr. W. J. Clark, Mr. G. H. Farrington, Dr. W. F. Higgins, Mr. W. B. Wright, Mr. C. R. Sams, Mr. E. B. Moss, Mr. R. E. Iggledon, Mr. F. C. Knowles, Mr. D. A. Oliver, Dr. H. S. Gregory, Dr. E. Griffiths, Prof. F. Debenham; hon. treasurer, Dr. H. B. Cronshaw; hon. secretary, Mr. L. B. Lambert.

Those interested are invited to send their name and address to the Hon. Secretary, 55, Tudor Gardens, London, W.3, who will forward details of membership and an application form.

It is intended to call a general meeting, probably in the early autumn, at which the constitution and rules, as recommended by the council, will be submitted for the formal approval of intending members.

Radiography of LIGHT-ALLOY CASTINGS

Based on a Paper Read Before a Joint Meeting of the Manchester and District Branch and the Industrial Radiology Group of the Institute of Physics, on May 20, 1944, in the University of Manchester. The Author Discusses Some Applications of Filters and Intensifying Screens

By
C. T. SNUSHALL

THE application of intensifying screens to the radiography of light alloys is not generally appreciated, and although filtration is, to a large degree, becoming more widely used, it seems that these two subjects are, as yet, far from being fully understood. It is for this reason that these particular items have been chosen to be the subject of a paper in the hope that by doing so some information might be gained from the experiments that have been carried out.

Unfortunately the experiments conducted were all done with alloys of which aluminium was the main constituent, but there is every reason to believe that similar results would be obtained had magnesium alloys been available.

It should be mentioned that these experiments were initiated with a particular purpose in view—that of increasing the output of radiography of castings from equipment that was becoming more and more difficult to obtain. Owing to the fact that large castings of a relatively thick cross-section were emanating from the foundry to which the author's laboratory is attached, it was found that exposure times were increasing to such a degree that if any large quantity of castings of a heavy section were to be produced, insufficient plant would be available for the radiography of the foundry's output. It was therefore decided to find some method of reducing this time factor. Numerous minor experiments were carried out and it was ascertained that it was possible to obtain satisfactory radiographs with intensifying screens, together with somewhat enhanced defect detection in the thicker sections in particular. By thicker sections a section of 3 ins. or more is indicated, and although intensifying screen technique applied to the radiography of light alloys is generally abhorred by radiologists, it was not found to interfere with the definition or resolution of defects in sections over and above 1 in. in thickness.

Having realized a possible radiographic technique by which sections of a light alloy up to 6 ins. thick could be rendered interpretable by exposures of 25 secs. or less, with a tube-film distance of 6 ft., it was decided to delve into

the matter more deeply to obtain as much data as possible with relation to the various combinations of intensifying screens, films, filters, kilovoltages and thicknesses.

For this purpose two step blocks were obtained varying in thickness from $\frac{1}{4}$ in. to 6 ins., together with various types of film, both for direct and screen radiography; and the following experiments were carried out with an X-ray set which has a maximum output of rays generated at 220 kilovolts. Although there are a number of different types of intensifying screens on the market, high definition screens were accepted as being the best suited for the job in question, being fine grained with a fairly high intensifying factor and, above all, durable so that they could be used in production, when wear and tear is considerable.

Film Characteristics

The first experiment was made to compare specific combinations of film and screens with results obtained when film only had been used, to produce a characteristic curve for each combination, thereby finding their relative effectiveness to X-rays generated at a number of different kilovoltages. Exposures were made with three different types of film, two of which were of the type for use with intensifying screens ("A" and "B" for the purpose of this paper), and the third being of the non-screen type ("C"). Each of these three films was exposed at 75, 100, 125, 150, 175 and 200 kv., both with and without high-definition intensifying screens. The exposures were such that when plotted on a logarithmic scale they would be the equivalent of equal increments along the horizontal axis of the characteristic curves, covering the regions of under- and over-exposure of the film. In this way it was only necessary to give about 15 exposures for each film to obtain as nearly as possible the characteristic curve of the material.

These exposures were then given normal development and the photographic density for each different exposure found by comparison with a standard strip of film calibrated beforehand. The densities were then plotted against

log exposure to obtain the characteristic curve in the usual way. A single set of curves is shown in Fig. 1 for each of the voltages stated above.

It will be seen from these curves that the higher the voltage applied the further to the left the curves are placed, within the range being investigated at any rate. It will also be noticed that the displacement of any one curve, due to the film being used in conjunction with screens, is not the same for each voltage.

Intensifying Factor

From these graphs the effectiveness of the intensifying screens, or the intensifying factor, can be found for any of the three combinations by measuring the horizontal distance between the two curves in question and taking the antilog of that distance as measured by the scale along the horizontal axis of the diagrams. These factors will be found to vary slightly according to the density for which the readings are taken and tend to increase as the density increases. This is another way of stating that if a film is used in conjunction with intensifying screens the resultant contrast or "gamma" is increased as well as the relative speed. This, however, is only a general statement, for the gamma in either case is a function of the nature of the photographic emulsion. In order, therefore, to find the voltage at which the intensifying screens give their maximum intensity it was decided to plot the intensifying factor against the kilovoltage for four different densities. These four graphs are shown in Fig. 2, giving without doubt the maximum efficiency in the region of 160 kv. As this agrees in the case of each of the three films used, the result is assumed to be correct for the type of screens being used.

It will be seen that for film "A" the factor varies from 17 at 75 kv. up to 40 just above 150 kv., and then falls to 30 at 200 kv. For film "B" the figures are relatively in the same proportions, the film being apparently less sensitive to the fluorescent light of the intensifying screens than film "A."

Film "C" being a non-screen film, shows considerably less reaction to the fluorescent light, but nevertheless when used with screens it forms a combination that is about three times as fast as the same film when used without screens at 160 kv. and at a density of 1.0.

Scatter from Object

It is known that when a beam of X-rays impinges upon an object of any material a certain amount of rays penetrates that body, a proportion is absorbed, and from that body certain secondary radiations are set up. This secondary radiation is always made up of at least three different types of rays: characteristic X-rays, being of a wavelength typical of the material of the body being irradiated; unmodified scattered radiations of the same wavelengths as the primary beam; and modified scattered rays of wavelengths longer than the original beam. This latter type of secondary radiation was investigated by Compton, and the wavelengths of these rays have been found to vary according to the angle between the scattered ray and the primary beam. It should be pointed out that the Compton Effect, as it is known, is independent of the atomic

number of both the target and the scattering element.

The ratio of the intensities of the modified and unmodified rays in the Compton Effect, however, varies with the atomic number of the scattering element, and in the case of the alloy dealt with in these experiments appears to be in the region of 2-1.

From this information the following facts can be obtained: that in the region in the direct path of the primary beam the modified rays are at their longest wavelengths, and that in this region the scattered rays are made up of about two-thirds modified and one-third unmodified rays. The wavelength variation in any other region need not be considered, for in all cases of examination of bodies for internal cavities or incongruities the photographic film or plate is placed directly below the object being radiographed.

Having ascertained the make-up of the scattered radiation the problem of eliminating them can be attacked. Methods of doing this are many and various, but there seems no method yet known which entirely eradicates these unwanted radiations.

Reduction of Scatter

We will consider some of the methods which are possible to reduce the effect of these scattered rays. First and foremost is the filtration method by which the secondary rays can be reduced in intensity, thereby affecting the photographic emulsion to a lesser degree. The question immediately arises as to which of the metals or combination of metals gives the maximum effect without making existing radiographic conditions impracticable. Unfortunately very few types of filtering materials were available to the author, but of those tested copper sheet appears to give as satisfactory a result as any. The position of filters is also of importance. Different people have different opinions in this respect and therefore there does not seem to be any real reason why a filter should be placed on the tube, or between the specimen and film. There are, however, certain points which are of importance when consideration is being given to the position of a filter for use as a partial eliminator of scattered radiation.

In favour of the use of a filter on or near the tube are the following points:—

1. That the addition of a filter in this position reduces at source the intensities of the longer wavelength rays, which give rise to a fair proportion of scattered rays.

2. That the introduction of a sheet metal filter between the object being radiographed and the film must of necessity increase the object-film distance which, if maximum sensitivity of fault detection is to be obtained must be kept down to a minimum.

3. A filter placed between the object and the film must be free from all incongruities and must be of uniform cross-section to give satisfactory results. This unfortunately is not always possible unless extreme care is exercised, which is unlikely when mass-production methods have to be operated with relatively unskilled labour, as is more often the case than not to-day.

In opposition to these must be borne in mind the fact that whatever filtration is placed

between the target and the object, scattered rays emanate from the object which, if not curtailed, may prove injurious to the resultant radiograph.

In favour of the filter placed between the film and the specimen is the point that it is the scattered radiation from the body which is the

chief concern, and although this can be reduced by partially eliminating the softer rays, which give rise to a large proportion of this scatter, by means of a filter placed on the tube, there still arises a certain amount of scatter from the specimen which has to be made ineffective. These unwanted rays can be reduced by the

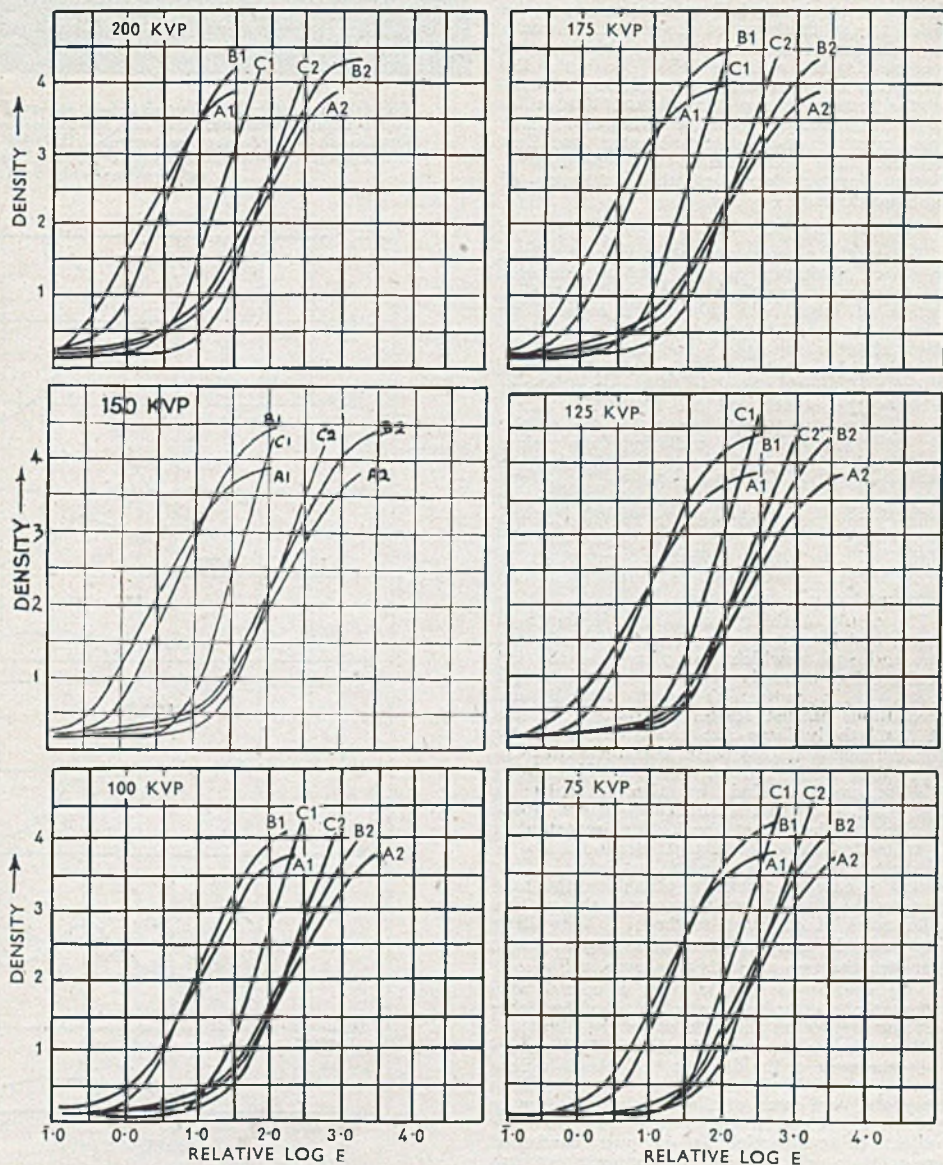


Fig. 1.—Characteristic curves showing relative effectiveness to X-rays generated at 200 kVp, 175 kVp, 150 kVp, 125 kVp, 100 kVp and 75 kVp respectively, of specific combinations of film and screen. It should be observed, inter alia, that, in the six sets of curves reproduced above, displacement of any one curve due to the film being used in conjunction with screens is not the same for each voltage.

introduction of a suitable filtering medium between the specimen and the film.

Against the use of filters in any position there is the important fact that any increase in thickness, whether of filter or object, leads to a reduction in the sensitivity, if scatter is neglected, as this, the sensitivity, is a function of relative thicknesses of defect and body, and when a filter is in use its equivalent thickness must be added to the thickness of the object to obtain the effective thickness of the object being penetrated. As well as this, due to the absorption of a proportion of the longer wavelengths forming the primary beam, less radiographic contrast is obtainable owing to the fact that rays of shorter wavelengths are less absorbed than those longer wavelength rays, thereby further decreasing the sensitivity of fault detection.

A Practical Test for Scatter

To test the amount of scatter radiating from an object of aluminium alloy of 6-in. thickness the following comparisons were made. A 6-in. section of metal was taken and exposed to X-rays, generated at 160 kv. with a small lead block about 1 in. square and one-sixth of an inch in thickness placed on the tube side of the object and another similar lead square placed between the object and the film. The difference in density of these squares is due to the fact that scattered rays radiating from points to the side of the lead square are affecting the photographic emulsion immediately below the lead square on top of the object, whereas all primary rays are absorbed. In the case of the lead square placed between the object and the film, all radiation, whether primary or secondary, is absorbed, which shows an almost unexposed area of emulsion.

The result of this practical test is shown in Fig. 3 and is rather astounding. It shows that the lead square which was placed on the top of the object is barely visible. Now this means that with a radiograph taken without any precautions against scattered radiation, defects of a relatively large size could be missed by the radiologist if they were near the surface of the object farthest from the film. This shows how serious the whole question of scatter is and that, particularly in cases where thick sections are being examined, how important it is to control these secondary radiations.

Similar tests were carried out with copper filters of 0.04 in. thickness placed on the tube and on the film in turn to compare the relative efficiencies of the two methods. Very little difference in amount of scatter was apparent between the two methods as shown in Fig. 4.

One thing was certain, that a considerable amount of scatter had been eliminated by either placing a filter on the tube or on the film.

According to theory it should be of advantage to place some of the filter on the tube to reduce the intensities of the softer rays emanating from the tube, and some of the filter on the film to reduce the actual scattered radiations from the object being examined. This was confirmed by test, in which 0.020 in. copper sheet was placed on the tube and 0.020 in. copper on the film. Comparisons as shown in Fig. 5 with either of the radiographs taken with the 0.040-in. filter show that the divided filter, as

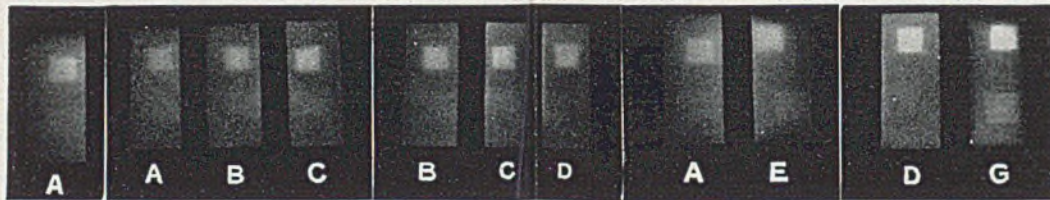


Fig. 3 (extreme left).—A, radiograph of 6-in. section of aluminium, 160 kv, no filtration. Fig. 4 and Fig. 5 (second and third groups of reproductions reading from left to right).—Taken at 160 kv as for Fig. 3, but under following conditions: A, no filtration; B, 0.04-in. copper sheet on tube; C, 0.04-in. copper sheet on film; D, 0.020-in. copper on tube and film. Fig. 6 (fourth group reading from left to right).—A, as in Figs. 3 and 4; E, with intensifying screens but no filters. Fig. 7 (extreme right).—D, as in Fig. 5; C, with intensifying screens and divided filter.*

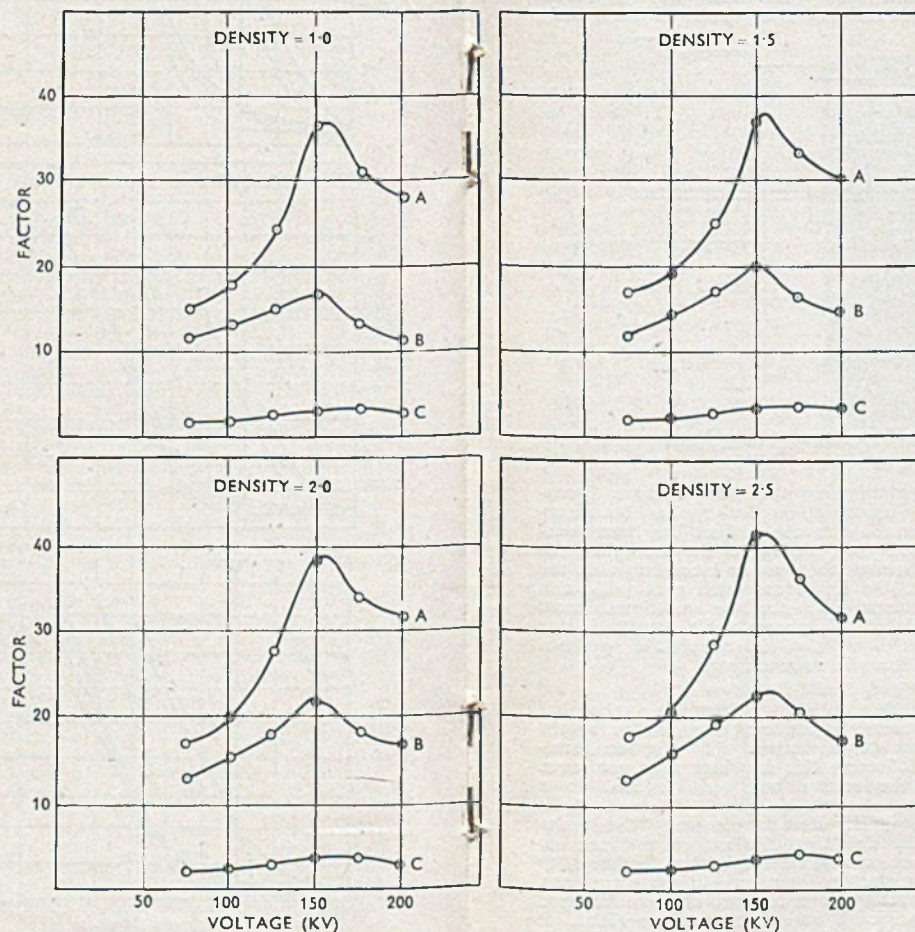


Fig. 2.—Curves derived by plotting intensifying factor against kilovoltage for four different densities. Maximum efficiency occurs in the region of 160 kv.

shown by "D," is slightly better for reducing the effect of scattered radiation.

In order to confirm the decision that the filter should be placed between the film and the object, rather than on the tube, an experiment was carried out with an ionization chamber calibrated directly in Röntgen units per minute. First a reading was taken with no filtration whatever, and then a filter of copper sheet of 0.040 in. thickness was placed on the tube and on the film in turn. A 5-in.-thick block of aluminium alloy was present as the specimen in each of the three cases.

The following readings were obtained:—

No filtration	0.21 "r" per min.
0.040-in. copper on tube	0.16 "r" per min.
0.040-in. copper under specimen	0.115 "r" per min.

This shows that although no increase in thickness of the effective specimen has occurred, the order in which the different metals are penetrated makes a considerable difference, being mostly due to the absorption of rays scattered by the specimen itself. This confirms the radiographic images produced, which are reproduced in Figs. 3, 4 and 5.

So far we have seen that some scatter, but not anything like all, may be eliminated by the use of filters.

Grids

Another method of eliminating scatter, or rather reducing scattered radiation during radiographic exposures, is by the use of a grid, of a design such as that marketed under the name of Potter-bucky. There is no doubt that the introduction of a grid of this description removes a large amount of scattered rays which do not travel in planes parallel to those of the grid itself and therefore the resultant radiographs will be improved considerably.

The main objections to the use of a grid are the fact that the object must be raised from the film to allow the grid to pass between, and also the fact that difficulties of handling are increased.

A fourth method of reducing the effect of scatter, which has been used successfully in the author's laboratory, is embodying the use of intensifying screens. As has been seen from experiments carried out with intensifying screens detailed earlier in this paper, the screens which were used were far more sensitive to X-rays generated at 160 kv. than to any other rays. This indicates that they are relatively insensitive to rays of long wavelength.

We have seen from an analysis of the scattered radiations that the majority of the rays are of a wavelength considerably longer than the effective wavelength of rays generated at 160 kv., and therefore it is reasonable to suppose that it is possible to reduce the scattered radiation, or rather the effect of the scattered radiation, by the straightforward use of intensifying screens. This assumption has been confirmed by test, similar to those carried out with filters, with the small lead blocks. The result is shown in Fig. 6.

The Effect of Intensifying Screens

The action of the intensifying screens is to intensify the effect of the primary rays of short

* A considerable amount of definition has been lost in the reproduction of these and subsequent radiographs.

wavelength to a much greater extent than the effect of those scattered rays of very much longer wavelengths. This results in the production of a density on the radiograph due to the primary rays, in a shorter time than would have been the case if screens had not been used, whereas the effect of the scattered radiations is reduced owing to the shorter time of exposure, and the relative insensitivity of the intensifying screens to radiations of long wavelengths.

Here then are four methods of reducing the effect of secondary radiation:—

1. The use of a filter on the tube.
2. The use of a filter on the film.
3. The use of a grid.
4. The use of intensifying screens.

None of these four methods interferes with each other and therefore all can be incorporated in one technique, giving possibly the maximum protection for the photographic emulsion against scattered radiation.

