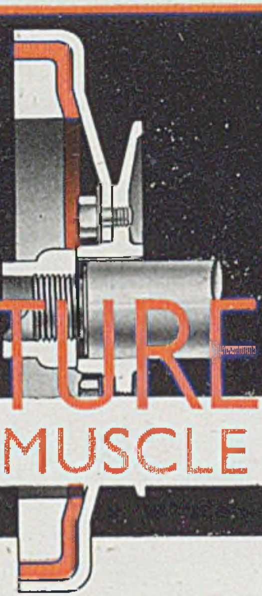
LIGHT ALLOYS IN CIVIL ENGINEERING

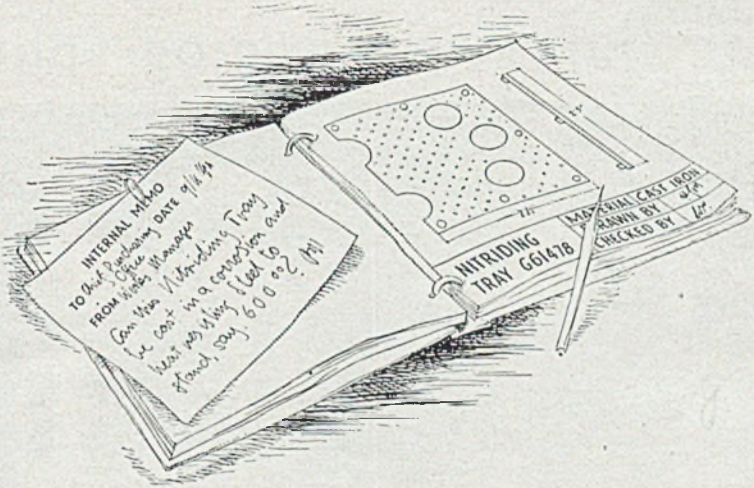
LIGHT METALS

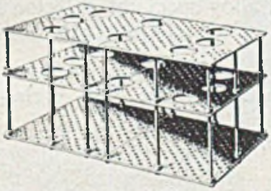
DECEMBER
1944

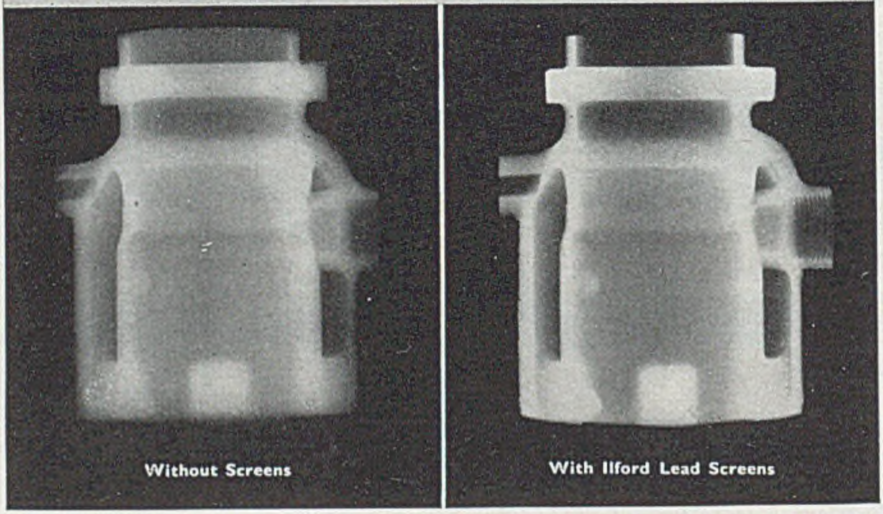
1/6

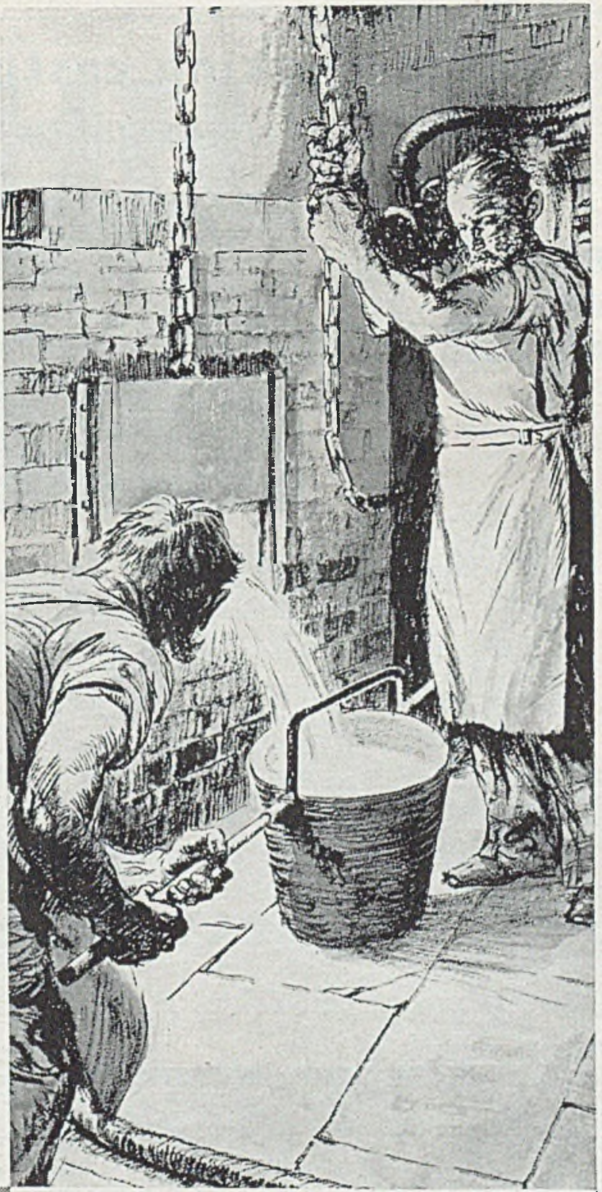
83




INTERNAL MEMO
TO Chief Purchasing Officer DATE 9/12/44
FROM Works Manager
Can this Nitriding Tray be cast in a corrosion and heat resisting steel to stand, say, 600°C? J.H.
NITRIDING TRAY G61478
MATERIAL CAST IRON
DRAWN BY
CHECKED BY

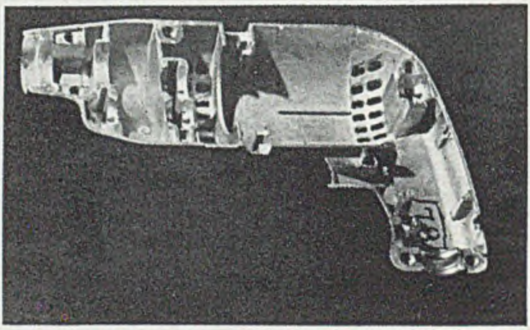



Without Screens
With Ilford Lead Screens



A fine-looking casting

—but is it as good as it looks?



Photograph of a light-metal casting (by courtesy of the Wolverhampton Die Casting Co. Ltd. and Messrs. Wolf Tools Ltd.)

The radiograph decides. It shows only slight traces of porosity, quite without detriment in use. It confirms that the casting is as good as it looks.