This combination was tried, and results showed that when all four methods were com-

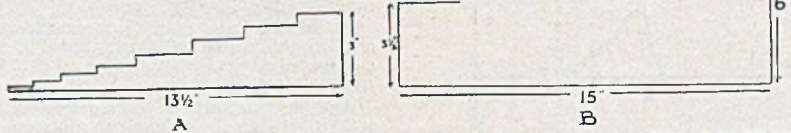
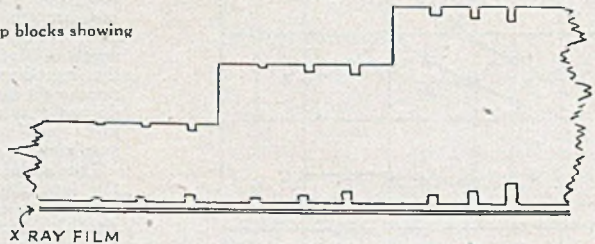


Fig. 8 (above).—Diagrams of step blocks showing measurements.

Fig. 9 (right).—Sectional diagram of part of block showing machining.



bined there was no visible difference with regard to definition of the lead square from the method when the grid was not used. This showed that very little photographic density was due to scatter on the radiograph that was taken with the divided filter, together with intensifying screens.

It was therefore decided that the introduction of the grid was an unnecessary addition, and a very cumbersome one at that, to the radiographic technique, and it was accepted that the best method was a combination of the filtration on the tube and on the film and the film itself placed between intensifying screens.

The result of this can be seen in Fig. 7, where "D" was taken as before with the divided filter and "G" under the same conditions, except for the fact that the film was placed between intensifying screens.

Under these conditions, then, we have a well-defined lead square showing that at any rate much of the scatter has been made ineffective. A method has therefore been established, combining three independent methods of producing a radiograph with as little fogging due to scatter as has been obtained. Now there are objections, in certain cases, to the use of intensifying screens in light-alloy radiography.

These are that the grain-size of the screen, which governs the quality of the radiographic image, is relatively large in comparison with the dimensions of the defects being sought, and also that as exposures for light alloys are short at any rate a reduction in exposure time is usually unnecessary as far as practical working ability is concerned, and the incorporation of an intensifying screen technique tends to make exposures too short to be made with accuracy unless counter-measures are applied.

Now it is not suggested that the method, as detailed, be used for thin sections of aluminium alloy, but it has been found that for thicknesses over and above 1 in. no interference is produced due to grain-size and with thicker sections of 3 ins. or more better sensitivity is obtained when screens are used.

From the experiments it has been found that, as is illustrated by the radiographic reproductions the radiologist is liable to be grossly

mised by thinking that just because a considerable photographic density has been produced on the film the subject has been penetrated and that, owing to the fact that the density is even, there are no incongruities in the specimen. As has been stated previously, this may be far from the truth as sometimes almost the whole of this photographic density is due to scattered radiation either from the specimen itself or from its surroundings.

Sensitivity of Fault Detection

So far, then, a fairly satisfactory method has been obtained of reducing the density of the radiograph due to scatter. The question immediately following this is whether or not, even though the scatter has been reduced to a minimum, a reasonable degree of sensitivity is being obtained. Most people accept the resolution of a defect, equivalent in thickness to 2 per cent. of the total specimen thickness, to be a satisfactory standard to maintain, and although this figure can probably be dropped to 0.5 per cent. under abnormal conditions it has been shown that unless a very strict watch is kept on the radiographic techniques employed, it is possible, and in fact quite probable, that the resolution of defects is more in the region of 5 to 6 per cent. in many

instances where large castings are being examined.

The degree of sensitivity of fault detection is dependent on at least eight factors:—

1. The effective target area of the tube.
2. The kilovoltage applied to the tube.
3. The object-tube distance.
4. The object-film distance.
5. The nature of the film being used.
6. The amount of filtration.

and, if relatively thin sections are being examined:—

7. Grain-size of the film.
8. Grain-size of the intensifying screens, if used.

Dealing with these factors independently, it is known that the effective target area of the tube is constant for any one X-ray generator and therefore can be neglected in this discussion. The kilovoltage applied across the tube, however, is most important, as the higher

the voltage applied the less radiographic contrast is obtained, hence causing considerable reduction in sensitivity, as this latter is directly reliant upon the interpreter being able to discern different densities on the film. A good general rule seems to be: "That the minimum voltage required for penetration of the thickest areas of the specimen should be used if maximum sensitivity is to be obtained."

As for the object-tube distance, this should be as great as is consistent with practicable exposure times, for it is obvious that if the target is of finite size, the nearer the object is to the tube the greater will be the penumbra effect on the radiograph, giving an unsharp appearance. Similarly, for simple geometric reasons, the object-film distance should be made as small as possible, for if this is not the case the same effects as would be obtained with a short object-tube distance would be experienced.

By nature of the film employed, the contrast or "gamma" and the latitude are indicated; for it is essential that all sections of the radiograph, in order to be interpretable, must be within the normal exposure range of the film.

As has been mentioned before, one of the disadvantages of the use of filters of any description is the effect they have on the radiographic contrast. This effect can be split into two independent items: First, filters have the effect of cutting down the intensities of the softer rays more so than the hard rays—but although rays of short wavelength do most of the work of image formation the longer wavelength rays, if they penetrate the specimen, as some are bound to do, also do a certain amount of work towards making the image, thereby having the effect of making the image more contrasty than would have been the case had

filtration been imposed. Secondly, filters, wherever they may be placed, relative to the object and the tube, are the equivalent of making the object itself of greater thickness, thus decreasing the ratio between defect size and specimen thickness. This is probably illustrated best by a numerical example:—

We will say, for instance, that an object of aluminium alloy of 2-in. thickness is being examined. Assuming the sensitivity to be 2 per cent., a defect of 0.040-in. diameter will be detected. If, now, a filter of 0.040-in. copper sheet is placed between the object and the film, it is obvious that the effective thickness is increased. By how much it is increased can be estimated as follows:—Let us assume that the specimen was being radiographed with rays generated at 120 kV. It has been found by experiment that the effective wavelength of this beam is about 0.16 Å, and so the absorption coefficients can be obtained from tables for both copper and aluminium. This was done and the mass absorption coefficients at this wavelength were 0.94 and 0.215 for copper and aluminium respectively.

As the intensity varies according to the formula

$$I = I_0 e^{-ux}$$

where

I = Intensity after x passing through thickness x .

I_0 = Intensity at same spot had there been no specimen.

u = Linear absorption coefficient.

We see, therefore, that any change in effective thickness will be proportional to the relative values of the linear

absorption coefficients of the two materials. Now the linear absorption coefficient is the product of the Mass Absorption coefficient and the density p of the material.

The linear values of the coefficients then become 0.94×8.95 for copper and 0.215×2.8 for the aluminium alloy, or 8.4 and 0.6 respectively.

The effective thickness of the specimen then becomes:—

$$2 + 0.04 \times \frac{\text{Linear absorption coefficient of copper}}{\text{Linear absorption coefficient of aluminium}} \text{ ins.}$$

$$\text{or } 2 + 0.040 \times \frac{8.4}{0.6} \text{ ins.}$$

$$\text{or } 2.56 \text{ ins.}$$

Now 2 per cent. of 2.56 is 0.0512 in. and this expressed as a percentage of the actual thickness of 2 ins. is 2.56 per cent.

This means that with the introduction of a 0.04-in. copper filter the sensitivity drops to just over $2\frac{1}{2}$ per cent. as against 2 per cent. without the filter. This calculation naturally neglects the gain in sensitivity due to elimination of scatter.

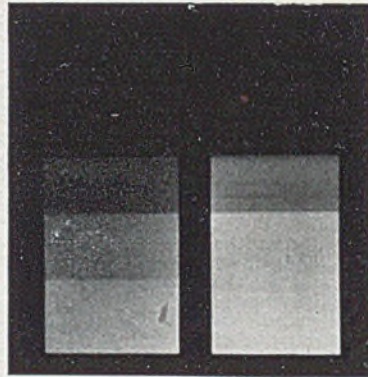


Fig. 10.—Reproduction of radiographs of step block. Left, high kV; right, low kV. Machined slots are fairly easily visible on the reproduction of the radiograph taken at low kV.

The last two factors upon which the degree of sensitivity depends are the grain-size of either the film or the intensifying screens if they are used. These two items only enter into the problem when the defect or incongruity to be resolved is of the same dimensional order as the grain-size. This only occurs when specimens of a thin cross-section are being examined.

To test the efficiency of the suggested radiographic technique in practice two step blocks of the same alloy were taken. They had machined surfaces and were such that one block covered the range $\frac{1}{8}$ in. to 3 ins. by steps of $\frac{1}{8}$ in. up to 1 in., and $\frac{1}{8}$ -in. steps up to 3 ins. The second block was machined in steps of $\frac{1}{8}$ in. from $3\frac{1}{8}$ ins. to 6 ins., thus giving a comprehensive range of thickness from which to carry out any test. In order to find approximately the sensitivity that was being obtained, slots were milled, on top and underneath, each step representing thicknesses of 2 per cent., 1 per cent. and $\frac{1}{2}$ per cent. of the thickness of the step in which they were cut.

These step blocks are shown in diagrammatic form in Figs. 8 and 9.

Slots were milled on each side of the step block so that those cut from the flat side of the block, i.e., those which would be almost in contact with the film, would give the greatest definition, and therefore the greatest sensitivity, and those from the top side would be in the worst position possible to obtain resolution.

In this way both the best and the worst possibilities of sensitivity were found.

Comparisons were again made between the various radiographic techniques, and these radiographs repeat the confirmation that the intensifying screen method gives the best results when thicker sections are being examined. Of course a milled slot is hardly representative of all defects, for it is very unlikely that a defect will have clearly defined edges, such as a slot. Defects such as blowholes are usually roughly spherical and therefore the density on the radiograph due to this type of defect usually blends into the general density and is not a direct change from one to another as is the case with the slot. However, as the $\frac{1}{2}$ per cent. slots showed on all steps it is considered fairly certain that any defect of the order of 2 per cent. of the total thickness would be resolvable.

In order to stress the importance of keeping the voltage as low as possible, further radiographs were taken at low and high voltages to compare the variation in sensitivity. These radiographs, reproduced in Fig. 10, confirm without doubt that as low a voltage as possible for penetration should be used.

During this paper it has been assumed that specimens of relatively even thicknesses are being radiographed. This is frequently not the case, and so many of the suggested practices have to be modified to suit individual instances. It should be remembered that all the previous radiographs were taken to produce the greatest sensitivity in any particular area and thickness, and where two, considerably different thicknesses are being examined in one radiograph several difficulties may be experienced.

General Radiographic Conditions

These difficulties are brought about because conditions which are well suited to one par-

ticular thickness may not be at all suitable for another area of the specimen. Say, for example, that a casting of aluminium is being examined which is made up of one section of $\frac{1}{2}$ in. in thickness and another of 2 ins. It is obvious that if the minimum voltage required to penetrate the $\frac{1}{2}$ -in. section is applied, the 2-in. section will not be penetrated. Conversely it is true that if the best voltage for the 2-in. section is used the $\frac{1}{2}$ -in. section will appear completely blacked out on the radiograph. It is therefore necessary to take two independent radiographs or to modify the technique to reduce the contrast of the radiograph. Naturally the first of these alternatives will give the most satisfactory results as far as sensitivity is concerned, but there will be very few laboratories to-day which can afford to take two or three, or even more radiographs to each casting being examined, for more often than not they are of uneven cross-section. Therefore steps are frequently taken to modify the technique. As this always means a method whereby a reduction in contrast is obtained, the same degree of sensitivity cannot be expected that is recorded with even sections. It is therefore necessary to find the happy medium between the two conflicting conditions.

There are several methods of reducing the contrast on the radiograph and it must be left to those actually dealing with particular specimens to find for themselves the most suitable method of doing this.

The contrast may be reduced by one or a combination of the following methods:—

1. An increase in the kilovoltage applied across the tube.
2. The addition of a suitable filter either on the tube or film.
3. The building up of the thinner sections of the specimen with a dense material, in suitable proportions to produce an even density on the radiograph.
4. The choice of a less contrasty film.
5. The use of a single-coated film or the stripping of one coating off a double-coated film, or if screens are being used the use of one screen only—preferably the back one.
6. The modification of the developing solution, either by actual formula or concentration.
7. The making of a double exposure on one film by masking off, with thick sheet lead, the thinner sections of the specimen for periods necessary to equalize the final densities.

This last method is only applicable where specimens have variations in thickness, such as lugs, which can be covered with lead sheet without interference with the remainder of the specimen. As this method is in fact equivalent to making two exposures on separate films, it is suggested that it should be employed whenever possible, to obtain maximum sensitivity.

Acknowledgment.—In ending this paper the author wishes to express his gratitude to the Northern Aluminium Co. Ltd., for allowing the use of their apparatus, the Victor X-Ray Corporation for making the tests with the grid and the ionization chamber possible, and also to Messrs. Kodak, Ltd., for their help in calibrating the original density strip, also to Mr. A. B. Capes, without whose untiring efforts the experiments might never have been completed.

Precipitation from Supersaturated Solid Solutions

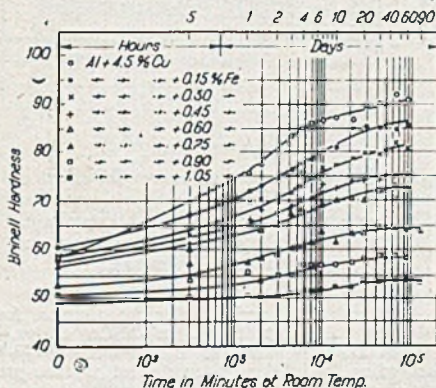


Fig. 41 (above).—Hardness-time curves for alloys of aluminium and copper from 4.5 per cent. to 10 per cent., quenched in boiling water and aged at room temperature.¹⁴⁷

Fig. 42 (right).—Hardness-time curves for alloys of aluminium containing 4.5 per cent. of copper with iron contents from 0.15 per cent. to 1.05 per cent., quenched in boiling water and aged at room temperature.¹⁴⁷

By

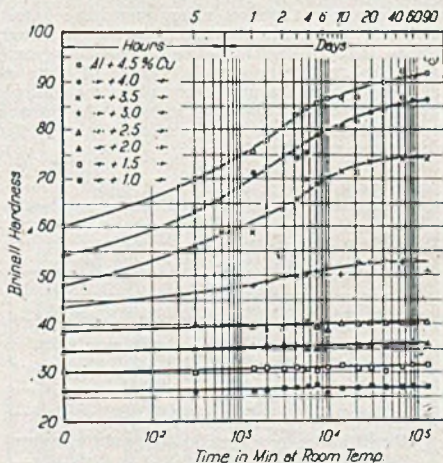
H. K. HARDY, M.Sc., A.R.S.M.

(Research and Development Dept.,
Northern Aluminium Co., Ltd.)

RATE OF PRECIPITATION AND EFFECT OF VARIOUS FACTORS ON THIS RATE AND ON THE MAGNITUDE OF PROPERTY CHANGES

The Rate of Precipitation. The rate of precipitation depends on the rate of formation of nuclei and on the rate of growth of these nuclei. No formal analyses have been made of these factors in agehardening alloys, although a start may be said to have been made by Johnson and Mehl¹⁴⁴ by mathematical analysis of the isothermal decomposition of austenite into pearlite. The determination of an exact quantitative method of evaluating the rate of precipitation is difficult owing to the complexities of the process; for instance, several different types of precipitation may be recognized. Most of the experiments that have been made are qualitative only, since it is necessary to measure the change in some property that bears

This Survey, which Refers Particularly to the Age-hardening of Aluminium Alloys, is Concluded from Page 349 of "Light Metals" for July. References are to the Complete Bibliography Contained on Pages 349, 350, and 351 of that Issue, which also Includes Figs. 1-40



a direct relation to the quantity of precipitate, and the relation of most properties to the quantity of precipitate is known only in general terms.

Attempts have been made to measure the amount of precipitate directly by microscopic methods; for instance, a micro-planimetric method has been employed to plot the change with time in the relative area in which decomposition had and had not occurred in a specimen during discontinuous precipitation in Cu-Ag alloys.

In all except the most extreme cases it may be anticipated that the rate of precipitation starts relatively slowly, reaches a maximum value, and then decreases as the stable (or meta-stable) structure of the alloy, under the operative conditions, is approached. In cases where the property under investigation changes continuously towards a steady value, e.g., the hardness change in aluminium alloys during natural ageing, the slope of the property-time curve may be used to indicate the rate of precipitation. This slope tends to be small initially (during the incubation period), reaches a maximum and then decreases slowly to a small value. (See Figs. 16, 17, 41 and 42.) Measurements of the maximum slope of similar property-time curves have been used to indicate the rate of precipitation under different ageing conditions. The time required to attain half the property change has also been used.⁷³ However, the property under investigation may pass through a maximum or minimum during ageing, and in such cases the measurement of the slope of the property-time curve gives little indication of the rates of precipitation involved. In such cases the time required to attain the maximum value may be used as an indication of the rate of precipitation. The above methods are qualitative only and may be employed only as long as this limitation is borne in mind.

The Incubation Period. After solution heat-treating and quenching an alloy so that it is supersaturated, the solute atoms in naturally ageing alloys may start their process of precipitation immediately after the quench, or there may be a short period after quenching before the first property changes can be detected. Alloys that do not age at room-temperature may also require a certain period of time at the ageing temperature before property changes can be detected. The time between the quench and the first change in properties is termed the incubation period.

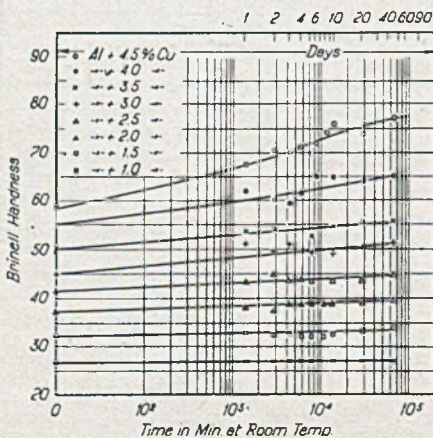


Fig. 43.—Hardness-time curves for alloys of aluminium and copper from 4.5 per cent. to 10 per cent., quenched in water at room temperature and aged at room temperature.¹⁴⁷

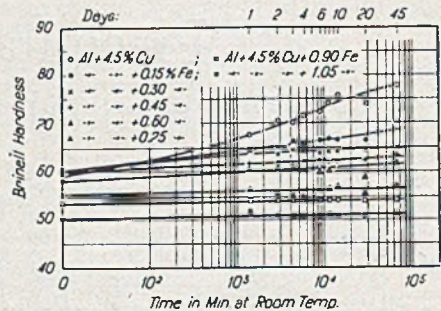


Fig. 44.—Hardness-time curves for alloys of aluminium, 4.5 per cent. copper and iron contents from 0.15 per cent. to 1.05 per cent., quenched in water at room temperature and aged at room temperature.¹⁴⁷

An incubation period of more than a few minutes has been found in Al-Cu alloys,¹³⁴ Cu-Be alloys,⁴⁰ and in duralumin.^{40, 30, 53, 65} According to Jeffries (discussion of 30) the property measured, say tensile strength, does not always remain constant during the incubation period, but often falls prior to the rise due to ageing. Arrowsmith, Wolfe and Murray²⁰⁷ have reported a similar effect in quenched duralumin sheet on ageing at different temperatures. Jeffries found that the incubation period and the increase in ductility were prevented if the alloy was given a slight deformation immediately after quenching.

As far as the writer is aware an increase in ductility a short time after quenching has not been generally noted in other than aluminium base alloys, although Sykes^{147A} found that some Fe-W and Fe-Mo alloys gave an initial decrease in hardness on ageing.

In the case of duralumin, Burns⁶⁵ has suggested that when an incubation period is present the solute has been retained in its entirety during quenching. Hartnagel¹³⁴ suggested for Al-Cu alloys that the incubation period was shorter the smaller the internal stresses.

Fraenkel⁵³ examined the effect of a large number of factors on the incubation period of duralumin, these included the following:—Origin of alloy, composition, size of the test piece, time of solution heat-treatment, variation in grain size. Unfortunately the results were inconclusive, and it was impossible to show why one material possessed an incubation period and another did not. It appeared that incubation was the result of several causes since samples having the same composition behaved differently.

Incubation periods tend to be eliminated by an increase in the degree of supersaturation. (See Fig. 22.) Mehl and Jetter¹³² consider that the incubation period is probably in part at least a pure rate effect, but Fraenkel's work shows that the rate is influenced by a number of factors.

The Effect of the Degree of Supersaturation. All investigators agree that increase in the degree of supersaturation increases the rate of isothermal precipitation. Fig. 22 shows the effect of Be content in Cu-Be alloys,¹⁸ similar

effects have been found in Al-Mg-Si alloys,⁸ Ag-Cu alloys,²¹ and Al-Cu alloys.^{3, 36, 145, 146, 147, 59} The effect of the degree of supersaturation on the magnitude of the property changes in Al-Cu alloys may be estimated from Fig. 23. It has sometimes been noted that the total increase in certain properties due to agehardening decreases when the solute is present beyond the maximum amount that can be taken into solid solution.²¹ (See Figs. 48 and 23; compare the curves showing yield strength "as quenched" ("O") and artificially aged ("T").)

Mehl and Jetter¹⁵² have pointed out that the rate of precipitation is more rapid in low melting point systems (Pb-Sb, Al-Cu) than in high melting point systems (Cu-Be, Fe-W) and that the same differences are found when the rates of recrystallization and rates of diffusion are compared.²⁰⁰ These rates are interdependent and are a function of the atomic mobility, which is greater nearer the melting point. The phenomenon is complex and not fully understood.

The Effect of Different Ageing Temperatures.

Like all chemical reactions, the isothermal rate of precipitation from supersaturated solid solutions is much influenced by the temperature at which it takes place. Gayler and Preston¹⁶ reported that the rate of agehardening increased rapidly as the ageing temperature was raised. Dix Jr.³² investigated the question from the point of view of deliberately retarding the ageing process in quenched duralumin by storing at low temperatures. He reported that the ageing could be retarded for at least 24 hours by storing at 0 degree C., and that the ageing process proceeded normally on raising to room temperature. More recently Arrowsmith and Wolfe¹⁶⁵ have examined the use of refrigeration for delaying the ageing of duralumin sheet. They found that at a temperature of -11 degrees C. the increase in hardness would take weeks to become serious enough to interfere with forming operations.

The first portions of the ageing curves obtained at different temperatures are very similar to those given with different degrees of supersaturation. At low temperatures the incubation period is much prolonged, and even when the rise in hardness starts the rate is much less rapid than at higher temperatures.