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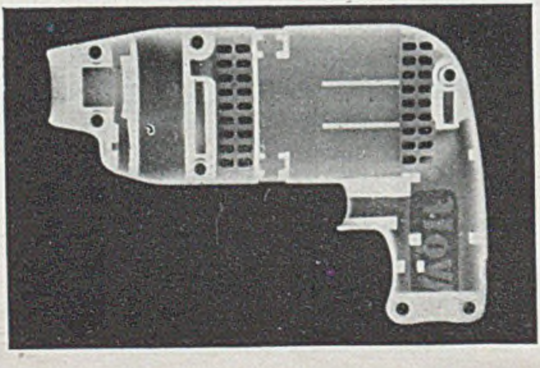
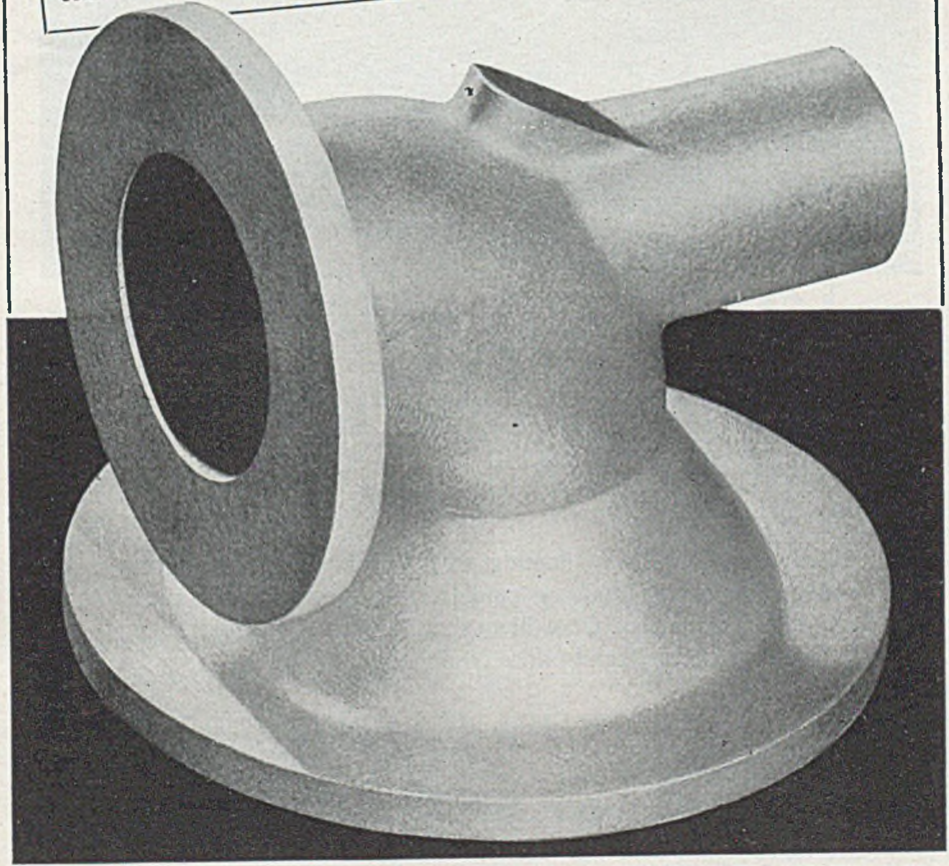


Radiograph of the same casting.



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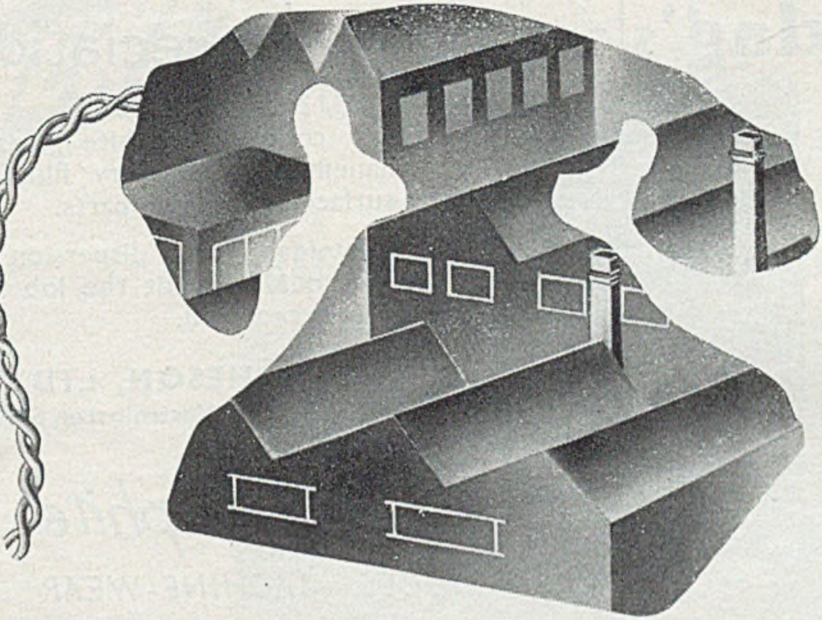

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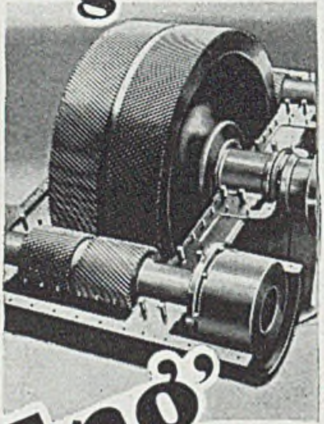