Jenkins and Bucknall⁷¹ were the first to show a relation between the ageing temperature and the time taken to attain maximum hardness. When the logarithm of this time was plotted against the reciprocal of the absolute temperature a straight line was obtained. Thus the equation connecting these effects is of the form

$$t = C e^{m/T}$$

where t is the time to maximum hardness, T is the temperature in degrees absolute, m and C are constants.

Jenkins and Bucknall were also the first to suggest that maximum hardness was reached at low ageing temperatures.

The exponential relation was tested by Cohen⁸⁸ on Ag-Cu alloys. His results are given in Figs. 24 and 25. Fig. 25 shows that there is an exponential relation between the reciprocal of the absolute temperature and the logarithm of the ageing time in the case of the time to the beginning of hardening, the time to attain

half the first hardness peak, the time to the first hardness peak, the time to the hardness valley, the time to half the maximum hardness, and the time to the maximum hardness. These points are indicated by arrows in Fig. 24. The last three of these times possess similar relationships, they all have the same slope, whereas the first three lines do not possess the same slope as one another or as the other three lines. Above 170 degrees C. the primary effects were swamped and could not be detected.

The general view now is that, given sufficient time and atomic mobility, the lower the ageing temperature the greater will be the final hardness in spite of the higher initial rate of harden-

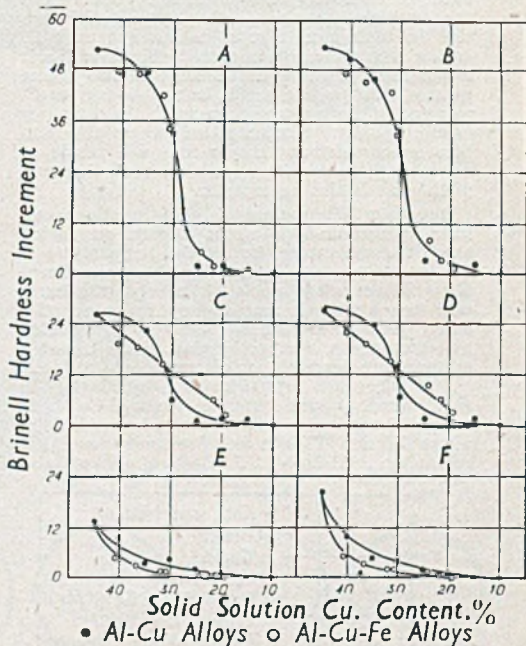


Fig. 45.—Hardness increment after ageing aluminium-copper and aluminium-copper-iron alloys of varying solid-solution copper concentration under the following conditions.¹⁴⁷ A, boiling water quench, aged 7 days at 150 deg. C.; B, boiling water quench, aged 10 days at 150 deg. C.; C, boiling water quench, aged 7 days at room temperature; D, boiling water quench, aged 10 days at room temperature; E, cold water quench, aged 6 days at room temperature; F, cold water quench, aged 10 days at room temperature.

ing with higher ageing temperatures. Figs. 16 and 17 bring out this point.

Cohen¹⁴² found that the exponential relation between the attainment of various stages in the hardening process and the ageing temperature in degrees absolute, held in the case of duralumin. It must be pointed out that a number of investigators have been content to show the straight line relation for one of the stages in the hardening process and then to draw straight lines parallel to this one through only two experimental points (or in some cases through one point only).

Gayler and Parkhouse¹⁶² obtained hardness-time curves on a high purity aluminium alloy containing 4 per cent. Cu. (See Fig. 18.) They used the results to check the exponential relation. Plotting the logarithm of the time between the first maximum and the start of the increase in hardness due to the second maximum against $1/T^{\circ}A$, the time to soften 10 Brinell Hardness Units after the second maximum against $1/T^{\circ}A$, the time to attain maximum hardness against $1/T^{\circ}A$ all gave straight lines. (See Figs. 26, 27 and 28.) As shown by Fig. 28 no straight line relation was found between the time to attain the first hardness peak and $1/T^{\circ}A$. The relation between the time taken to reach maximum hardness (second peak) and $1/T^{\circ}A$ holds only over a limited range of temperature, although the line shown in Fig. 28 is straight over all ageing temperatures examined. However, as it is possible that the second stage in the ageing process would never set in below 30 degrees C. this end of the line must approach the time axis asymptotically. Similarly, holding at the solution heat-treatment temperature will result in no increase in hardness, so that the other end of the line is also asymptotic.

Reversion (Retrogression). Al-Cu alloys and some duralumin-type alloys harden on ageing at room-temperature, but if the temperature is raised to, say, 100 degrees C., the agehardened alloy softens after a short time and the hardness may approach that of the "as quenched" alloy. This phenomenon is known as reversion or retrogression, further heating at the elevated temperature leads to an increase in hardness.

The effect was first discovered by Gayler³ in 1922, when it was reported that Al-Cu-Mg-Si alloys showed the effect, but that Al-Mg-Si alloys did not. Gayler and Preston³⁶ found that Al-Cu-Mg, Al-Cu-Si, Al-Cu-Fe alloys also

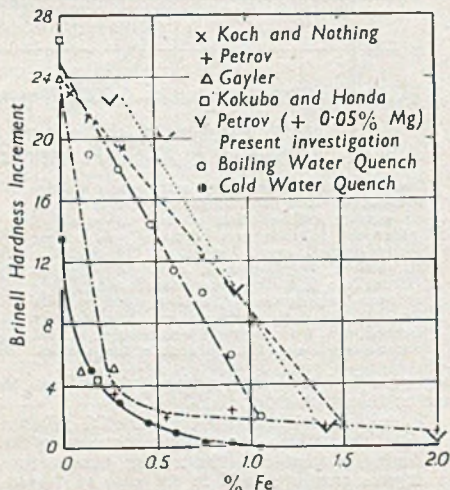


Fig. 46.—Comparison of published data on room-temperature agehardening of aluminium alloys containing 4 per cent of copper, together with varying amounts of iron. Alloy used by Hunsicker in "present investigation" contained 4.5 per cent. copper.¹⁴⁷ The effect of an addition of 0.05 per cent. magnesium (according to Petrov¹¹¹) is also indicated.

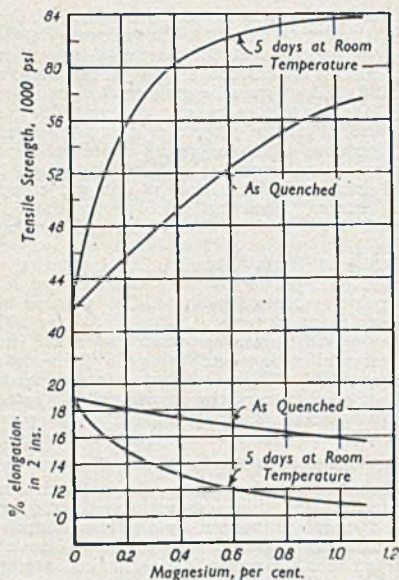


Fig. 47.—Effect of magnesium additions to a wrought aluminium-copper alloy containing 5.25 per cent. of copper.¹⁴⁵

softened initially on artificial ageing following natural ageing.

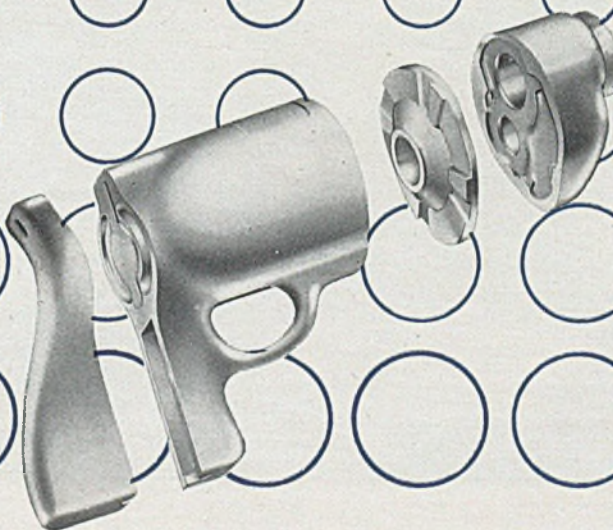
Masing and Koch⁵² found the effect in Cu-Be alloys and in duralumin, although the effect in Cu-Be alloys was not very pronounced. Their results on duralumin are shown in Figs. 33 and 34. Similar effects have also been reported in Cu-Ni, Cu-Si, Cu-Al, and Cu-Mn alloys.¹⁶⁶

Hartnagel¹³⁴ found that on ageing Al-Cu alloys at room-temperature the electrical resistance increased initially to a maximum, in about 10 hours, and then gradually decreased. On heating air-cooled specimens that had been aged at room-temperature for about three minutes at 215 degrees C., the resistance change was reversed, and the alloy possessed the same resistance as after quenching. This process was repeated 10 times, and in every case the "as quenched" resistance was obtained exactly. Reverting water-quenched specimens produced a lower resistance than that present immediately after quenching.

Dreyer also studied the phenomenon¹⁵⁷ and found that heating the naturally aged alloy softened it initially, although prolonging the treatment at elevated temperature led to an increase in hardness due to normal artificial ageing effects.

After cold rolling the naturally aged alloy the softening that occurred on ageing for five minutes at 220 degrees C. was lower the greater the deformation given¹⁵⁷ (see Fig. 35), the amount of re-hardening that took place on standing at room-temperature was also reduced. However, Brenner and Kostrom¹⁰⁸ found that the initial decrease in proof stress on artificial ageing was greater the greater the amount the naturally aged alloy (duralumin) had been cold rolled. These results are not necessarily in

The Lightest Structural Metal



THE LIGHTEST CASINGS FOR ELECTRIC TOOLS

The ultra-lightness and strength of **MAGNUMINIUM** magnesium base alloys makes them most desirable for use in the manufacture of portable electric tools, domestic appliances and a host of other products, all subject to frequent lifting and handling. In the operation of reciprocating parts of machinery Magnuminium overcomes starting inertia, decreases power consumption and permits increase of speed. Magnuminium has excellent machining properties and can generally be fabricated by methods similar to those used in other metals. Full technical details available from the Sales Department.

MAGNUMINIUM
MAGNESIUM BASE ALLOYS



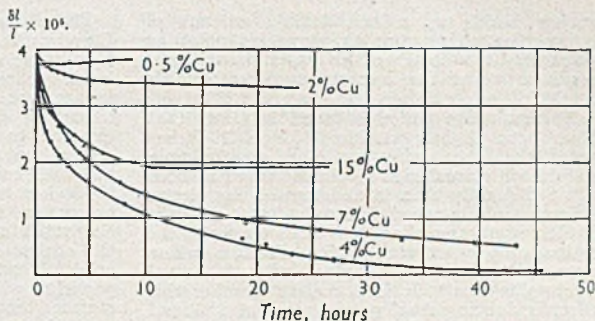


P O R T A B L E
E L E C T R I C
T O O L S

Wolf
Regd.

S. WOLF & CO. LTD., PIONEER WORKS, HANGER LANE, LONDON, W.5, PERivale 5631-3

Fig. 48.—Changes in length of specimens of aluminium-copper alloys during ageing at room temperature.⁶¹



opposition to one another, since the hardness changes do not necessarily follow the changes in proof stress. Fraenkel³⁴ found that the amount of softening that occurred on ageing a cold worked Al-Cu-Si alloy at 130 degrees C. was greater the greater the amount of deformation given, no reversion was shown by the undeformed alloy (see Fig. 36) which had not been aged at room temperature.

Preston's results on the X-ray diffraction investigation of reversion have been given; relevant information as to structural alterations during reversion is also given by the measurement of changes in the apparent instantaneous specific heat on heating naturally aged alloys.

The Effect of Plastic Deformation. Data on the effect of deformation on the rate of precipitation are voluminous, and the results of the different investigators are in good agreement on the salient points. Wilm¹ stated that the maximum obtainable hardness was attained by cold working the aged alloy rather than by deformation immediately after quenching. The aluminium base alloys have been studied most completely, by Fraenkel,³⁴ Teed,⁸² Bungardt,¹⁰⁷ Brenner and Kostron,¹⁰⁸ Lindsay and Norton,¹⁴³ Kostron,¹⁵⁸ Meissner,⁴⁴ and Jackman¹⁹⁷ among others. The results are summed up in Fig. 29, where the effect of cold stretching both the quenched and naturally aged alloy is shown. Stretching immediately after quenching increases the hardness the greater the deformation given; the increase in hardness after this process (by ageing) is lower the greater the amount of deformation applied, although the final hardness may exceed that of the undeformed alloy. Working after ageing gives the greatest hardness of which the alloy is capable; after this treatment there is a further very slight rise in

hardness on standing at room temperature. Fig. 30 shows that the speed of ageing following deformation immediately after quenching is greater the greater the deformation.

Electrical resistance measurements show the same effect,³⁴ the increase in resistance on ageing is lower, but the rate of increase is greater the greater the deformation given to the quenched alloy. (See Fig. 31.) The increase in resistance varies directly with the amount of stretching.

Similar effects have been observed in nickel-bronze alloys.⁶³ (See Fig. 32.) After cold rolling the maximum hardness is obtained more rapidly on ageing and is greater than in the undeformed alloys.

The phenomenon of strain ageing in steels is well known,¹⁴⁸ although it is beyond the scope of this dissertation to discuss it fully. It is but an exaggerated example of the effect in which deformation is necessary to make the rate of ageing rapid enough to be detectable. A somewhat similar phenomenon is found in Cu-Sn alloys. By drastic cold working followed by long annealing Haase and Pawlek¹⁵⁴ showed that the solubility of tin in copper decreases considerably with decreasing temperature below 520 degrees C. Most investigators have indicated that the solubility decreases only slightly from this temperature (that of the eutectoid), because the change is extremely sluggish under normal ageing conditions.

Harrington^{149, 100} has claimed to show that split ageing (i.e., ageing in two separate periods with an intermediate cooling) is more effective in producing hardening than one single ageing treatment of the same total length. This is ascribed to thermal stresses set up in cooling after the first ageing treatment. Although the

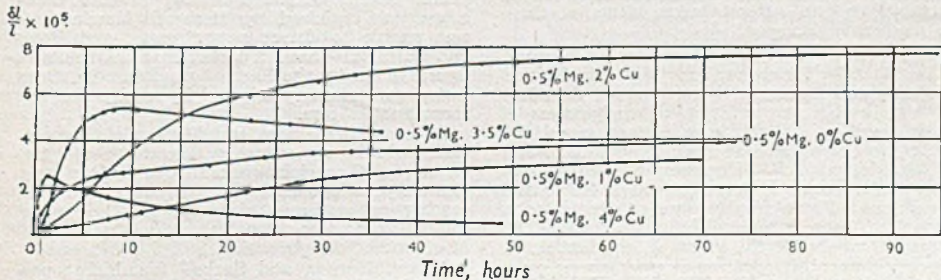


Fig. 49.—Changes in length of specimens of aluminium-copper-magnesium alloys during ageing at room temperature.⁶

author builds up a considerable amount of information to attempt to prove his point he gives very few details of his experimental technique to assist the correct assessment of his results.

No incubation period is found in alloys that have been slightly strained.³⁰ Kostron¹³⁵ has noted that the ageing curves of a duralumin were much smoother in specimens that had been strained slightly than in undeformed test pieces.

Some cold worked brasses show a slight hardening on annealing,^{195, 209} this occurs in the region of the recrystallization diagram where recovery normally takes place prior to actual recrystallization.* It is not clear whether this effect is due to actual precipitation of a second phase or brought about by the presence of the crystal nuclei, that later grow into the recrystallized grains. The latter suggestion has been put forward by Maddigan and Blank (dis-

The Effect of the Passage of an Electric Current. It was suggested by Andrew and Hay¹¹ that the agehardening of duralumin might be a colloidal phenomenon and, if so, the passage of an electric current through the quenched material during ageing would be expected to accelerate the process. Two samples of duralumin were quenched from 500 degrees C., one was subjected to alternating current and the other left to age naturally. Slight differences were found and these were attributed to the action of the electric current in hastening the coalescence of the colloidal particles. By colloidal particles the authors meant small particles with no tendency to coalesce, high surface tension and an electric charge. As pointed out in the discussion, it is difficult to imagine how particles that are "colloidal" in the exact sense of the word can be present in solid metals. Also it would be unwise to attach too much importance to the results of one experiment of such a nature. One point of considerable interest arose in the discussion, i.e., Gayler reported that after passing a high direct current through an Al-Mg₂Si alloy for two weeks at elevated temperature the particles of the second phase were slightly larger in the specimen through which the current was passed than in the specimen through which no current was passed, both specimens being heated to the same temperature.

Seemann¹⁵⁹ has carried out a more complete investigation, samples of duralumin sheet being heat-treated at 505 degrees C. and quenched in water. Alternating and direct currents were passed through some of the specimens, other specimens being left to age naturally. The ageing temperature was kept constant at 28 degrees C., all the specimens being aged in an oilbath so that any effects would not be due to a rise in temperature caused by the electric current. After ageing, the tensile strength values and hardness values were found to be identical within the limits of experimental error.

The Effect of Rotating Magnetic Fields. Herbert claimed^{26, 28, 29} that the application of rotating magnetic fields to duralumin caused the hardness to fluctuate, a fall-rise-fall being obtained, the amplitude of the changes and the time required for their completion, decreasing with repetition. He suggested that the cause was due to the rotating magnetic field giving rise to fluctuations of a periodic character in the system of electrons, which in turn caused periodic fluctuations in molecular cohesion.

However, Matuyama^{39, 38} could not obtain similar results, although his experimental technique was criticized by Herbert. Harrington⁴³ was unable to detect any changes, and Esser and Cornelius⁵⁸ have reported that the hardness figures given by the Herbert pendulum hardness tester were strongly affected by changes in the room temperature.

Effect of Grain Size and Method of Preparation. It is necessary to consider these two effects together, since specimens of similar grain size may be prepared by different methods of casting or working, although each of these different processes normally produces a material of characteristic grain size.

Ageew, Hansen and Sachs²¹ found that precipitation in a recrystallized polycrystalline alloy of copper containing 10 per cent. Ag was

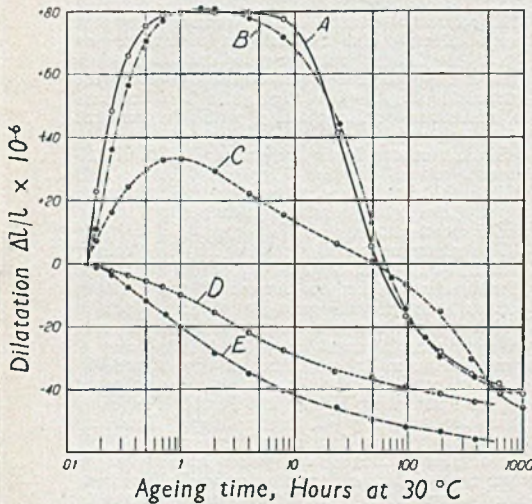


Fig. 50.—Dilatation of aluminium-copper-magnesium alloys during ageing at 30 deg. C.¹⁴⁶ A, aluminium with 4 per cent. copper and 1.5 per cent. magnesium; B, 4 per cent. copper and 1 per cent. magnesium; C, aluminium with 4 per cent. copper and 0.5 per cent. magnesium; D, aluminium with 4 per cent. copper and 0.25 per cent. magnesium; E, 4 per cent. copper and 0.1 per cent. magnesium.

ussion of 195); more fundamental work is required on this subject before either of these views can be accepted.

The Effect of High Hydrostatic Pressure. Van Wert,⁷⁴ Tammann and Hartmann⁹⁶ and Selisskiy and Kuznezov¹¹⁶ have studied the effect of high hydrostatic pressure on the process of agehardening. All the investigators found the ageing to be retarded at room temperature, and at 150 degrees C.¹¹⁶ However, the final hardness was the same as that obtained under normal conditions. These results were attributed to a reduction in the rate of diffusion because of the impeded motion of the atoms in the lattice.

* Similar results have now been reported by Harrington et al.^{211, 212} on phosphor-bronze and 1 per cent. cadmium copper.

complete after 25 hours at 300 degrees C., as determined by measurements of the lattice constants, while in a cast single crystal, precipitation had not started after 550 hours at this temperature, and was complete only after 50 hours at 420 degrees C. Wiest⁴⁸ reported a greater solid solubility of silver in single crystals of copper than in polycrystalline material. (See Fig. 37.) Also the mechanism of precipitation was not the same in the two forms of material; in the single crystal there was a gradual change from the lattice parameter of the quenched alloy to that of the aged alloy (continuous precipitation), whilst in the polycrystalline material both lattices occurred together and varied in intensity (discontinuous precipitation). The speed of ageing was greater in the polycrystalline than in the single crystals⁵⁶ and Wiest suggested that this could be explained by the greater degree of supersaturation in the polycrystalline material. However, Schmid and Siebel⁴⁷ did not find that the solid solubility of silver in copper varied with the grain size, although Wiest and Dehlinger confirmed the previous result.⁵⁵ Wiest⁵⁴ reported that single crystals of Cu-Ag alloys hardened to a greater degree than polycrystals, which became overaged in the time the single crystals took to reach maximum hardness.

In Au-Ag alloys, Wiest⁶¹ found a difference in lattice constants between cast and recrystallized polycrystalline material of the same grain size, but no difference between cast single crystals and cast polycrystalline materials.

Sohnchen⁶⁹ reported that the grain size of cast Y alloy, Lual and Silumin gamma influenced the ageing, the increase in hardness on ageing being lower the larger the crystal size. Worked duralumin showed a similar effect, but it must be pointed out that it is impossible to judge how far these results are affected by a greater degree of supersaturation in the fine-grained material due to more rapid and more complete solution on heat-treatment of the finer constituents.

Al-Mg, Zn-Mg, Mg-Al and Cu-Al alloys were reported by Schmid and Siebel⁴⁷ to possess a lattice parameter that was independent of the grain size. Cast alloys were used, and no differences were observed in the rate of precipitation with differences in grain size.

Wiest and Dehlinger⁶⁸ found that Cu-Ag alloys subjected to increasing amounts of prior deformation showed greater rates of ageing, after large reductions only one maximum was obtained on the hardness-time curves as opposed to two on material that had had smaller reductions. It was suggested that the cause lay in the degree to which the different materials possessed a mosaic structure.

Bumm and Dehlinger⁶² have shown also that precipitation is more rapid in recrystallized polycrystalline material than in a cast single crystal. A conical depression was made in a cast single crystal of a Cu-Ag alloy, and the specimen was solution heat-treated at 800 degrees C. and aged at 420 degrees C. Precipitation was much more rapid adjacent to the impression where recrystallization had taken place than away from it.

In Al-Cu alloys, Phillips and Brick^{57, 51} have shown that the solid solubility is dependent on

the grain size (see Fig. 38), the solubility being greater in single than in polycrystalline material. This was ascribed to a lower solubility of copper in the grain boundaries of the polycrystalline material, and the suggestion was made that the presence of low density material adjacent to particles of precipitate might also influence the solubility. Wassermann⁶¹ considered that the results of Phillips and Brick (and others) may be explained by quenching stresses, but this is insufficient to explain all the effects satisfactorily.

Phillips, Brick and Smith⁷³ have also reported that the rate of ageing of Al-Mg alloys was dependent on the grain size, as follows:—

Per cent. Mg.	Average grain diam. in.	Time for half the reaction in hours.
8.4	0.001	20
8.4	0.005	45
8.4	0.060	100

Dean and Davey¹³¹ have found the grain boundaries of Zn-Cu alloys to be depleted in copper. They interpreted their results in terms

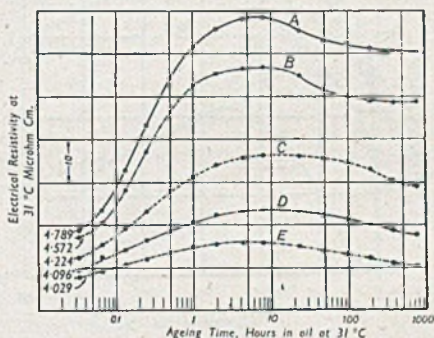


Fig. 51.—Electrical resistivity changes in aluminum-copper-magnesium alloys during ageing at 31 deg. C.¹⁴⁶ A, aluminium with 4 per cent. copper and 1.5 per cent. magnesium; B, aluminium with 4 per cent. copper and 1 per cent. magnesium; C, aluminium with 4 per cent. copper and 0.5 per cent. magnesium; D, aluminium with 4 per cent. copper and 0.25 per cent. magnesium; E, aluminium with 4 per cent. copper and 0.1 per cent. magnesium.

of surface tensions, copper with a higher surface energy than zinc would tend to separate away from the grain boundaries to keep the free energy of the alloy a minimum. Considered from this point of view Al-Mg and Mg-Al alloys investigated by Schmid and Siebel⁴⁷ would not be expected to show more than slight variations in solubility with grain size.

Karnop and Sachs¹³ reported that single crystals of an aluminium alloy containing 5 per cent. Cu aged more rapidly and to a greater degree than polycrystalline material. Phillips and Brick⁵¹ suggest that this is because to achieve equal degrees of supersaturation, without which it is difficult to compare the ageing characteristics of different forms of material, solution heat-treatment of the single crystal at 515 degrees C. and the polycrystalline material at 540 degrees C. would be necessary, and since Karnop and Sachs used a lower temperature full solution would not be obtained in their polycrystalline material.

Katori^{117, 118} and Nakamura¹¹⁰ have studied the effect of different mechanical treatments before solution heat-treatment on the precipitation of Cu-Be alloys and Cu-Ag alloys respectively. Both investigators found that the prior history of the alloy influenced the property changes under examination. Wrought Cu-Ag alloys of eutectic composition undergo a contraction on ageing at 450 degrees C. compared to an expansion by cast alloys of the same composition aged at the same temperature.

Gayler¹¹³ and Gayler and Parkhouse¹⁶² found that high purity aluminium base alloys containing 4 per cent. Cu had ageing characteristics which were much influenced by the method of working employed. The effects were most noticeable in the purest alloys, which could be heavily cold worked at room temperature without appreciable work-hardening. The agehardening could be prevented by employing

indicated in Al-Cu alloys, but the results on which these conclusions are based are not convincing. In view of the differences between extruded duralumin and the same alloy worked by other methods it is very unfortunate that no published information seems to be available on the ageing characteristics of extruded material. Japanese investigators have suggested that the high properties of extruded material are due to the fact that the crystal boundaries in extruded duralumin are not smooth as in forgings, but serrated.^{183*}

The Effect of Small Quantities of Additional Elements on the Ageing Characteristics of Binary Alloys.—(1) Introduction. The major portion of the work that comes under this heading has been carried out on Al-Cu alloys, particular attention being given to the effect of iron and magnesium.

Sohnchen⁶⁹ has suggested that the effect of a third element on a binary system is to shift the solid solubility curve to either higher or lower concentrations of solute, it being possible to obtain the same degree of supersaturation between given temperatures (in other words the solid solubility curve is shifted bodily to the right or left of the equilibrium diagram). However, the effects are often much more complex than this would lead one to expect.

(2) **The effect of iron on: Al-Cu alloys.** There is general agreement that the effect of iron is to reduce the rate and extent of agehardening of Al-Cu alloys, but disagreement as to the magnitude of the effect caused by the addition of very small quantities.

Gayler and Preston³⁶ found that the addition of 0.32 per cent. Fe to an aluminium alloy containing 4 per cent. Cu inhibited ageing at room temperature and decreased the maximum hardness obtained on ageing at 200 degrees C. In the discussion Kempf and Dean suggested that an Al-Cu-Fe compound might be formed, which would withhold the copper from solution, and in support of this they stated that the addition of 0.5 per cent. Fe had a greater effect on a 4 per cent. Cu alloy than on a 5.8 per cent. Cu alloy, as in the latter case there would be enough copper remaining after the formation of the ternary compound to saturate the solid solution. In a later paper Gayler⁹⁴ showed that the addition of as little as 0.1 per cent. Fe had a marked effect on the room-temperature ageing of a 4 per cent. Cu alloy, the effect being less apparent on ageing at elevated temperatures. The presence of 0.6 per cent. Fe had a considerable effect, however, on the agehardening at all ageing temperatures investigated.

Koch and Nothing⁸⁰ found that up to 2 per cent. Fe reduced the hardness of a 4 per cent. Cu alloy quenched from 525 degrees C., but there was no change in hardness with iron content on quenching from 380 degrees C. The increase in hardness during room-temperature ageing showed a considerable drop on the addition of a small quantity of iron, further additions producing a gradual decrease in hardness increment as the iron content was increased.

* This subject has now been examined by Ueckel^{211, 212, 214} and by Hansen and Drayer,²¹³ the higher properties of the extruded and heat-treated materials being due to the fact that it is in the work-hardened uncrystallized condition, superimposed on which there may also be a preferred orientation.

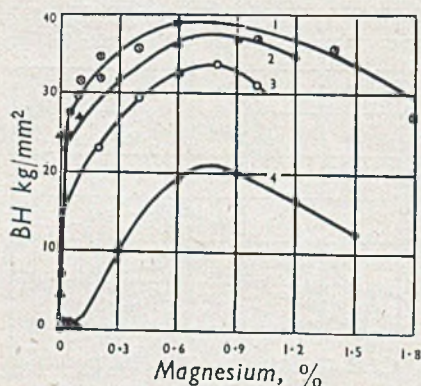


Fig. 52.—Agehardening capacity of commercial aluminum-copper-magnesium-iron-silicon alloys in relationship to magnesium content.¹¹¹ 1, 4 per cent. copper; 2, 3 per cent. copper; 3, 3.2 per cent. copper; 4, 4 per cent. copper. Open triangular mark at 24 kg./mm.² refers to results of Gayler and Preston³⁶ for 4 per cent. copper alloy free of iron and magnesium.

an unsuitable method of working and the method of working actually employed had a greater influence than the degree of working.

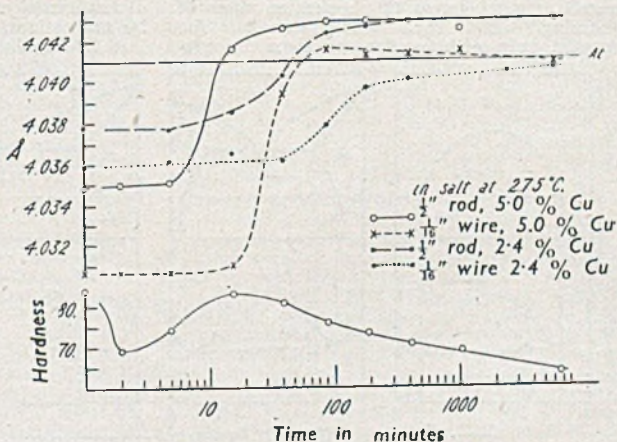
Frommer¹³⁸ showed that the θ' lattice was transformed into θ in RK56 sheet that had been cold rolled 86.5 per cent. before solution heat-treatment, whereas some θ' remained in specimens that had been rolled only 6 per cent. and then given the same heat- and ageing-treatments. The crystals were larger in the lightly deformed sheet than in the specimens heavily deformed.

There is ample evidence that extruded and heat-treated duralumin and Al-Mg-Si alloys have higher tensile properties than the same material given similar heat-treatments, but prepared by different methods of working. Working the extruded material prior to heat-treatment also reduces the properties to those of forged material.^{137, 139, 202, 136, 161, 188, 186, 187, 160, 46} Bohner^{184, 93} has suggested that Al-Cu-Mg and Al-Mg-Si alloys that have been hot worked only give higher properties than material that after hot working has been substantially cold worked before heat-treatment. The opposite is

Microscopic investigations showed that an increase in iron content was accompanied by a decrease in the amount of CuAl_2 present, its place being taken by a complex ternary compound, to which the composition Cu_2FeAl was given. On the basis of this composition it was calculated that the amount of iron required to withhold all the copper from solid solution in a 4 per cent. Cu alloy would be 1.35 per cent. No CuAl_2 was found in alloys containing more than 1.5 per cent. Fe. The hardness of the alloys was proportional to the amount of copper dissolved.

Petrov¹¹¹ determined the effect of up to 2 per cent. Fe. In magnesium free (silicon containing) alloys he found that 0.05 per cent. Fe decreased the room-temperature agehardening capacity very considerably. (See Fig. 46, which summarizes the results of several investigations, the "iron free point" being taken from earlier results of Gayler³⁶ on high purity Al-Cu alloys.) Larger addi-

Fig. 53.—Effect of quenching stresses on rate of agehardening of aluminium-copper alloys as measured by lattice parameter changes (back reflection method).⁶²



tions decreased the ageing capacity gradually.

The results of Fink, Smith and Willey¹⁴⁶ are not in agreement with those of Petrov and Gayler described above. They reported a gradual decrease in the ageing capacity on the addition of small quantities of iron. (See Figs. 40 and 41.) After 500 hours at room temperature, the contraction of a 4 per cent. Cu alloy was roughly 10, 32, 46, 66 parts in 10^6 for iron contents of 1.0, 0.5, 0.25, 0.0 per cent. respectively. The effect of iron in withholding copper from solution by the formation of a ternary compound was determined by lattice parameter measurements and solution potential measurements, the amount of copper left in solution after the addition of certain quantities of iron to 4 per cent. Cu alloys being calculated from the results. In the following table the amount of copper used by different amounts of iron has been calculated by the writer and the results are compared with those of Hunsicker.¹⁴⁷

The amount of copper made unavailable for solution in aluminium due to the presence of certain amounts of iron

(a) Calculated from Fink, Smith and Willey's results¹⁴⁶

Fe content Per cent.	Cu required for combination (from parameter meas.) Per cent.	(from solution potential meas.) Per cent.
0.26	0.52	0.67
0.51	1.26	1.24
0.99	2.32	2.02

(b) Hunsicker's results¹⁴⁷

Fe content Per cent.	Cu required for combination (from parameter meas.) Per cent.
0.14	0.36
0.28	0.68
0.43	1.02
0.57	1.38
0.70	1.67
0.86	2.02
1.01	2.27

Fink, Smith and Willey gave ageing curves for alloys containing copper contents approximating to the amount of copper that would be available for solid solution in 4 per cent. Cu alloys containing 0.5 per cent. and 1.0 per cent. Fe respectively. The resulting curves were very

similar in form to those shown in Fig. 41, although the absolute values of the conductivity were not exactly the same.

Hunsicker¹⁴⁷ found a decrease in the agehardening of a 4.5 per cent. Cu alloy with addition of iron. (See Figs. 41, 42, 43, 44.) It was stated that binary and ternary alloys with equal amounts of copper available for solid solution gave equal degrees of agehardening, except in the case of alloys quenched in boiling water and aged at room temperature. His results are summarized in Fig. 45.

As shown in Fig. 46, the increase in hardness found by Hunsicker after quenching in boiling water is comparable to the effects found by Koch and Nothing, and Petrov on an alloy containing 4 per cent. Cu + 0.05 per cent. Mg + 0.4 per cent. Si (this latter point has been added in to Fig. 46).

Duralumin. Kroenig³⁵ determined the effect of additions of up to 1.5 per cent. iron on the properties of 2 mm. thick duralumin sheet after quenching from temperatures of 500-540 degrees C. and room-temperature ageing. Increase in iron decreased the final ultimate tensile strength obtained. This paper is sometimes quoted as showing that the deleterious effect is increased as the quenching temperature is raised, but this is not strictly accurate. The final ultimate tensile strength increases with increase in

quenching temperature when the iron content is below 0.9 per cent. and decreases slightly when the iron content exceeds this amount. Microscopic examination showed that the effect of iron was due in part to the formation of a ternary eutectic with Cu-Al₃, thus hindering the solution of the copper by fixing it in pools of eutectic.

Fry, Wiederholt and Boehme¹⁵⁶ studied the effect of iron on the mechanical properties of extruded duralumin, and concluded that up to 0.75 per cent. Fe had no effect on the properties provided that the correct heat-treatment temperature was used, the effect of iron being greater at higher solution heat-treatment temperatures. Dreyer and Seemann²⁰⁴ also studied the effect of iron on the mechanical properties of duralumin and stated that alloys with more than 0.7 per cent. Fe which were solution heat-treated at 540 degrees C. showed no signs of "burning," but such statements can be accepted only with caution, as signs of over-

Igarasi⁶ examined the change in length of Al-Cu-Mg alloys during room-temperature ageing. (See Figs. 48 and 49.) He found that on room-temperature ageing all binary Al-Cu alloys contracted in length, the contraction being greatest in the 4 per cent. Cu alloy. Binary Al-Mg alloys also contracted on ageing. Al-Cu-Mg alloys expand on ageing, for a 0.5 per cent. Mg alloy the expansion was greatest with 2 per cent. Cu, whilst when the copper is raised to 4 per cent. there occurs a rapid expansion followed by a contraction. It was also found that the addition of magnesium to a 4 per cent. Cu alloy causes an expansion which is greatest with 2 per cent. Mg.

Fink, Smith and Willey¹⁴⁶ noted that 4 per cent. Cu alloys with 1.0 and 1.5 per cent. magnesium gave a large expansion on ageing, followed by a contraction. (See Fig. 50.) The decrease in electrical conductivity was increased by magnesium. (Fig. 51.)

Al-Cu-Fe alloys. There is good agreement

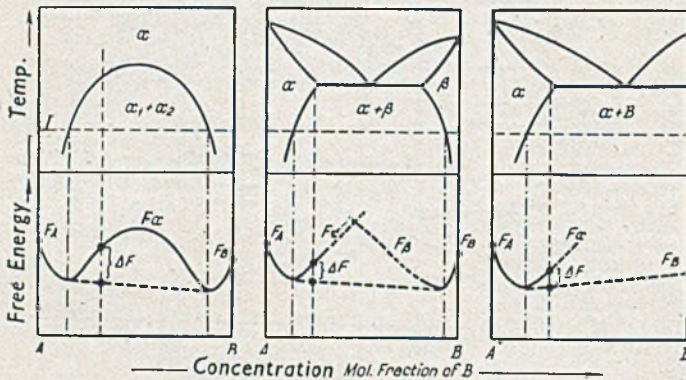


Fig. 54.—Diagrams showing the change in total free energy (ΔF) on precipitation from super saturated solid solutions, in several types of system.¹⁵² F_A and F_B = free energy of pure components; F_α and F_β = free-energy curve of solid solutions; ΔF = free energy change on precipitation. The free-energy composition curves of the solid solution are those at the precipitation temperature.

heating are extremely difficult to detect in aluminium alloys. There is agreement that the effect of high quantities of iron is increased as the temperature of heat-treatment is raised, no explanations have been put forward to account for this, the most simple being probably that fusion of some of the constituents occurs.

(3) **The effect of magnesium on: Al-Cu alloys.** There is general agreement that the addition of magnesium increases the agehardening capacity. Gayler and Preston³⁶ found that a 4 per cent. Cu alloy with 0.5 per cent. Mg aged faster and to a greater degree both at room temperature and at 200 degrees C. than the same alloy without the addition of Mg.

Kempf,¹⁴⁵ reporting some work of Dean, states that the maximum effect seems to be achieved when the concentration of magnesium is about 1.5 per cent., higher amounts of magnesium decreases the effect because of the formation of a complex Al-Cu-Mg constituent of limited solubility. The "as quenched" hardness increases almost linearly with increase in magnesium content. (See Fig. 47.) However, Fig. 47 (given by Kempf) shows that the maximum increase in U.T.S. is obtained with 0.4 per cent. Mg for a 5.25 per cent. Cu alloy. Petrov's results show (on alloys containing Fe) a maximum increase in hardness with the addition of approximately 0.6 per cent. Mg.

that the addition of magnesium destroys the deleterious action of iron. Gayler and Preston³⁶ found that the addition of 0.5 per cent. Mg neutralized the influence of 0.32 per cent. iron. Petrov¹¹¹ found that 0.03 per cent. Mg caused an iron containing alloy to behave as a pure Al-Cu alloy. (See Fig. 52.) With larger amounts of iron and 0.05 per cent. Mg the agehardening capacity is very similar to those of the Al-Cu-Fe alloys of Koch and Nothing. (See Fig. 46.)

Duralumin. In the case of duralumin, Hansen and Dreyer^{157A} found that the effect of magnesium was a function of the copper content, viz.:

Cu content. Per cent.	Mg content for maximum change on ageing.	
	Magnesium content for maximum tensile properties. Per cent.	Per cent.
4.0	2.0	0.5
3.0	2.5	1.0
2.0	3.0	1.5

(4) **The effect of manganese on: Al-Cu alloys.** Fink, Smith and Willey¹⁴⁶ report that 0.25 per cent. Mn has no effect on the ageing of a 4 per cent. Cu alloy, but that additions of 0.5 and 1.0 per cent. reduce the extent of the agehardening. This is shown by ageing curves for yield strength, dilatation and electrical conductivity.

Al-Cu-Mg alloys. Dreyer and Hansen²⁰³ found that up to 1.0 per cent. Mn had no effect on the rate or extent of agehardening after solution heat-treatment at 500 degrees C. After quenching from temperatures of 350-450 degrees C. the ageing process was prolonged.

(5) **The effect of silicon on: Al-Cu alloys.** There is general agreement that the addition of silicon to high purity Al-Cu alloys has no effect on the agehardening.^{146, 36, 94, 113}

Al-Cu-Fe alloys. As described before, these alloys ageharden to a lesser extent than the iron free alloys. Silicon tends to neutralize the effect of the iron, probably by the formation of an Al-Fe-Si compound, thereby reducing the amount of iron available for the adverse effect on the agehardening.

(6) **The effect of other elements on the ageing of Al-Cu and duralumin-type alloys:—**

The effect of Nickel. Bingham,¹² Moringa,¹⁶⁷ Koch and Nothing⁸⁰ and Cook and Chadwick²⁰⁸ found the agehardening of duralumin to be retarded and decreased by the addition of Ni in a manner similar to that of iron, and with increasing Ni content the "as quenched" hardness was decreased. Here again this was put down to the formation of a ternary compound, with a consequent reduction in the amount of copper available for solution. NiAl₃ can itself probably produce a slight ageing effect.

Effect of Cobalt. Koch and Nothing found that the "as quenched" hardness of duralumin containing Co was increased with increase in cobalt content. The increase in hardness on ageing was reduced by very small additions, but with from 0.1-2.0 per cent. the hardness increment was almost constant.

The Effect of the Rate of Cooling from the Solution Heat-treatment Temperature. There is some contradiction to be found among the results of different investigators on the effect of different rates of cooling after solution heat-treatment. Taking duralumin as an example, agreement is general that the slower the quench the greater the speed of ageing, but the lower the final tensile properties. This is shown by Wilm,¹ Konno.⁴ Also the slower the quenching rate the higher the "as quenched" tensile properties.

However, Hunsicker¹⁴⁷ and Kempf (discussion of 62) found that the final aged hardness of Al-Cu and Al-Cu-Fe alloys quenched in boiling water was greater, after both natural and artificial ageing, than that of the same alloys quenched in cold water. Hunsicker's results for the naturally aged specimens are shown in Figs. 41, 42, 43 and 44, his specimens were in the form of sheet quenched from temperatures of 20 degrees C. above the solid solubility curve. Sykes¹⁷⁴ attempted to check these findings

on Fe-W and Fe-Mo alloys, and found that specimens air cooled from the solution heat-treatment temperature gave slower ageing and lower maximum hardness than specimens water quenched, but the effect of air cooling and boiling water quenching are not directly comparable since the rates of cooling in the two cases are extremely different.

Hunsicker found a different relationship between the agehardening capacity (measured by the hardness increment) at room-temperature and copper content in Al-Cu alloys on specimens quenched in boiling water compared with others quenched in cold water. (See Fig. 45.) The agehardening capacity of the specimens quenched in cold water decreases rapidly with a slight decrease in copper content from 4.5 per cent., whereas the specimens quenched in boiling water show a more regular reduction in ageing capacity with reduction in copper concentration. The Al-Cu-Fe alloys behaved very differently from the Al-Cu alloys; with equal "available copper" contents the ageing capacity was greater with high available copper in the Al-Cu-Fe alloys than in the Al-Cu alloys, and lower with low available copper in the Al-Cu-Fe alloys than in the Al-Cu alloys, the curves crossing at approximately 3.25 per cent. of available copper.

It must be pointed out that both Hunsicker and Kempf worked entirely on hardness figures, whereas other investigators used tensile properties and there is only a vague connection between hardness and tensile strength.

It is, of course, well known that the rate of quenching has a considerable influence on the quenching stresses produced; Fink and Smith¹²² found differential etching along slip planes on naturally ageing for one and a quarter hours an aluminium alloy containing 4 per cent. copper, quenched in cold water, but did not find this initial effect in the same alloy quenched in oil at 100 degrees C. and aged at this temperature. Phillips and Brick^{62, 73} found that the rate of precipitation in the surface layers was influenced by the specimen size. (See Fig. 53.) The lattice parameter (measured by back reflection method) of 1/2-in. dia. specimens of aluminium containing 2.4 and 5.0 per cent. Cu started to change sooner than in 1/16-in. dia. wire. Also the final lattice parameters of the 1/2-in. dia. specimens were larger than that of pure aluminium; whereas the 1/16-in. dia. specimens attained lattice parameters of just less than pure aluminium.

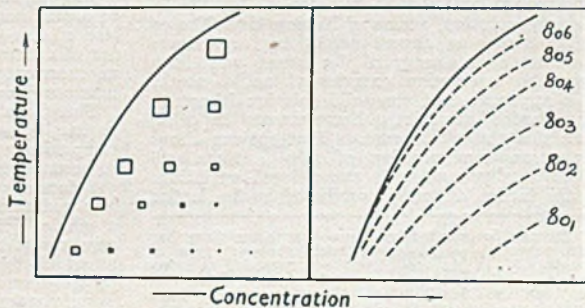


Fig. 55.—Diagrams showing relative nucleus size for various degrees of undercooling and supersaturation. The size of the nucleus along the solid soluble curve is infinite, it decreases with increasing degrees of supersaturation and of undercooling. (Contour lines are regions of equal nucleus size; size decreases with subscript number.¹⁵²)

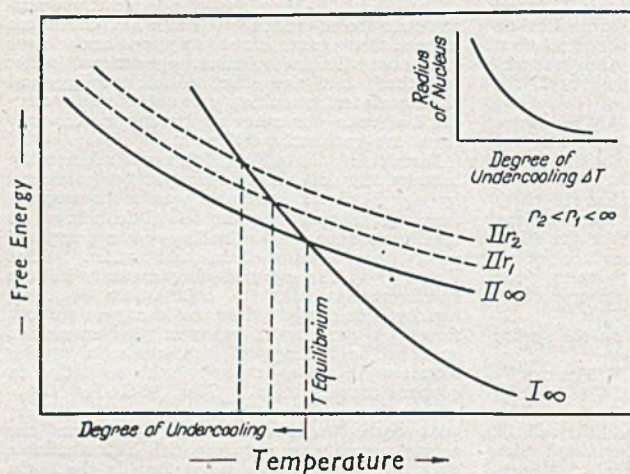


Fig. 56.—Diagram showing relationship between free energy per mol and temperature or degree of undercooling for different particle sizes of phase II (r —radius of particle).¹⁵²

THE RELATION BETWEEN THE SOLID SOLUTION MATRIX AND THE PRECIPITATE

The Solid Solution and Solid Solubility. Before the changes that occur on the decomposition of supersaturated metallic solid solutions can be understood fully, a complete knowledge of the solid solution state would be required, but this is by no means available at present. The reaction taking place is that in which a new phase develops spontaneously from an unstable one, an interface being formed between the new and old phases. The physical chemistry of such heterogeneous reactions has been discussed by Mehl and Jeter,¹⁵² who suggested that the reactions take place in two stages, (i) the formation of nuclei, and (ii) the growth of these nuclei.

In the solid solution solute atoms are distributed throughout the solvent lattice; in the substitutional type of solid solution, which is the only one of interest in the present discussion, atoms of solute Y occupy lattice positions in the solvent X, which in the pure substance would be occupied by atoms of X. The atoms of the solute may differ from the atoms of the solvent in many respects, all of which affect the solid solution, e.g., valency, atomic size as defined by the distance of closest approach in the pure substance,¹⁴ ionic size,^{157, 158} polarizability.^{129*} In the solid solution, atoms of X may have like or unlike atoms as closest neighbours, and since the interaction energy of like atoms will differ from the interaction energies of unlike atoms it is apparent that the solid solution is not to be regarded as strictly homogeneous in other than the statistical sense. Fluctuations about the mean concentration of solute atoms will occur locally, and will cause local variations in the lattice distortion produced in the lattice

* It may be pointed out here that aluminum has been regarded as having a fairly "open" type of structure.¹⁵⁷ It has sometimes been regarded as being incompletely ionised, although the evidence for this has been considered inconclusive.¹⁵⁹ and in a later paper Hume-Rothery and Raynor¹⁵⁷ state that incomplete ionisation is very improbable.

of the solvent by the introduction of foreign atoms.

The atoms are in constant motion, moving from point to point within the lattice, by atomic interchange or by the occupation of empty points in the lattice. Before the movement can take place the atom must possess a certain minimum energy in order to surmount the potential barrier between two lattice points.¹²⁹ The rate of diffusion (D) depends on the temperature and on the energy required for diffusion,^{209, 210} the connection between these factors is given by

$$D = Ae^{-Q/RT}$$

where A is a constant, Q the activation energy required for diffusion, R is the gas constant and T the absolute temperature. However, it is known that D also depends markedly on the concentration of solute.^{198, 121} Diffusion is well known to take place more rapidly along grain boundaries than within the crystals themselves, Barrer¹²⁴ states that the activation energy required within the lattice is greater than that needed at a grain boundary, and both are greater than that required for surface diffusion.

It is possible to calculate, for the ideal case, the likelihood of the occurrence of groups of solute atoms of various sizes that may exist in the solid solution, due to fluctuation concentrations, by the use of Poisson's formula¹⁷²

$$P_J = \frac{\xi^J e^{-\xi}}{J!}$$

P = probability of occurrence of a group,
J = number of solute atoms in that group,
 ξ = average number of solute atoms in a group,
 P_J = probability of occurrence of J atoms in a group.

The probability of the occurrence of a group of atoms was found to decrease rapidly as the size of the group increased. The values found are of course statistically correct only, and take no account of different interaction energies between like and unlike atoms.

The phase diagram is determined by variations in free energy of the system due to changes in temperature and composition of the alloys.¹⁴⁹ A homogeneous structure exists only so long as the formation of a new phase does not result in a reduction of the free energy of the alloy as a whole. The limit of the solid solubility at any given temperature is given by the point at which the lowest tangent to the free energy-composition curves of the phases of the alloy system meets the free energy-composition curve of the solid solution. (See Fig. 1.) Phases with

free energy-composition curves above the lowest tangent are not stable at the given temperature.

Breakdown of a supersaturated solid solution is accompanied by a decrease in free energy,¹⁶² as shown in Fig. 54. A solid solution may decompose in two ways, either (a) with the formation of a super-lattice, or (b) with the formation of a second phase. The manner followed depends upon the interaction energies of the atoms, i.e., if the attraction between like atoms is greater than between unlike atoms precipitation will occur, but if the reverse is the case a super-lattice will be formed.

The total quantity of solute that may be taken into solid solution depends on many factors (which operate by influencing the course of the free energy curves). (See in particular papers by Hume-Rothery and others.^{144, 145, 114, 123, 126}) Conditions operative within perfect crystals will be changed by imperfections, internal surfaces within the crystal and grain boundaries. Gibbs theoretical work shows that the solute concentration at a surface differs from that inside the crystal, being higher at the surface when the solute possesses a lower surface energy than the solvent; this leads to different solid solubilities with different grain sizes. The presence of a second phase has been suggested as affecting the solid solubility in the same manner as grain size,²¹ although experimental evidence of this is lacking and contradicted by work of Stenzel and Weerts.³⁹ Little is known of the effect of mosaic structure on solid solubility. The solid solubility at a polished surface may differ from that within the crystal.⁴⁴

The solid solubility curve may be calculated for ideal solutions from the thermodynamic considerations¹⁰ and also from free energy considerations.¹²² The equation connecting solute concentration and temperature is of the form

$$\log_e x' = -L/RT + C$$

where

- x' = mol fraction of alloying element,
- L = molar heat of solution,
- R = gas constant,
- C = integration constant,
- T = temperature in degrees absolute.

Fink and Freche⁴⁴ have shown that the experimental results are in agreement with the theory in the case of aluminium base alloys, even though the calculations make assumptions that are applicable to dilute solutions only. A straight line is obtained when the reciprocal of the absolute temperature is plotted against the natural logarithm of the mol fraction or molar per cent. of the solute. However, at low temperatures the experimentally obtained curves

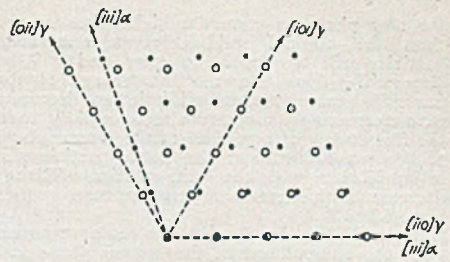


Fig. 57.—Orientation relationships on the position plane between a FCC γ phase and a BCC α phase, showing the superimposition of these two planes and parallelism of directions.¹⁶²

are at higher concentrations with Al-Cu, Al-Mg and Al-Mg-Si alloys probably due to lack of true equilibrium conditions.

The Formation and Growth of Nuclei. On cooling a solid solution to a point below the solid solubility curve, the solution becomes unstable and tends to reject solute atoms until the remaining solid solution is of equilibrium composition. The solute atoms that are rejected form a new phase which appears first in the form of nuclei which may grow into larger crystals.

The free energy of the supercooled state will be greater than that of the equilibrium state, while precipitation is accompanied by a decrease in free energy. (See Fig. 55.) It is this decrease in free energy which is the driving force of the reaction, the energy being dissipated by the formation and growth of the nuclei.

Mehl and Jetter¹⁵² have reviewed the literature dealing with the theories of nucleation, and a brief survey of their results and of information published since the issue of their paper is given here.

Early work was applied to simple phase changes, such as the condensation of vapours. Volmer and Weber^{33, 39} showed that there was a stable nucleus size associated with any given degree of undercooling, nuclei smaller than the critical size being dispersed, while those larger than the critical size grew. The stable nuclei size decreased with increase in the degree of undercooling and increase in the degree of super-saturation. (See Fig. 55.)

Growth of the nuclei will occur if their free energy is less than that of the original phase, but the free energy is a function of the particle size, and increases as the particle size decreases. Hence it is possible for a very small particle of

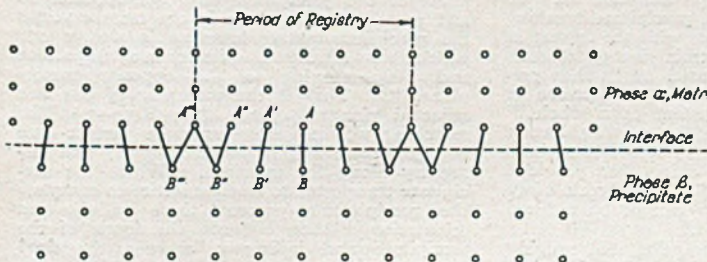


Fig. 58.—Diagram showing periodicity in an atomic matching, and straining, of the atom "bonds," on composition plane between matrix and precipitate. Tendency toward lattice adaptation on composition plane will distort both lattices in the layers adjacent to the composition plane.¹⁶²

the new phase to possess a higher free energy than the original solid solution, and such particles will be unable to grow and will be dispersed. However, the free energy of the unstable supersaturated solid-solution decreases with decreasing temperature more rapidly than the free energy of a particle of the second phase of a given radius, and the stable particle size in equilibrium with the solid solution will thus decrease with decreasing temperature. (See Fig. 56.)

Becker¹⁷⁹ has described a nucleus as a region with the composition of the second phase and of such a size that it remains, as it is, in equilibrium with the supersaturated solid solution. He has proposed the following formula for the frequency of nuclei formation (by spontaneous fluctuations in the atomic lattice).^{179, 180}

$$I = C e^{-(Q+A)/kT}$$

where

C is a constant,
T is the temperature in degrees absolute,

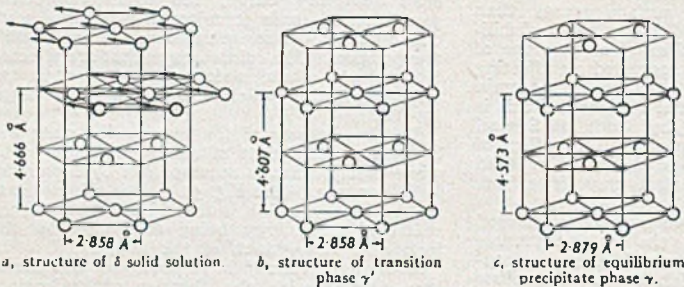


Fig. 59.—Atomic rearrangements accompanying precipitation in aluminum-silver alloys.¹⁸⁴

k is Boltzmann's constant,

Q is the activation energy of diffusion,

A is the work required to form a nucleus.

Nabarro^{181, 182} and others have pointed out that the work required for the formation of a nucleus depends on the shape it takes, the energy being less for lenticular nuclei than for other shapes. The shape may be altered if the degree of supersaturation is high, since the diffusion of atoms to the nucleus is then rapid and the tendency will be to form spherical rather than lenticular nuclei.

The nucleus is formed within the solid solution, the lattice of the two regions being continuous across the boundary, and this will lead to the formation of strain at the interface due to the interaction of the two different lattices. This strain energy is large and can only be reduced by the particles of precipitate breaking away from the parent lattice with the formation of an interface. If the strain energy of such regions could not be released no further precipitation could occur without an increase in the free energy of the system as a whole.¹⁷⁸ The strains may be relieved by recrystallization of the solid solution grains as occurs sometimes in Ag-Cu alloys. Nabarro states that provided a particle of precipitate does not break away from the lattice its energy cannot be reduced greatly by change of shape.

On the basis of the assumption that roughly the same amount of energy is required to melt a

mon-atomic layer at the surface of the particle as to fracture it, it was calculated that the sheet of precipitate in Ag-Cu alloys should be only two atoms thick when it breaks away. Barrett, Geisler and Mehl¹⁸⁴ have applied the same formula to Al-Ag alloys and find that the break-away is predicted when the precipitate is 320 atomic layers thick. They point out that the fact that Debye rings can be obtained from the γ' phase before it becomes large enough to break away and become the γ phase is in accordance with theory.

After a stable nucleus has formed it grows by diffusion, the rate of growth depending on the rate at which solute atoms reach the nucleus, and the rate will decrease as the matrix is depleted in solute.

A mathematical analysis of the process of isothermal decomposition of austenite, or any metastable phase breaking down in a similar manner, has been made by Johnson and Mehl.¹⁴⁴ They calculate the amount of material transformed in a given time in terms of the rate of

nucleation and the rate of growth, allowance is made for the impingement of growing nodules on one another, and for the decreasing rate of nucleation as the solute concentration decreases. The results have been tested on steels, but not on agehardening systems covered by the present review.

Crystallographic Relationships. It has been known for a long time that there was frequently a relation between the pattern formed by crystallites separating from a solid solution (the Widmanstätten figure) and the lattice of the matrix. Apparently Mehl and Barrett⁸⁷ were the first to realize that there might be a relation between the orientation of the precipitated crystallite itself and the matrix from which it formed. A number of systems have now been studied and it is well established that "the plane of the precipitate that lies opposite to and parallel to the plane in the matrix across the precipitate-matrix interface is always one which shows a marked similarity in atom pattern and atom spacing to the opposite matrix plane."¹²² That is the matching of the two adjacent planes is good. (See Fig. 57.) The matching will not necessarily be perfect (see Fig. 58), there will be periodic registry and disregistry along the interface. Where the precipitate transforms to another lattice to complete the precipitation process, there will be an orientation relation between the forms of the precipitate and indirectly between the final product and the matrix also.

In Ag-Cu and Cu-Ag alloys the lattice parameters of similar planes differ by only 10 per cent.^{41, 72} It was suggested that precipitation was on (100) planes in the Cu rich alloys. An orientation relation was found between the crystals of the Ag-rich alloy before and after the recrystallization that occurred during ageing.

Al-Ag alloys were found to precipitate on (111) planes,³¹ it was suggested that Al-Cu alloys precipitated on (100) planes.⁴²

Barrett, Geisler and Mehl³⁴ state that there is no doubt that registry exists between the basal plane of the γ' and the (111) plane from which it forms, as the atomic array on these planes is identical in pattern, interatomic distance and orientation. Interatomic spacings that do not lie on these planes are altered, the (111) plane spacing of the matrix contracts 1.4 per cent. on forming the (0001) plane of the γ' . On forming γ from γ' there is a further contraction of 0.74 per cent. in the (0001) plane spacing and an expansion of 0.73 per cent. in all atomic distances lying in this plane. The manner in which the changes occur may be represented as a series of shearing operations, either simple or complex. The atomic disregistry and the resultant lattice strain in both lattices tend to resist these movements; this is probably the explanation of the formation of intermediate lattices, the strain energy required for the formation of the stable phase directly being greater than that required for the formation of the transition lattice. As the size of the particles of the intermediate phase increases the strain at the interface becomes more than can be withstood, and the stable phase forms instantaneously from the transition lattice. This is accompanied by the formation of a definite interface between the stable precipitate and the matrix, and until the stable lattice is formed there is no real interface between the lattice of the matrix and the transition phase.

The case of the Al-Cu alloys is more complex. Precipitation takes place along cube planes of the matrix, and before the orientation relation between θ' and the matrix can be defined it is necessary to state whether the unit cell of Wassermann and Weerts⁷⁹ or Preston¹⁰⁰ is being used, the relation between these being shown in Fig. 61. Fig. 60 shows the Al-Cu solid solution ready to precipitate according to Fink and Smith.⁷² Samans⁷¹ has proposed a complex system of atomic shearing actions to account for the changes from supersaturated solid solution to the stable θ lattice.

DISCUSSION OF THE THEORETICAL AND EXPERIMENTAL EVIDENCE

Nomenclature. Before discussing the experimental and theoretical work described in the preceding pages it is advisable to consider the definition that should be applied to certain terms which are frequently used in this connection but rarely defined.

After reviewing the literature of agehardening in 1939 Mehl and Jetter came to the conclusion that "... the changes in properties observed may be explained on the basis of precipitation alone without recourse to theories concerning a homogeneous precipitation reaction" (i.e., a pre-precipitation process). Before such a statement can be accepted it is necessary to define what is meant by "precipitation" and "pre-

precipitation." If "precipitation" is to be extended to cover all changes in the atomic lattice of the supersaturated solid solution as it transforms into the equilibrium solid solution and the equilibrium precipitate, then the first part of the above statement is correct, and the second part merely nonsense as by definition the term "precipitation" includes the "homogeneous precipitation process." If, however, the term "precipitation" is to be kept for application to the formation of a second phase distinct from the matrix and separated from it by an interface,* then the process preceding the formation of the phases on either side of the interface requires some name and "pre-precipitation" would seem to be as good as any.

It seems that American workers are tending to use "precipitation" to cover all atomic changes from that of the supersaturated solid solution. Fink and Smith have used this terminology⁷² and have criticized early theories of Gayler³⁵ in which the term "pre-precipitation" was used. It may be pointed out that Fink and Smith arrived at their conclusion on incorrect metallographic evidence and partly by apparently disregarding the work of Preston¹⁰⁰ and Guinier¹²³ on X-ray diffraction, although these latter papers were published before the paper by Fink and Smith.

Seyt⁷³ has also criticized the work of Gayler. Criticism may be offered that the first stage in the process (i.e., the formation of G-P zones) is possibly not one of segregation of solute atoms but rather of the formation of two dimensional sheets of the intermediate transition phase,¹¹⁴ and that in Gayler's work little was said of the nature of the forces causing the precipitation process or of what the process consisted. Similarly the ideas of a number of German workers that there was a fundamental difference between "hot" and "cold" ageing have come in for much criticism, although this is on more logical grounds.

But the remainder of the differences of which so much has been made appear to the writer to be due almost entirely to indecisive terminology. It appears more convenient to use the term precipitation as it is used by Mehl and others, that is to cover all stages in the atomic process that occur during the breakdown of the supersaturated solid solution and it is used with this meaning in the following pages.

The latest X-ray diffraction investigation indicates that the G-P aggregates may actually consist, not of segregations of solute atoms, but of very small particles of the transition phase. If this latter is correct the term "G-P zone" becomes unnecessary; however, as this point is not yet definitely proved, this term is used subsequently to indicate the regions in the matrix in which the first change to the equilibrium precipitate starts, whether this possesses the structure of the intermediate phase or not.

The phrase "precipitation hardening" has been avoided in order to employ "agehardening," which does not imply that the property

* A definition of "interface" is required here. Is the boundary between the intermediate phase, which is still continuous with the matrix, to be covered by the use of the term "interface" or should this be kept for the boundary between a particle that has broken away from the solid solution matrix?

changes are necessarily accompanied by the formation of actual precipitated particles.

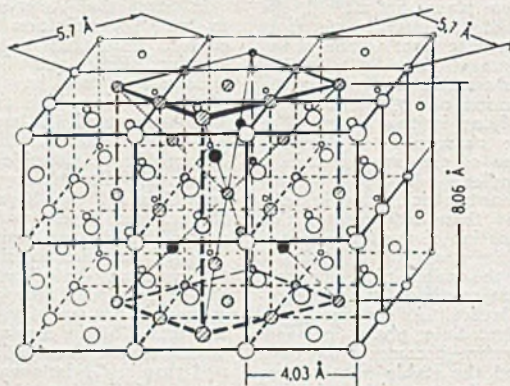
It would seem that the term "nucleation hardening" would indicate better than any other phrase the actual structure formed in naturally aged Al-Cu alloys; however, this has already been employed by Maddigan and Blank to indicate a possible cause of hardening on annealing cold worked brass.

The Precipitation Process. Wilm¹ who discovered the phenomena of agehardening was unable to explain it, as he could detect no change in the microstructure during ageing. Merica, Waltberg and Scott² believed that agehardening was due to the precipitation of CuAl_2 in a colloidal form, and they remarked:

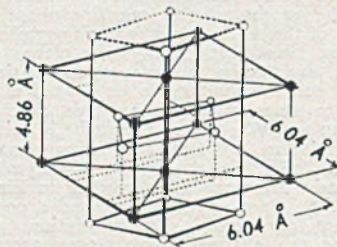
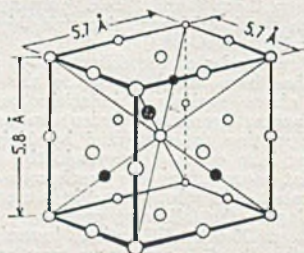
distribution formula,¹⁷² but this does not take into account that the stability of the groups is affected by any thermodynamic considerations. These deviations from the statistical distribution will increase as the temperature is lowered and the time for which they are in existence will also increase. The presence of such groups does not indicate "up-hill" diffusion, and they must be considered normal to all solid solutions.

If in any solid solution there are a large number of groups of atoms of the size and composition required by the nuclei of the second phase, there will also be many more regions which are only slightly imperfect from this point of view, i.e., they lack possibly one or two atoms.

Fig. 60.—Lattices in precipitation in aluminium-copper alloys. Full circles are copper atoms, hollow circles aluminium atoms. Lattices drawn to show orientation relationships: A (right), aluminium-copper solid solution before precipitation. Inscribed tetragonal prism shows grouping of atoms which become θ' unit cell in B (below). Four copper atoms in the centre of—



the tetragonal prism are retained in the θ' lattice; the aluminium atoms which occupy the corresponding positions are lost; B (below, left), the θ' lattice; C (below, right), the θ , CuAl_2 lattice (not the unit cell) drawn to show orientation relationships and to include a grouping of atoms comparable to that of B. Successive horizontal layers are equidistant at 2.43 Å.¹⁷²



"... if we are not able to show that actual phase changes take place during ageing, we must then ascribe these changes to alterations in the atomic or molecular structure."

It has been stated above that precipitation is by the formation of nuclei and the growth of these nuclei into particles of the second phase. The distribution of atoms in the solid solution can be regarded as uniform only in the statistical sense, even at the solution heat-treatment temperature fluctuations in the concentration of the solute atoms will occur in the parent lattice, these being due to chance atomic movements, and being affected by the interaction energies of like and unlike atoms. There will be zones in which the composition and size are those of the nuclei that form during ageing. The number of such groups that form by chance can be determined by the use of Poisson's

On quenching, these potential nuclei are "frozen in" the lattice of the matrix and will be favourably situated for the first stage in the precipitation process, which starts in such regions.

The supersaturated solid solution possesses a higher free energy than the equilibrium solid solution (see Fig. 54), and some of the energy is dissipated by the formation of nuclei. The work required to form a nucleus is probably a function of the nature of the orientation relation existing between the matrix and the nuclei,¹⁵² of the volumetric change that must be undergone, and of the amount of adaptation between the two lattices at the interface (these three factors are obviously interconnected).

It is suggested that the first change in the regions, where the size and composition are those of the nuclei, is probably towards the

correct distribution of solute atoms. When this has been attained the atomic movements leading to the formation of a small region with a different lattice from that of the matrix can start.

The new lattice forms from the old with the minimum expenditure of energy. Fig. 62 shows diagrammatically the change in free energy of a system which passes through several stages in the process of precipitation; the minimum change in free energy occurs at each stage. The size of the nucleus that forms is affected by the temperature of formation. (See Fig. 55.) The exact nature of the atom movements leading to the formation of the new lattice is not clear, the end product may be said to form from the matrix lattice by a series of shearing operations.^{194, 197} There is no doubt that there is an orientation relation between the G-P aggregates and the lattice in which they form, the lattice of the G-P zones being continuous with the matrix. The lattice adaptation at the interface that is necessary causes the building up of stresses which tend to prevent the formation of the equilibrium precipitate and the continuity of the lattice leads to the presence of transition phases. Theoretical work of Nabarro¹⁹⁴ indicates that the strain generated is proportional to the total volume of the precipitate and not to the surface area. The strain energy at the interface is given up when the stresses involved cannot be borne and the precipitate is able to break away, after which there is no further hindrance to the formation of the equilibrium structure of the precipitate.

It must be remembered that isothermal precipitation does not occur at an equal rate in all parts of the supersaturated solid solution, even in individual crystals, the extent to which the process has occurred at any given point in the lattice will differ from that at any other point. The property changes accompanying precipitation are the results of the integrated sum of the degree to which precipitation has occurred throughout the matrix as a whole. Also during precipitation the solvent is being continuously depleted in solute and (neglecting the effect of strain at the interface) the lattice distortion in the matrix lattice is continuously being diminished.

In the Al-Cu and Al-Ag system precipitation is known to take place in three stages.* X-ray diffraction photographs show that the first stage is the formation of the Guinier-Preston aggregates; secondly, the presence of the intermediate θ' or γ' lattices can be recognized, and thirdly, this transforms into the equilibrium precipitate θ or γ . There is some evidence that the Al-Mg system passes through a similar process (discussion of 194). The G-P zones are plate-like and form along certain crystallographic planes in the matrix.

The exact nature of the G-P aggregates is not quite clear. Preston and Guinier considered them to be composed of plate-like segregations of copper atoms which possessed the lattice of the matrix. There is no direct evidence available at the moment as to the lattice spacing that they actually possess, but it is possible

that they have the spacing of the intermediate phase of which they are the forerunners. There is some evidence for this in that it has been reported that the streaks on the Laue photographs have been found in Al-Mg alloys (discussion of 194), in this case it would be impossible to distinguish the Mg atoms from the Al atoms by X-ray diffraction, as they have similar scattering powers. Another argument against the theory of segregation of copper atoms is that it is difficult to imagine how such segregates can easily transform into the intermediate phase. No explanation is required if the G-P zones already possess the spacing of this transition lattice, although added complexities arise in explaining the property changes.

The transformation from the intermediate phase to the equilibrium lattice may be simple as in the Al-Ag system.¹⁹⁴ In these alloys the atomic array on the (111) plane of the aluminium matrix and the (0001) plane of the γ' is identical in pattern, interatomic distance and

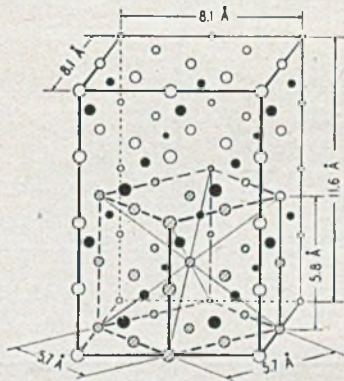


Fig. 61.—Relationship between the unit cells of θ' according to Wasserman and Weerts,⁷⁹ and Preston¹³⁰ (from discussion of 172).

orientation. The structures could be obtained by the following sequence of lattice changes. In regions with the correct silver content, parallel (111) planes of the matrix move over one another during precipitation so as to convert the face centred cubic structure into the hexagonal close-packed structure. This movement (see Fig. 59) is in the direction $[10\bar{1}0]$. If it occurs with sufficient regularity, the sequence of the F.C.C. planes, A, B, C, A, B, C, . . . will be altered to A, B, A, B, A, B, . . . which is the sequence of the H.C.P. structure. In the transformation $\gamma' \rightarrow \gamma$ there is no transition of atom layers, but only adjustment of the atom spacings.

Samans¹⁹¹ has put forward a complex shearing mechanism to describe the formation of the equilibrium precipitate throughout its various stages in Al-Cu alloys. Fink and Smith have suggested that the relationship existent between the lattice of the solid solution and θ' is as illustrated in Fig. 60, the 16-atom group in the solid solution forms a 12-atom group of the intermediate phase. If the unit cell of

* No further references will be given to the source of the experimental information which has been described in the individual sections, in which the relevant references may be found.

Wassermann and Weerts be used, instead of that due to Preston, the relationship requires that 12 aluminium atoms are lost from a group of 64 atoms in the matrix, which is an equivalent loss. The nature of the mechanism of the change was not indicated.

Examinations for intermediate lattices in other systems have not been carried out.* The existence of several stages in the precipitation process is to be anticipated, although the stability of such regions may not be great and their size small. Theoretical work of Nabarro¹⁷⁴ has indicated that in the Ag-Cu system the precipitate will break away from the matrix when it is about two atoms thick. The exact nature of the precipitation process in any system is a function of the thermodynamics of the system, the geometric relation between the lattices of the matrix and the precipitate, the complexity of the precipitating phase and the volume changes involved.

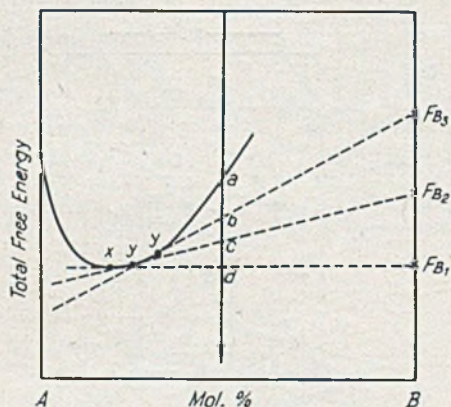


Fig. 62.—Diagrammatic representation of the changes in free energy accompanying the breakdown of a supersaturated solid solution, shown by the arrow, when the precipitate (B) can assume forms of differing free energy B1, B2, B3. When the form of highest free energy appears, the free energy change is least (a, b, etc.).¹⁵²

The formation of the equilibrium lattice from the transition phase is accompanied by a further reduction in free energy. The process of the formation of the equilibrium phase is shown diagrammatically in Fig. 63.

The Interrelation of the Property and Structural Changes. The increase in mechanical properties on ageing may be considered anomalous under certain conditions. The addition of solute atoms to a metal increases its hardness due to the distortion caused in the parent lattice, this increase in hardness can, in some cases at any rate, be expressed as a fairly simple function of the atomic percentage of solute.[†] The hardness of a heterogeneous mixture is proportional to the amounts and hardnesses of the constituents. Excluding the possible effects of particle size, and provided that the second phase does not possess a hardness greater than the hardness the solid solution would possess if it extended

to the composition of the second phase (this is true in the majority of cases) a decrease in hardness would be expected to accompany precipitation.

It is not proposed to discuss all the theories that have been put forward from time to time to explain the changes in mechanical properties on agehardening. Of the early theories to account for the increased resistance to deformation on ageing the slip interference theory of Jeffries and Archer⁹ is the most important. It was considered that precipitation took place during ageing, the precipitate first formed being of colloidal size and growing with time. The precipitate was present on the slip planes as discrete particles which interfered with slip by acting as keys, and it is obvious that there will be a critical particle size that will give the maximum keying action. While this theory can be applied to certain systems, a theory of simple precipitation does not describe all the facts observed with Al-Cu alloys.

Exactly how the G-P aggregates in these alloys contribute to the increase in hardness is not quite clear, but it seems probable that this is in some way connected with the lattice strain at the interface between the matrix and the precipitate, which may reach high values over a few atomic distances.

Preston¹⁰⁰ has estimated that at the time of maximum hardness at room temperature the G-P zones are about 200 Å apart, i.e., about 50 atomic distances. Sykes (discussion of 162) suggested that the first maximum on the time-hardness curve (Fig. 18) was due to the growth of the G-P zones, and that during the flat portion the bigger aggregates grew at the expense of the small ones. Further, that the second maximum was due to the formation of θ' and the drop after the second maximum to the growth of θ' . Gayler and Parkhouse were unable to detect signs of θ until after the second maximum, in which case true precipitation is here accompanied by a softening.

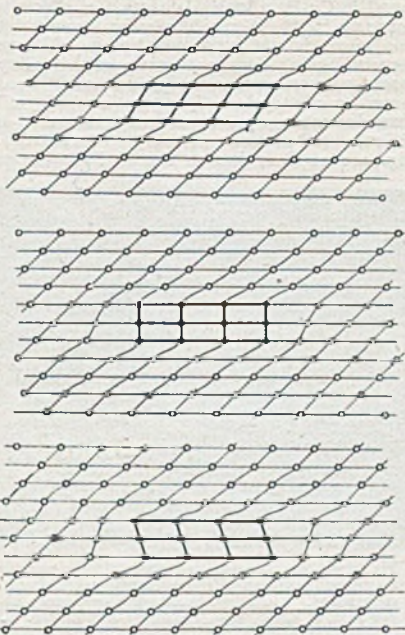
It will be seen that it is much more simple to explain these hardness-time curves on the basis that the G-P zones are distinct from the θ' phase, since if θ' is precipitated initially the cause of the two stages in the hardening process is obscure since θ' does not occur before the second maximum. It may be pointed out that only a few results of X-ray diffraction experiments were given in this paper¹⁰² and these did not allow a correlation between structure and the early property changes. The relation between the size of the G-P aggregates, the amount of strain at the interface, the distance between them on the one hand, and the properties on the other, is very complex, and an experimental investigation is desirable.

The theory of Fink and Smith on double ageing peaks has been criticized elsewhere. While it is now possible that θ' is actually formed on ageing at room temperature, as first suggested by Fink and Smith, it must be noted that this deduction was based on the incorrect interpretation of metallographic work and the criticism of their theory as to the cause of double ageing peaks still holds.

* Written in summer of 1942. See Appendix.

† See also recent work of Hume Rothery, Frye Jr. et al.^{111, 112, 113}

Alexander (discussion of 95) suggested that double ageing peaks were elusive and transitory in nature, but the careful work of Gayler and Parkhouse shows that they have a very definite existence. It is usually impossible to obtain the true ageing curve on the results of single tests, as the scatter of results is too great; it is necessary therefore to take the average of a number of tests. This may account for the difficulties that some investigators have experienced on this point. Also some of the published information is open to criticism on other points; mention has already been made of straight lines drawn through single points on a graph. A number of authors have presented



is evidently because the strain energy required for the formation of a nucleus is less than within the crystals. Although grain size may affect the solid solubility nothing is known of the degree of supersaturation that is existent in the grain boundaries compared with that within the crystals. In Cu-Fe alloys precipitation starts in the grain boundaries, although these would be expected (on surface energy grounds) to be low in iron compared with the crystals themselves. Also this precipitate is ferromagnetic from the start, but in the crystals a paramagnetic form is first precipitated. It would be interesting to follow this process by Laue photograms. The writer suggests that it is possible that heterogeneous precipitation is favoured by a high activation energy for the formation of nuclei within the crystals, and that this is decreased in the boundary between the original and undecomposed solid solution. It also seems probable that the size and complexity of the nucleus stable at any given ageing temperature plays an important part in determining the type of precipitation.* Small simple nuclei (Cu-Be alloys would be expected

Fig. 63.—Uppermost diagram: first stage in imaginary precipitation process. Nucleus ("black" atoms) has begun the movement which ultimately will transform it to the lattice of the precipitate. Straining of "bonds" at interface is shown, together with the fact that adjacent matrix ("white" atoms) are somewhat displaced. Centre: intermediate meta-stable transition. Lattice straining of atom "bonds" at interface is more severe. Atom displacement in matrix is more severe and more extensive. Although not shown in the diagram, the lattice of the nucleus will also be distorted by strain. Bottom: final stage in precipitation process. The nucleus has now assumed the lattice of the equilibrium phase. There is maximum straining of atom "bonds" at the interface and maximum distortion of lattice in both matrix and nucleus.¹⁵²

their time-property curves only, without indicating the experimental points on which they were based. Such a method of presentation makes it impossible to assess the validity of the curve, and the value of the paper is thereby seriously diminished.

One important effect about which relatively little is known is the reason why some alloy systems show much smaller mechanical property changes on agehardening than others. This is, of course, bound up with cause for any increase at all in the mechanical properties.

Preston has pointed out that the Laue X-ray diffraction photographs show a number of unexplained effects.¹⁵³ It is highly desirable that similar investigation be carried out on as many alloy systems as possible, as knowledge of the initial stages in the precipitation process is very scanty.

Similarly little that is fundamental is known about the cause of heterogeneous precipitation. It may be pointed out that precipitation nearly always occurs first in the grain boundaries; this

to give a complex one) would be expected to precipitate easily without the added inducement of lattice strain. Also the discontinuous type of precipitation would be favoured when the change in free energy accompanying the precipitation is small and does not produce a large driving force, such may be the case in the Ag-Cu and Cu-Ag alloys. However, the above is hypothetical at present and experimental investigations are required.

A number of the etching effects noted by Gayler¹⁵² are very difficult to explain, e.g., those illustrated in Fig. 4.

The results of investigations into changes in thermal properties accompanying precipitation were described in detail because their fundamental significance is considerable. It was calculated by Swindells and Sykes¹⁵⁴ from the ST (instantaneous apparent specific heat-temperature) curve for Ag-Cu alloys that at maximum hardness the minimum linear dimensions of the copper particles are 20 atomic distances, although the accuracy of this calculation is not great.

The results of thermal measurements on Cu-Be alloys¹⁵⁵ have been compared with the theory of Becker. The value of the activation energy Q in the formula for the frequency of nuclei

* Dehlinger (vide ref. 214 bibliography) has suggested that heterogeneous precipitation occurs when there is a large difference between the sizes of the solvent and solute atoms.

formation can be determined roughly from the specific heat measurements. When the degree of supersaturation is great, the work done to form a stable nucleus may be put equal to zero. The behaviour of the alloy is then considered as being determined entirely by diffusion. The probability that two adjacent atoms will change places during an atomic oscillation equals $e^{-Q/RT}$ and the fraction of atoms changing places per second is $ve^{-Q/RT}$, where v is the frequency of atomic vibration (about 10^{13} times/second). At 120 degrees C., i.e., 400 degrees A, $ve^{-Q/RT} = 10^{-9}$ (with $Q = 40,000$ cal), but before any appreciable effects could be observed experimentally this value would need to be increased to about 10^{-4} .

Jones and Leach estimate that the value of Q required to make Becker's formula fit the experimental evidence of the ST curves would be 31,000 cal. Whereas for copper $Q = 40,000$ cal and this value should be fairly accurate for dilute solutions also. It was suggested that the difference may be due to variations in the value of Q as precipitation proceeds, or to some effect other than that considered by Becker. The activation energy Q may be reduced by lattice distortion in small regions where, due to fluctuations, the concentration of solute approaches that of the precipitated phase.

The cause of the anomalous behaviour of the ST curve for agehardened Al-Cu alloys in the range 140-220 degrees C. (wherein energy is absorbed) is discussed by Swindells and Sykes¹²⁶ on the basis of Preston's X-ray diffraction work.

The equilibrium state of the 4 per cent. Cu alloy is that in which the majority of the copper is present as $CuAl_2$ particles. The material, as hardened at room temperature, is in a metastable state. Thus the free energy of the hard alloy at room temperature is not the minimum value. The relation between free energy F , internal energy U and entropy S is given by

$$F = U - TS \quad \text{where } T \text{ is the temperature in } ^\circ A.$$

The temperature dependent parts of F , U and S are taken care of by the CpT curve, and it will be considered that the various parameters in the free energy equation are affected only by changes in the state of the alloy.

Referring to Fig. 11c, it is seen that on heating from room temperature the internal energy U is increasing, since the apparent specific heat S is greater than C_p , but since F cannot increase, the entropy S must also be increasing. The maximum entropy of a solid solution is obtained when it is completely disordered, therefore the increase in entropy may be due to the disordering of the hard alloy. This may be interpreted in the light of the nucleation theories. The size of the nucleus that is stable at one temperature is smaller than that stable at a higher temperature and, since the free energy of a particle is a function of its size, on heating the small nuclei are redissolved with a decrease in the overall free energy. It may be noted that the absorption of energy on heating was greater the longer the alloy had been aged at room temperature. The hardening process at room temperature is accompanied by the liberation of energy (as shown by Polish workers), this is due to the ordering of the solid solution by the formation of G-P zones.

In spite of the excellent agreement found between the absorption of energy on heating the aged Al-Cu alloys and the softening accompanying it (see Fig. 11h), the agreement in other alloy systems is not so good. In the case of Ag-Cu alloys, Cohen found⁹⁹ (Fig. 24) double ageing peaks, although as pointed out by Swindells and Sykes the effects were small, but no absorption of energy was detected on heating Ag-Cu alloys. Gayler⁷ found no retrogression on re-ageing Al-Mg-Si alloys, although the absorption of energy shown by the ST curve indicates that it should occur, and Swindells and Sykes found two maxima on the hardness-temperature curve. Reversion phenomena have also been found in Cu-Be alloys, although the effects were not large.^{52, 106} It can hardly be suggested that this result is not predicted by the ST curves because ageing does not occur in this alloy at room temperature, since Jones and Leech¹⁷⁹ found an absorption of energy in Al-Ag alloys that do not age at room temperature. It is difficult to understand why, if the dip in Fig. 11c at F is due to the θ' changing to θ ,

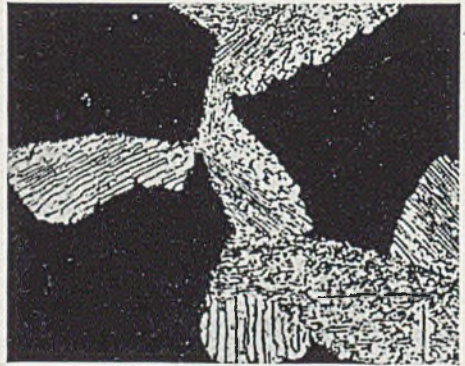


Fig. 64.—Colonies containing plates of γ growing from the grain boundaries into a matrix containing precipitated γ' . The alloy consists of aluminum with 20 per cent of silver, aged six hours at 303 deg. C.²²³ (Equivalent magnification in reproduction = 640 diams.)

as suggested by Swindells and Sykes, this alloy does not show the effects of growth of the particles of precipitate as shown by the Ag-Cu and Cu-Be alloys. The cause of the minima in Figs. 11f and g at C (in Fig. 11f) is obscure.

Objections to the simple precipitation theory in the case of Al-Cu alloys have often been based on the initial increase in electrical resistance that occurs on ageing the quenched alloy at room temperature. Most writers have considered that such an increase is anomalous. Mehl and Jetter¹³² have suggested that an increase in resistance on precipitation is anomalous only if it is considered that an alloy consisting of a finely divided phase dispersed throughout the matrix has the same electrical properties as an alloy in which the same phases are present in massive form. Mott (discussion of 95) pointed out that from the point of view of wave mechanic theory, small particles should give the alloy a very high resistance when their size is comparable with the wavelength associated with the conducting electron. This size is

given as 4 to 5 atomic distances. (This is of the same order of size as that given by Preston for the size of the G-P zones after natural ageing.) Fink and Smith¹⁷² have suggested that the increase in resistance passes through its maximum when the maximum number of particles possess the size equal to the wavelength associated with the conducting electron, the resistance decreasing with further increase in particle size.

However, if it may be argued that an increase in resistance is not anomalous in this system it remains to be shown why similar increases have not been reported in most other systems during low-temperature ageing, since presumably under some ageing conditions (of time, temperature, concentration) the size of the nuclei formed will be comparable with the wavelength associated with the conducting electron.

It seems probable that the formation of lattice strain accompanying the formation of nuclei

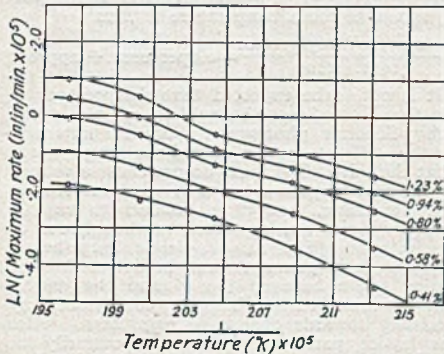


Fig. 65.—Effect of ageing temperature on the maximum rate of dilatation of various aluminium-silicon alloys.²²²

plays an important part in causing the increase in resistance. However, the correlation between these two effects is not at all clear.

It must be pointed out that although it is not necessary to regard the increase in resistance as an anomaly, it certainly indicates either that there is a fundamental difference between the mechanism of ageing in Al-Cu alloys and other systems, or that some stage of the process is much more sharply differentiated in these alloys. It may be suggested that the abnormality is most marked in Al-Cu alloys because in other systems the particles of precipitate break away from the matrix either before a high degree of lattice strain is reached or before the size of the particles approaches the wavelength associated with the conducting electron. In such a case, when this size is reached, the particles would no longer be continuous with the matrix lattice and may therefore cause no increase in resistance. This point could probably be checked by calculations similar to those of Nabarro.¹⁷⁴

The dilatation changes in Al-Cu alloys are abnormal, even if they are not considered anomalous. Fink and Smith (discussion of 172) believe that they can be explained on the basis

of precipitation of θ' at room temperature. Using Poisson's formula they calculate the probable number of groups containing a total of 16 atoms with varying proportions of Cu:Al in 1 mm.³ of a 4.78 per cent. Cu alloy (94 atoms of Al, two atoms of Cu). Fig. 60 shows the relation between the group of 16 atoms (with Cu to Al as 1 is to 3) in the solid solution (Fig. 60a) and the group of 12 atoms (Fig. 60b), forming the unit cell of θ' ; four of the aluminium atoms are lost, according to this mechanism, from the solid solution lattice when it transforms to θ' .

The volume of a 16-atom group in the matrix = $5.7 \times 5.7 \times 8.06 = 261.87 \text{ \AA}^3$ (a)

The volume of 1 unit cell of θ' = $5.7 \times 5.7 \times 5.8 = 188.44 \text{ \AA}^3$ (b)

The volume of a 4-atom group in the matrix = $4.03 \times 4.03 \times 4.03 = 64.45 \text{ \AA}^3$ (c)

The decrease in volume on the formation of 1 unit cell of θ' = $(a - (b + c)) = 7.98 \text{ \AA}^3$

With 14×10^{14} 16-atom groups/mm.³ present on quenching, each containing 4 atoms of copper, the decrease in volume during precipitation is

$$14 \times 10^{14} \times 7.98 = 11.2 \times 10^{15} \text{ \AA}^3/\text{mm.}^3 \\ = 11.2 \times 10^{-6} \text{ mm.}^3/\text{mm.}^3$$

This gives a change in length of

$$3.73 \times 10^{-6} \text{ mm./mm.}$$

With 17×10^{14} 16-atom groups/mm.³ each lacking one copper atom (assuming that this is supplied by diffusion), the decrease in length on precipitation of these groups is 45.2×10^{-6} mm./mm., or about 70 per cent. of the total change. (See Fig. 39.)

From the above Fink and Smith conclude that the volume change can be explained without bringing in the formation of new groups of atoms at the ageing temperature by chance diffusion. The calculations are based on the tacit assumption that the constant lattice parameter indicates that there is no change in the density of the matrix during room-temperature ageing.

However, it does not seem possible to reconcile this statement with the theory of Fink and Smith that the change in electrical resistance is due to the variation in the size of the nuclei, since it seems unlikely that regions containing the right proportions of copper and aluminium atoms would fail to transform as a whole, and if the variation in the size of the groups is due to diffusion, then new groups would also be formed by diffusion. Also, it is to be noted, Preston¹⁷⁵ states that the X-ray diffraction study of a single crystal of an Al + 4 per cent. Cu alloy indicates that after three days' natural ageing all the G-P aggregates are not dispersed on reverting at 200 degrees C., the larger ones remain. Thus while the correlation between the volume change and the number of 16-atom groups (with atoms in the ratio Cu:3Al) is good, it represents an over-simplification of the process.

On the basis of the dilatometer change and using the lattice parameter measurements given above it is possible to determine the percentage of copper atoms actually participating in the formation of G-P zones at room temperature.

* These figures are calculated from Poisson's formula.

As an example the writer has made the following calculation:—

Taking the contraction of a 4 per cent. Cu alloy at 30 degrees C. after 1,000 hours.

as 70×10^{-6} mm./mm. (Fig. 39)

this is equivalent to 210×10^{-6} mm.³/mm.³

or 210×10^{15} Å³/mm.³

To produce this volume change, the number of 16-atom groups/mm.³ each containing 4 atoms of copper is

$$\frac{210 \times 10^{15}}{7.98}$$

Number of copper atoms involved

$$\frac{210 \times 4 \times 10^{15}}{7.98}$$

65.45 \AA^3 of the solid solution contains 4 atoms
1 mm.³ of the solid solution contains

$$\frac{4 \times 10^{21}}{65.45} \text{ atoms}$$

1 mm.³ of the solid solution contains

$$\frac{4 \times 10^{21} \times 4 \times 2}{65.45 \times 4.78 \times 94} \text{ atoms of copper}$$

Thus the percentage of the copper atoms actually participating

$$= \frac{4 \times 210 \times 10^{15} \times 65.45 \times 4.78 \times 94 \times 100}{7.98 \times 4 \times 10^{21} \times 4 \times 2} \text{ per cent.}$$

i.e., approximately 10 per cent.*

A similar figure has been given by Preston¹⁰ based on X-ray data, although details as to the method used were lacking. The change in size of the nuclei during room-temperature ageing does not affect the above calculation, since the nuclei size is always a simple multiple of the size of the 16-atom group.

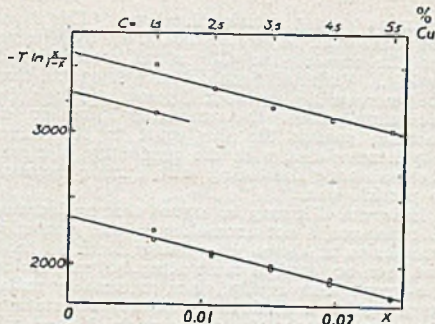


Fig. 67.—Diagram for the determination of the energy constants for the equations of the solubility curves given in Fig. 66.²²⁵

The percentage of atoms involved in the precipitation at room temperature is thus

$$\frac{16 \times 210 \times 10^{15} \times 65.45 \times 100}{7.98 \times 4 \times 10^{21}} = 0.6 \text{ per cent.} + \text{ approx.}$$

It is not to be expected that the presence of the first formed nuclei would be visible in the Debye-Scherrer photograph, since the intensity of the diffracted rays would be very weak. That the initial G-P zones do not cause a change in the lattice parameter as a whole is readily understandable, but it is difficult to explain why a definite etching effect, as though due to precipitation (Fig. 4), is visible long before any change in parameter can be detected. The lattice strain between the θ' and the matrix will to some extent help to counteract any tendency towards change of parameter. Also the lattice parameter will not necessarily be altered measurably if the regions depleted in copper are extremely small in volume (i.e., immediately surrounding the G-P zones), and as shown above only a very small proportion of the atoms probably take part in the process.

Factors Affecting the Rate of Agehardening and the Magnitude of the Property Changes. Little that is fundamental is known about the cause of the effect of the various factors described in these pages on rate of agehardening and magnitude of the property changes. The whole subject has been very much neglected and would repay detailed examination. The incubation period is a particular example of this. It may be suggested that the incubation period is a function of the time taken by the quenched solid solution to redissolve the small nuclei and form nuclei above the critical size which are able to precipitate. It might be possible to explain the increase in ductility shortly after quenching on this basis. While the relief of internal stress may cause the dilation effect noted in pure aluminium the rise in ductility would hardly be due to a similar cause; this could be proved by taking time ductility curves on pure aluminium test pieces.

* These values are probably an underestimate as there is no certainty that the lattice spacing of the G-P aggregates is necessarily exactly that of the θ' ; when the θ' is very small its lattice will probably be distorted by the surrounding matrix.

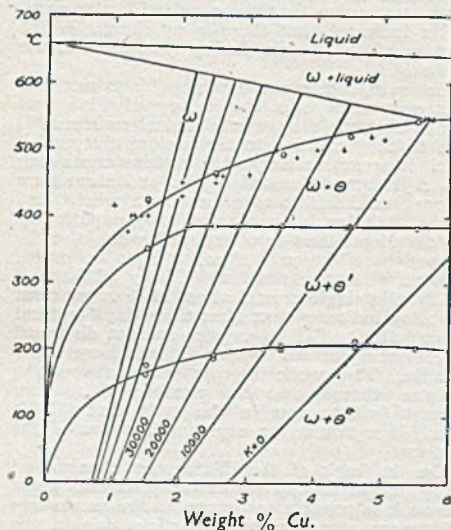


Fig. 66.—Solubility curves for θ , θ' , θ'' (the G-P zones) in aluminium-copper alloys, derived from heating curves of quenched specimens.²²⁵

The exact significance of the exponential relationships between the ageing temperature and the time to reach certain points on the ageing curves is not quite clear. The rate of diffusion possesses a similar relation; however, the agehardening does not depend solely on the rate of diffusion since factors such as particle size and the formation of strain between the particle and the matrix play an important part. Also the hardness, which is usually measured, is not a fundamental property of the material. It may be noted that in the case of the time to the first maximum on the time-hardness curve (Fig. 28) Gayler and Parkhouse did not obtain a straight line relationship between the reciprocal of the absolute temperature and the time required, although this may to some extent be because maximum hardness was not reached.

While it is apparent that the passage of an electric current does not affect the final properties, there is no evidence as to its possible effect on the rate of ageing, although this would presumably not be great. An authoritative paper dealing with the effect of rotating magnetic fields would be welcome as the present knowledge is in a very confused state.

The phenomenon of reversion has been cited by a number of writers as evidence that the process of ageing in Al-Cu alloys is different from that in other systems. Reference has already been made to the discrepancies in the experimental information available. Masing and Koch interpreted their results in the light of the hypothesis of Volmer and Weber, that each temperature possesses its critical nuclei size, and nuclei smaller than this are redissolved on heating since their free energy is greater than that of the original phase. The direct experimental work of Preston has given the cause as being due to the resolution of the G-P zones formed on ageing at the lower temperature, and the work of Swindells and Sykes confirms this. The G-P aggregates are continuous with the matrix, experimental evidence is lacking in these alloys (Al-Cu) as to whether reversion may be found when the size of the precipitate is fairly large and θ' definitely present. The retrogression found by Koch and Masing after "hot" ageing is to be expected as they aged for only one hour at 100 degrees C. before reverting. The hardening of Cu-Be alloys is generally taken to be due to actual precipitation, in which case the particles of precipitate will possess an interface with the matrix. That reversion occurs in these alloys is not direct evidence that areas analogous to G-P zones in the Al-Cu alloys are actually formed. X-ray diffraction investigations are required to prove this point. It is probable that whether or not reversion is detected is a function of the rate of growth of the particles precipitated at the lower temperature, even particles that have broken away from the lattice of the matrix will still possess surface energy and should therefore behave as predicted by Volmer and Weber, but where the rate of growth of the particles is large the critical particle size corresponding to the higher temperature may be exceeded before the temperature is raised.

There seems to be no published information dealing with the effect of reversion on the etching characteristics of Al-Cu alloys. It

would be of considerable interest to examine this point, since some indication would probably be obtained as to whether the precipitate within the grain boundaries is also dispersed as well as the precipitate within the crystals themselves. Solution potential measurements may also be effective in clearing up this point.

The experimental evidence now available disposes of the "overageing theory" of reversion in favour of the theory based on the existence of a critical nuclei size (as described above). According to the "overageing theory," pre-precipitation is given as the cause of room-temperature ageing. On raising the temperature the first effect is to cause actual precipitation of all the regions in which the pre-precipitation has occurred, this being accompanied by softening. On further ageing at elevated temperature the pre-precipitation effect occurs again and leads to the increase in hardness which is finally followed by softening due to precipitation and coalescence. This is, however, disproved by a number of facts: (i) X-ray data, (ii) Hartnagel found no variation from the electrical resistance of air-cooled specimens on reversion, and if the overageing theory were correct a drift in the resistance of the reverted alloy would be apparent, (iii) the overageing theory predicts a decrease in internal energy on reverting, whereas Swindells and Sykes found an increase in the apparent instantaneous specific heat on heating naturally aged specimens.

There seems to be no published information available as to possible changes in properties on natural ageing after an artificial ageing treatment. As indicated before, only a few of the copper atoms take part in the precipitation process at room temperature, even assuming that more than 50 per cent. of the copper atoms are precipitated in the form of large G-P zones during an artificial ageing treatment, it seems possible that a further precipitation will occur on standing at room temperature by the formation of G-P aggregates below the critical size corresponding to the elevated temperature. Even if only 20 per cent. of the copper atoms remain in the solid solution, precipitation of half of these would affect the properties and it would be of considerable interest to investigate this possibility.*

Plastic deformation increases the rate of precipitation by setting up points in the crystal lattice of high energy content, these aid precipitation by contributing energy to the formation of nuclei. This effect will be aided where diffusion is accelerated by cold work. The effect of cold work immediately after quenching may be to make the final properties lower than they would otherwise be; this is apparently because precipitation occurs in regions which have already been strengthened by cold work and is therefore much less effective in proportion to the amount of precipitation involved. The maximum properties are obtained by cold working after agehardening, but the cause of afterhardening (see Fig. 29) is not at all clear, unless it is due to extra precipitation in the deformed regions.

* The writer now finds that work of Dreyer¹¹ has covered this, although the artificial ageing was carried out after reverting, and confirms the suggestion.

The importance of the effect of prior history on the rate and capacity of agehardening has been overlooked by some investigators. It is obvious from the experimental results described that it would be unwise to attempt to correlate property and structural changes in two or more specimens of the same alloy that have been prepared by different methods, e.g., wire is used for electrical conductivity measurements, but more massive specimens are used for hardness and dilatometry. In order to make the correlation exact, structural and property changes must be followed simultaneously on the same specimen.

The subject is in a very confused state, much of the evidence is contradictory, although it is well established that prior history can be very important. Theories that have been put forward to explain the phenomena may be divided into two types: (a) those explaining the effect of grain size on the basis of different degrees of supersaturation obtained by solution heat-treating alloys of the same composition but different grain sizes at the same temperature.^{31, 32} This involves the idea that the solid solubility is a function of the grain size.

(b) those introducing the presence of a mosaic structure.^{33, 34, 35, 36}

Work of Gisen³⁷ has indicated that recrystallized single crystals of aluminium possess a more pronounced mosaic structure than cast single crystals, and varying amounts of mosaic structure are ascribed to explain the results obtained by different investigators. A more rapid rate of ageing is said to be due to precipitation occurring more easily in the boundaries between the mosaic blocks. However, the examination for the presence of a mosaic structure is difficult and there seems to be no direct evidence available as to how the degree to which the mosaic structure is present is affected by the method of preparation.

Differences in the property changes recorded by different investigators on the same alloy, and differences in the rate of ageing have been ascribed to the effect of grain size and the method of preparation¹²³ and such is probably the case, although this merely serves to show the lack of knowledge on the subject.

The whole subject of the effect of grain size, and method and degree of working on the solid solubility, rate of agehardening and the magnitude of the property changes should repay intensive investigation.

There is general agreement that one effect of iron on Al-Cu alloys is to lower the agehardening capacity by the formation of an insoluble Al-Cu-Fe compound; however, there is disagreement as to the existence of the large reduction in ageing capacity found by some investigators on the addition of small quantities of iron. Petrov considers that the explanation must be found in the effect of iron on the lattice structure of the solid solution. His curves are drawn on the basis of Gayler and Preston's results on high purity Al-Cu alloys, and in view of the possible effect of prior history it cannot be taken that this is wholly justifiable.

Hunsicker believes that the whole effect (cold-water-quenched alloys) is explained by the removal of copper from the solid solution; however, this does not explain the greater reductions in ageing capacity found by other workers

on the addition of very small quantities of iron. (It may be pointed out here that the curves of Fig. 46 are not all correctly drawn, the curves for the results of the boiling-water-quenched specimens and for the results of Koch and Nothing should be taken up to a value of about 26½ B.H.N., showing in these cases also that the effect of the first addition is greater than that of larger additions.) The work of Koch and Nothing is frequently quoted as showing that the effect of iron is proportional to the amount of copper it withholds from the solid solution, but it should be noted that these authors themselves state that the effect of the first addition is greater proportionally than that of subsequent additions. Petrov has suggested that Koch and Nothing used alloys containing magnesium on the basis of his experiments on Al-Cu-Fe-Mg (0.05 per cent.) alloys. Hunsicker suggests that his experiments show that iron has a greater effect than had hitherto been reported, as his curve for the cold-water-quenched specimens Fig. 46 is to the left of the others; however, it seems to the writer that the difference lies in the low ageing capacity of the pure Al-Cu alloys rather than in the reduction in ageing capacity due to the iron, and as Hunsicker points out this may be due to the very low magnesium content of his alloys (0.0005-0.001 per cent.).

The authors of the two most recent papers^{144, 147} consider that the effect of iron can be explained entirely on the basis of the removal of copper from solid solution, but it may be pointed out that the evidence cannot be regarded as conclusive on this point. It would seem more than merely a coincidence that in all cases shown in Fig. 45, with cold-water-quenched specimens aged at room temperature, the increase in hardness of the ternary alloys is less than that of the binary alloys with the same amount of copper in solid solution, this effect being greater with small quantities of iron.

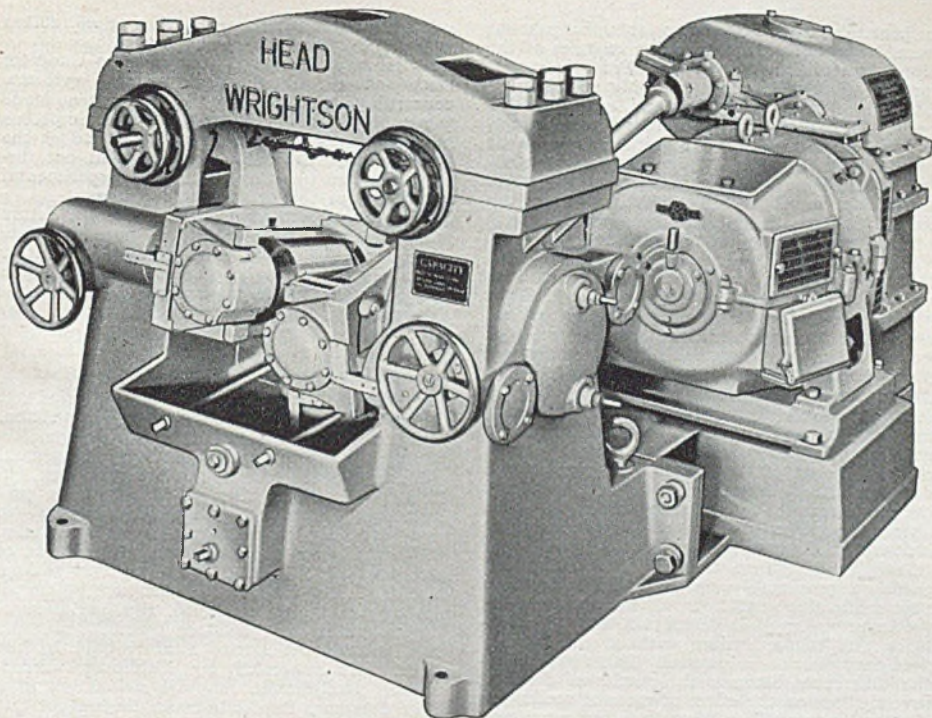
A full solution of this question would require X-ray diffraction investigations, although there is no doubt that the major effect of iron is to withhold copper from solid solution.

Petrov¹¹² attempted to explain the dilatometer results of Igarasi (Fig. 49) on Al-Cu-Mg alloys as being due to the precipitation of Al₂Cu₃Mg₂ as well as to CuAl. The alloys that gave the greatest expansion (Cu 4 per cent., Mg 2 per cent.; Cu 2 per cent., Mg 0.5 per cent.) contain the amounts of copper and magnesium to form this ternary compound.

Fink, Smith and Willey consider that the effect of magnesium in Al-Cu-Mg alloys is due to the precipitation of β' (Al-Mg) (a transition lattice of β (Al-Mg)) and θ'. Their argument is based on their dilatation curves (see Fig. 50), and it was suggested that with up to 1.5 per cent. Mg the expansion is due to the precipitation of β' (Al-Mg), the subsequent contraction being due to precipitation of θ'. However, no suggestions were made to show why this contraction is more than twice that of the binary alloy.

Archer has put forward the view that the more rapid ageing of Al-Cu-Mg alloys is because the magnesium atoms expand the aluminium lattice and thereby allow easier diffusion of the copper atoms.

None of the explanations is satisfactory; it



HEAD, WRIGHTSON *Aetna Standard* REELERS

The illustration is of a Reeler suitable for 2-in. steel bars. The machine is of robust construction, simple to adjust, has a totally enclosed gearbox and well-designed flexible spindles. The machine is capable of dealing with a wide range of sizes.

For Bar, Tube, Sheet and Strip Mill Equipment consult—

HEAD, WRIGHTSON & CO. LTD.

Consultants, Designers and Builders to the Steel and Non-Ferrous Industries

THORNABY-ON-TEES



22-L.

ENGINEERS TO THE EMPIRE

is probable that magnesium acts, in part at least, by altering the interaction energies of the aluminium and copper atoms. Petrov's results for the effect of 0.03 per cent. Mg on Al-Cu-Fe alloys is difficult to understand on any other basis. Here again X-ray diffraction and microscopic investigations are required. It may be pointed out that the addition of 0.04 per cent. Mg would give approximately one atom of magnesium in all the unit cells of θ' that participate in precipitation at room temperature.

No general theory as to the effect of the small quantities of added elements, other than that of Sohnchen,⁶⁹ has been put forward to account for the results discussed above. It is generally possible to give the cause of the effects due to large additions, from microscopic examination, but the explanation of the changes produced within the solid solution await X-ray diffraction analysis.

It is probable that the faster rate of ageing found by all investigators brought about by a reduction in the quenching rate is due to a certain amount of "seeding" or "nucleation" during cooling. Sohnchen⁶⁹ has suggested that the profuseness of any mosaic structure may be altered by different rates of cooling from the heat-treatment temperature.

It is evident that the rate of cooling and therefore, presumably, the effect of this rate on any nucleation effect is a function of the specimen size, and there may be critical conditions that allow seeding without causing the final properties to be lowered. This may explain the differences between the results of different investigators on the effect of rates of cooling on the final properties, although as indicated previously these may be due to the fact that their conclusions were based on the changes in different mechanical properties.

Conclusion. The information at present available dealing with the phenomena accompanying precipitation from metallic supersaturated solid solutions, and with the effect of a number of factors on the rate of precipitation and the magnitude of the property changes, has been surveyed critically.

The theory of the process of precipitation has been described, together with the actual precipitation process in Al-Cu alloys. Particular attention has been given to correlating the significance of the different mechanical and physical property changes with the experimental observations of the structural alterations, and with the theoretical studies. It is possible to explain only a small part of the experimental evidence satisfactorily, and while a larger portion can be explained in rather vague terms very much is as yet inexplicable.

Discrepancies in the experimental evidence and regions of the subject in which present knowledge is scanty, have been pointed out; these could suitably serve as a basis for future research work.

The theoretical meaning of the variations in the rate of precipitation under different conditions is discussed, although fundamental knowledge of many of the phenomena is almost non-existent. Experimental investigations into this subject would be amply repaid by the results.

There is considered to be no fundamental difference between the "precipitation" and "pre-precipitation" theories as they were

originally formulated, since they were stated without definition of "precipitation."

As far as is known to the writer, a complete discussion of all the experimental evidence concerning agehardening has not been made previously, and, in particular, little attempt has been made to correlate the significance of the various property changes, or to point out discrepancies in the theoretical and experimental knowledge of the precipitation process.

It is probable that much work in the future will be directed to gaining a more complete insight into the atomic rearrangements operative in the first stage of the precipitation process, in this connection it is particularly desirable that as many systems as possible should be examined.

APPENDIX

Fundamental Work Published Since 1942

IN general, the fundamental work carried out since the bulk of this account was written, whilst clarifying the subject in some ways, has produced no revolutionary changes in outlook.

Jones, Leech and Sykes²¹⁴ found that, in Cu-Ag and Ag-Cu alloys, discontinuous precipitation occurred with high degrees of supersaturation and low ageing temperatures. Differences were observed between the rate of precipitation in single and polycrystalline materials. In view of the difference in size of the copper and silver atoms, the formation of an intermediate structure would not be expected, as the lattice strain would be too great. As suggested by Dehlinger, discontinuous precipitation may be a function of a large difference in size between the solvent and solute atoms.

The mechanism of precipitation in Al-Cu and Al-Ag alloys has been further studied by Guinier using X-rays. Precipitation in Al-Ag alloys was described as occurring by the collection of silver atoms at irregularly distributed centres, followed by the transformation of these nuclei into the equilibrium phase without the formation of a transition lattice.²¹⁷ In Al-Cu alloys²¹⁸ the first stage in precipitation was the collection of copper atoms on the (100) planes of the matrix. This was followed by the formation of a superlattice with short range order; in these regions the concentration of copper atoms reached a maximum at every fourth (001) plane of the "precipitate," accompanied by slight changes in the interplanar distance. This structure is then transformed into θ' , which may, itself, be transformed into θ .

In continuation of their earlier work,¹⁹¹ Geisler, Barrett and Mehl (223) found, by X-ray examination, that aluminium alloys containing 10, 20 or 30 per cent. silver formed the coherent transition lattice on precipitation at all ageing temperatures, this later transformed into the stable equilibrium precipitate. It was also found that the transformation from transition to stable precipitate was accompanied by a discontinuous type of reaction nucleated at the grain boundaries, and probably by recrystallization of the matrix. Fig. 64 shows several colonies of γ plates with different orientations growing into a matrix which contained the transition precipitate (γ'). Hardening which accompanied the formation of the intermediate precipitate was attributed to lattice strain

around the coherent particles. The mechanism of the change from intermediate to stable lattice of the precipitate was not clear, involving as it did some re-solution and diffusion.

X-ray examinations were also made²²⁴ of precipitation in Al-Mg, Al-Zn, and some Mg-base alloys. In all cases, evidence was found that the fundamental mechanism of the change was the same as in Al-Ag alloys, although the transition phases were of very small size when they broke away from the matrix. It appears that the authors regard these two papers as producing strong additional evidence, by inference, that in Al-Cu alloys the G-P zones are θ' in an extremely fine state of subdivision.

It has previously been reported that the logarithm of the rate of precipitation is a linear function of the reciprocal of the absolute temperature (71), the relationship possessing the following form:—

$$V = C'e^{-Q'/RT}$$

where V = the rate of precipitation,
 Q' = the activation energy for precipitation,
 C' is a constant.

However, Jetter and Mehl²²² did not obtain a straight line when the logarithm of the maximum rate of volume change in Al-Si alloys was plotted against the reciprocal of the absolute temperature (see Fig. 65). They point out that from Becker's expression for the rate of nucleation, viz.:

$$I = C_e^{-Q + A}/RT$$

where I = the rate of nucleation,
 C = a constant,
 Q = the activation energy for diffusion,
 A = the work required to form a nucleus,

an exactly linear relation between I and the reciprocal of the absolute temperature is not predicted. It is approximated to at low temperatures, in which case

$$Q' = Q + \left\{ A + \frac{1}{T} \cdot \frac{\delta A}{\delta T} \right\}$$

since A is very small and increases with increasing temperature, the quantity in the brackets is negative, and therefore Q' should be less than Q .

Thermodynamical theory has been used by Konobeevski²¹⁹ and by Borelius *et al.*²²⁵ The former calculated the number of particles of precipitate formed on natural ageing of Al-Cu alloys, making use of the Thomson-Freundlich formula for the relation between concentration, size, temperature, surface tension, density and molecular weight of the particles of the second phase. This paper, which is entirely theoretical, is useful in indicating the possibilities and limitations of the application of thermodynamical theory to such a complex problem as precipitation from solid solutions.

Borelius *et al.* made thermal analyses on Al-Cu alloys on the lines of those by Swindells and Sykes. The apparent solubilities of θ , θ' , θ'' (the G-P zones) were derived from the change of direction of the experimental differential temperature-temperature curves and are

given in Fig. 66. Fig. 67 shows these solubility curves plotted to obtain the energy constants for their equations. Measurements were also made of the heat evolved during natural ageing, and in general this was approximately half the value calculated from free energy considerations and the equation for the solubility of θ' . A 4 per cent. Cu alloy evolved approx. 1 cal/gm on natural ageing, leaving 1 cal/gm to be accounted for by an increase in strain energy. Very approximate calculations by the writer give a value for the strain energy of the same order of magnitude.

Discussion

Very great progress has been made since the existence of the G-P zones was first recorded in 1938. Evidence has been produced to show that transition precipitates are formed in at least a number of systems. The hardening accompanying the decomposition of a supersaturated solid solution is now associated chiefly with the lattice strain induced by the presence of a coherent "precipitate," the nature of which has not been entirely cleared up.

It is still not possible to say whether precipitation in Al-Cu alloys is essentially a "two-stage" or "three-stage" process (and Guinier has proposed a "four-stage" process). Barrett *et al.* have interpreted the X-ray evidence in favour of the "two-stage" process, but it appears to the writer that more general evidence favours the "three-stage" mechanism; much work remains to be done on this point, particularly in the correlation of as many structural and property changes as possible on one specimen or under similar experimental conditions.

BIBLIOGRAPHY

- 210.—R. H. Harrington, R. G. Thompson, *Trans. A.S.M.*, 1940, 28 (4), 933. 211.—H. Unckel, *Metallwirts.*, 1940, 19 (3), 37. 212.—K. L. Dreyer, H. Seemann, *Aluminium*, 1941, 23 (9), 437. 213.—J. H. Frye, Jr., W. Hume-Rothery, *Proc. Roy. Soc.*, 1942 (A), 181, 984, 1. 214.—F. W. Jones, P. Leech, C. Sykes, *Proc. Roy. Soc.*, 1942 (A), 181, 985, 154. 215.—H. Unckel, *Metallwirts.*, 1942, 21 (13/14), 185. 216.—H. Unckel, *Metallwirts.*, 1942, 21 (35/36), 531. 217.—A. Guinier, *Compt. rend.*, 1942, 214 (1), 34. 218.—A. Guinier, *J. Phys. Radium*, 1942, viii, 3 (7), 124. 219.—S. T. Konobeevski, *J. Inst. Met.*, 1943, 69, 307. 220.—J. H. Frye, Jr., J. W. Caud, *Trans. A.I.M.M.E.*, 1943, 152, 75. 221.—J. H. Frye, Jr., J. W. Caud, R. M. Treco, *Trans. A.I.M.M.E.*, 1943, 152, 83. 222.—L. K. Jetter, R. F. Mehl, *Trans. A.I.M.M.E.*, 1943, 152, 166. 223.—A. H. Geisler, C. S. Barrett, R. F. Mehl, *Trans. A.I.M.M.E.*, 1943, 152, 182. 224.—A. H. Geisler, C. S. Barrett, R. F. Mehl, *Trans. A.I.M.M.E.*, 1943, 152, 201. 225.—K. Borelius, J. Andersson, K. Gulberg, *Ingenjörsvetenskaps, Akademien*, 1943, *Handlingar* No. 169. 226.—R. H. Harrington, L. E. Cole, *Trans. A.S.M.*, 1943, 31 (3), 651.

NOTE.—Attention is drawn to the following error which occurred in the first part of this survey, on page 341 of "Light Metals" for July. The last paragraph should read—"Instantaneous specific-heat/temperature curves for some agehardening alloys."

NEW BOOKS REVIEWED

Extrusion of Metals

WRITTEN by Clifford E. Pearson, M.Met. (Sheffield), head of the Metallurgy Department, King's College, University of Durham, and published by Chapman and Hall, Ltd. (18s. net), a 200-page manual entitled "The Extrusion of Metals" fills most adequately a space too long vacant on the metallurgical bookshelf.

In his foreword, Genders (now attached to the Ministry of Supply) pays tribute to the research work carried out by the author himself in the field upon which he writes with such authority. No better recommendation is required than examination of the contents, which include:—Historical survey; extrusion of lead and other soft metals; extrusion of lead cable sheathing; equipment for the hot extrusion of hard metals; flow in metals during extrusion; pressure of extrusion; metals and alloys for hot extrusion; properties of extruded metals;

impact method of extrusion, and some special applications of extrusion.

In relationship to the last section, it is interesting to note that reference is made to the compacting of metal powder by extrusion (tungsten and hard carbides are singled out for special mention).

Chapter 9, dealing with impact extrusion, complete as it is in the light of modern knowledge, does indicate the vast amount of work which must still be done before our insight into the fundamental theory of this technique can be considered complete. Already industrial practice is demanding data, not yet available, which are of vital importance for the rapid maturing of many post-war plans. For example, a curve relating impact-pressure required, to diameter of the extrusion produced, would be exceedingly valuable to the production engineer and to works planning departments.

Metals in the Service of Man

THIS Pelican book by Doctor Alexander and Doctor Street (or by Doctor Street and Doctor Alexander—for the order of precedence on the title page is opposite to that given on the cover) will fulfil an ever-present need. There is a growing number of people who, even if they are not, and do not intend to be, metallurgists or foundry technicians, should be intelligent about metals. One may recall a cost accountant on the staff of a light-alloy concern of national fame, who asked whether anyone had ever thought to weigh castings and forgings after solution treatment in a salt bath to determine how much metal was lost! It was necessary to explain that the solution concerned constituents within the alloy, and not, of course, dissolution of the alloy itself.

There is no need to feel superior because of an accountant's misunderstanding of what, after all, is a technical term. There is, however, cause for alarm when the same sort of ignorance is frequently met in quite a number of apparently capable engineers and Government inspectors, who, when chided gently, with one voice reply: "But I don't really know anything about metals."

This book is a thrilling example of what really first-class popular scientific journalism should and can be. Street and Alexander have shown themselves to be expositors of the first order. The reader is taken through the complete drama of metals—ferrous and non-ferrous, ultimate structure, mechanical testing, working by all the accepted methods—a chapter on powder metallurgy gives up-to-the-minute information, with a provocative, suggestive chapter on the future of metals concluding the 190 absorbing pages.

Naturally, it is to the sections on aluminium and magnesium alloys that the reader of this journal will be likely to give his critical eye. The salient points of aluminium metallurgy, at least in relation to fabrications, are quite adequately dealt with. If one thinks over the

range of aluminium subjects, there does emerge, however, a vague question: have the authors made the whole business of production metallurgy appear too easy? There might have been value and instruction, even for the lay reader, in detailing the difficulties often met by the foundryman in producing castings free from gas porosity. Perhaps this admittedly half-hearted criticism is really a tribute to the book's general excellence and completeness; we are told so much that we think we ought to be told a lot more.

Care has been taken to lay the inflammability bogey in respect of magnesium alloys: it is demonstrated that the properties of the incendiary bomb are not a true guide to the engineering use of the metal. That the large proportion of the chapter on magnesium spent on this subject is justified, all magnesium-minded metallurgists will agree. It is refreshing also to be told that corrosion difficulties are not serious. If this book reaches the sort of reader by whom we hope it will be adopted, it will perform a useful service to the ultra-light alloy industry. It is gratifying to see that England's part in the "magnesium-from-sea-water" business is at last given a place in the metal history of our time.

This book should be in the private reference library of every engineer, and should be interest-reading in junior technical schools. By no means least—every works metallurgist should possess a copy for the edification of operatives who want to know just that little bit more of their own job.

It was Galsworthy, writing of the Forsyte era, who said that the spirit of the time seemed to be "Nothing for nothing, and very little for sixpence." Galsworthy's age has given place to better things it seems, for here we have for ninepence (war-time sixpence) the most adequate popular treatment of the whole field of metallurgy, colourful, but quite unexaggerated, that we have yet seen.



The last 'General' horse bus leaving London Bridge station for Moorgate, Oct. 25, 1911

WHEN WE WERE YOUNG

Time could no longer wait for the horses, it was marching quickly on to a new era. It is significant that Cellon should be founded in that year, Cellon that was to become so closely associated with the progressive and new industries. As we look back over those thirty odd years we see how close are the parallel lines of Cellon's development and the trend of industrial progress. It is true to say that each has helped the other.

CELLON LTD., KINGSTON-ON-THAMES TELEPHONE: KINGSTON 1234 (5 lines).

The perfect finish

CELLON
CERRIC CERRUX

A new
COPPER BASE ALLOY
with Hardness, Strength
and Conductivity

"KUMIUM"

"Kumium" is the trade name of this new alloy developed by I.C.I. Metals Ltd. and possessing these properties to a remarkable degree. It is particularly suitable for use as electrodes in spot or seam welding machines and retains its strength for continuous service at temperatures of the order of 350°C. Available in rod, plate, sheet and sections, "Kumium" can be supplied to give the following range of properties:

Maximum stress	23-30 tons/in 2
Elongation	20-15% on 2"
Conductivity	82-80% that of H.C. Copper

Please write for further information to:

I.C.I. METALS LTD
WITTON, BIRMINGHAM



Sales Offices at:

MILL HILL, LONDON, N.W. 7 · BELFAST · BRADFORD
BRISTOL · CARDIFF · DUBLIN · GLASGOW · LIVERPOOL
MANCHESTER · NEWCASTLE-ON-TYNE · SHEFFIELD
SHREWSBURY · SWANSEA · YORK

M.31



**BRIMULTA
BLUE**
(TRADE MARK)

The only flux combining degasifying, fluxing
and refining, guarantees first-class sound
CASTINGS in Aluminium and Light Alloys.

BRIMULTA FLUXES
are inexpensive because
of their economical use
and powerful effect.

Export enquiries & Representatives invited.

Full details from
MULTIPLE ACTING FLUX LTD.
SHEFFIELD, 1 & 10

Telegrams:
"Brimulta, Sheffield."

Telephone:
Sheffield 613381 & 23808

ILFAR

ON A.I.D.
APPROVED LISTS

ALUMINIUM
CO. LTD.

Aluminium Alloy Ingots to Specification
CANLEY COVENTRY Phone 3673

PITMAN

THE PRACTICE OF ARC WELDING

By *W. Heigh*. Presents the fundamental principles of successful welding in a simple, convenient and practical light, and contains a wealth of data based on the experience of welders of all kinds. 5s. net.

PANEL BEATING & SHEET METAL WORK

By *Sidney Pinder*. A practical guide for all students and apprentices who are connected with this branch of metal work, particularly the motor and aero trades. 4s. net.

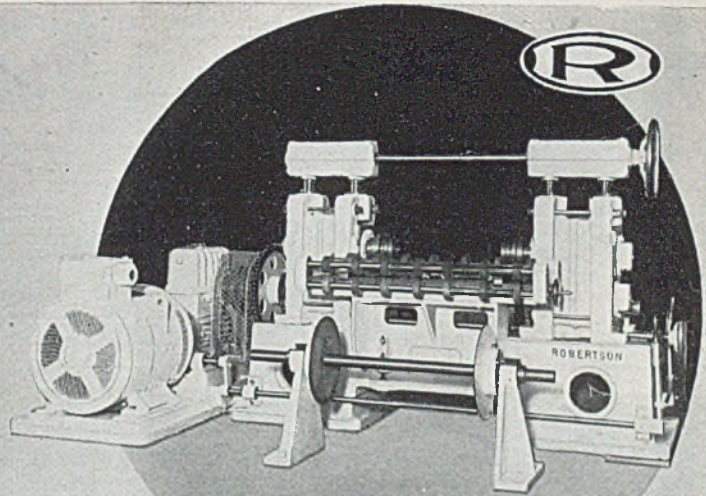
PARKER
STREET

KINGSWAY
W.C.2

BOOKS

TRIMMING & SLITTING EQUIPMENT

Double Head Edge
Trimming Machine for
Aluminium alloys from 12"
to 40" wide and up to
1/2" thick complete with
unwinding stand, scrap
edge winder and coiler.

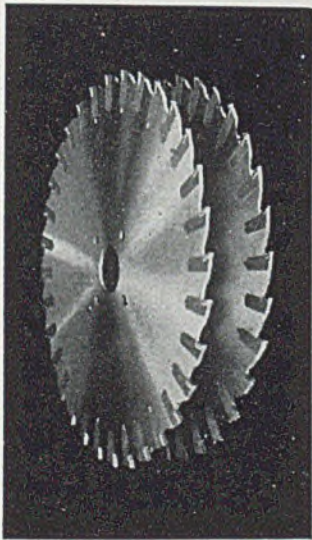


ROBERTSON

W. H. A. ROBERTSON & CO. LTD

BEDFORD

ENGLAND



FIRTH BROWN "MITIA" CARBIDE TIPPED SAWS

ESSENTIAL TO HIGH-SPEED
PRODUCTION

SPEEDS IN EXCESS OF 3,000 FT.
PER MINUTE WITH HIGH RATES
OF FEED

Saws are fitted with renewable
inserted teeth

THOS FIRTH & JOHN BROWN LTD

SHEFFIELD

HARDENERS

"LION BRAND" AND ALUMINIUM MASTER ALLOYS

ALUMINIUM alloyed with
MANGANESE, TITANIUM, CHROMIUM,
NIOBIUM, TANTALUM, TUNGSTEN, BORON,
VANADIUM, ZIRCONIUM, MOLYBDENUM,
IRON, SILICON, MAGNESIUM, NICKEL, ETC.

ESTABLISHED 1869

Telegrams - Blackwell, Liverpool.
Telephone - Garston 980 (3 lines).

BLACKWELL'S METALLURGICAL WORKS LTD.
THERMETAL HOUSE, GARSTON, LIVERPOOL 19
Works: Banks Road, Speke Road and Church Road, Garston

To SMELTERS & USERS of ALUMINIUM
LARGE QUANTITIES of SEGREGATED

Aluminium Alloy Turnings & Solid Scrap

AVAILABLE for IMMEDIATE DISPOSAL

R. J. COLEY & SON (HOUNSLOW) LTD. LONDON
BIGGLESWADE

JUBILEE WORKS, CHAPEL ROAD, HOUNSLOW, MIDDLESEX MANCHESTER



COMMERCIAL X-RAYS LTD.
LONDON & BIRMINGHAM

These A.I.D. Approved Laboratories are now used exclusively by all leading Aircraft Producers for the X-Ray Examination of Class I and Class II Castings.

INDUSTRIAL AND METALLURGICAL X-RAY SERVICE

LONDON LABORATORIES:
Grove Works, Grove Place, ACTON, London, W.3.
Head Office and Midland Laboratories:
53, Wentworth Road, Harborne, BIRMINGHAM, 17.

MISCELLANEOUS

MONOMARK Service, Permanent London address. Letters redirected 5/- p.a. Write BM/MON092, W.C.1. 843124

ALUMINIUM CASTINGS

SAND & GRAVITY DIE CASTINGS
FOR ALL TRADES

The
BRIDGE FOUNDRY CO., LTD.
WEDNESBURY · STAFFS

PHONE: WEDNESBURY 0109
GRAMS: ALSPELCO, WEDNESBURY

SUBSCRIPTION RATES: *Light Metals* will be sent post paid for one year for 20/-. Shorter periods pro rata. Send remittance to the publishers.

DYSONS

Dependable DIE CASTINGS

Complete range of Gravity and Pressure Die Castings in Aluminium Zinc Base · Lead Base · Tin Base

Specialists in
Pressure Castings in
ZINC, LEAD and TIN
BASE, also Gravity
Castings—BRASS and
ALUMINIUM BRONZE
A.I.D. APPROVED

DYSON & CO., ENFIELD (1919) LTD., Southbury Works, Ponders End
TELEGRAMS: - DIESINKER. PHONE, ENFIELD.
TELEPHONE: HOWARD, 1484 (5 LINES)

ON, TO VICTORY



They depend

on you!

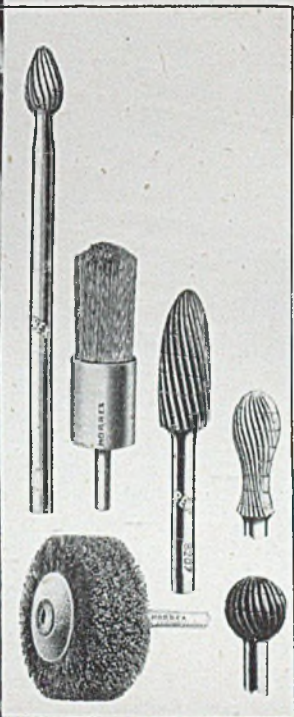
You depend on

Morrisflex

FLEXIBLE SHAFT EQUIPMENT

It will not let you down

B·O·MORRIS LTD. SHIRLEY. BIRMINGHAM.



dependability...

We cannot claim that you depend upon our furnaces quite so much as an airman does upon his parachute. It is hardly a question of "life or death," but rather one of a high standard of dependability that present conditions have taught you to expect. This then, is the aim behind all our endeavours.



The illustration features a complete installation for the heat treatment of forgings. The plant consists of heat treatment furnaces, quenching tanks, loading racks and an electrically operated High Speed Charging Machine.