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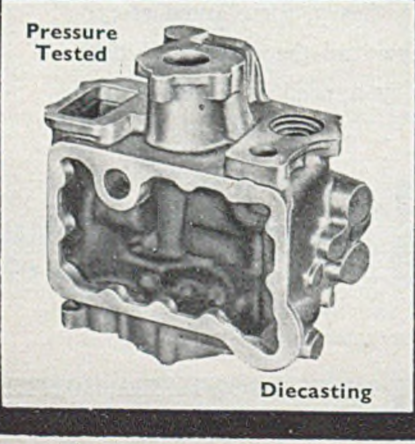

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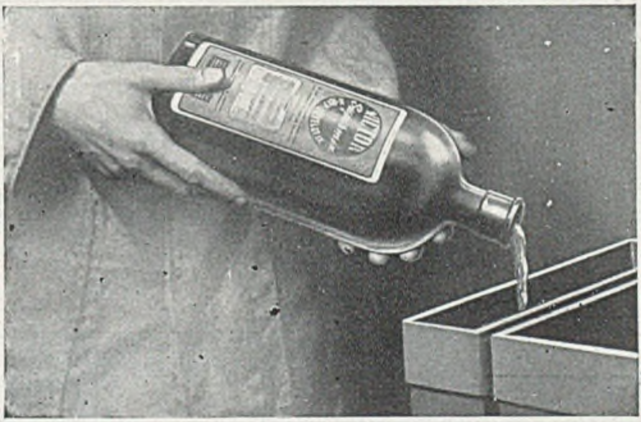

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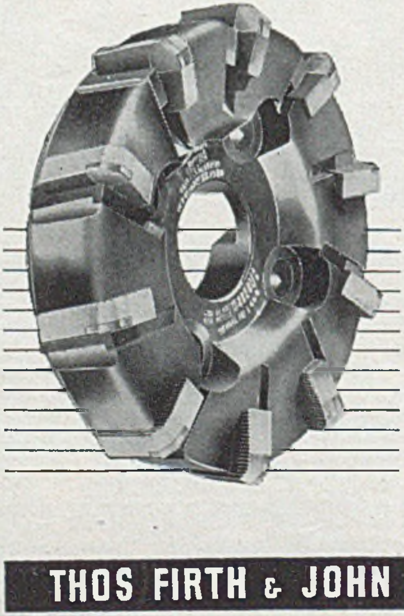
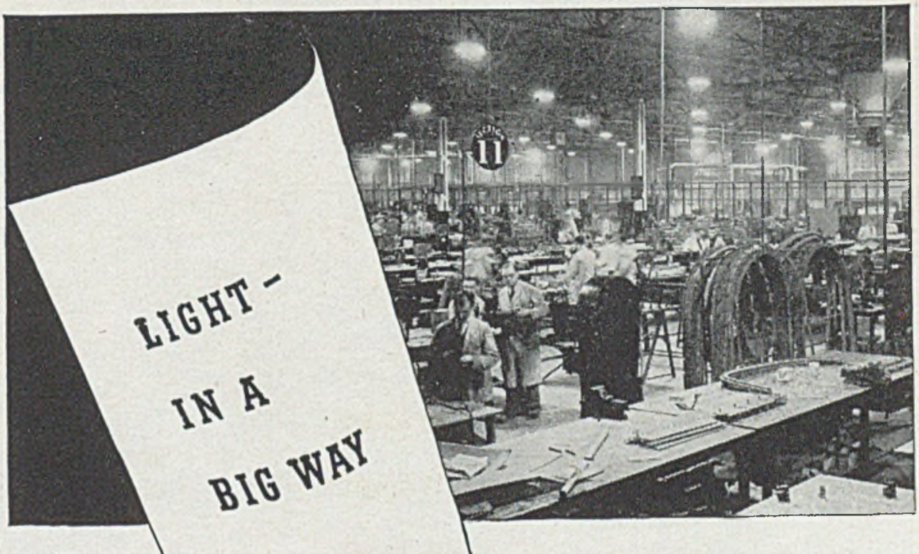



SUPREMACY in
LIGHT ALLOYS



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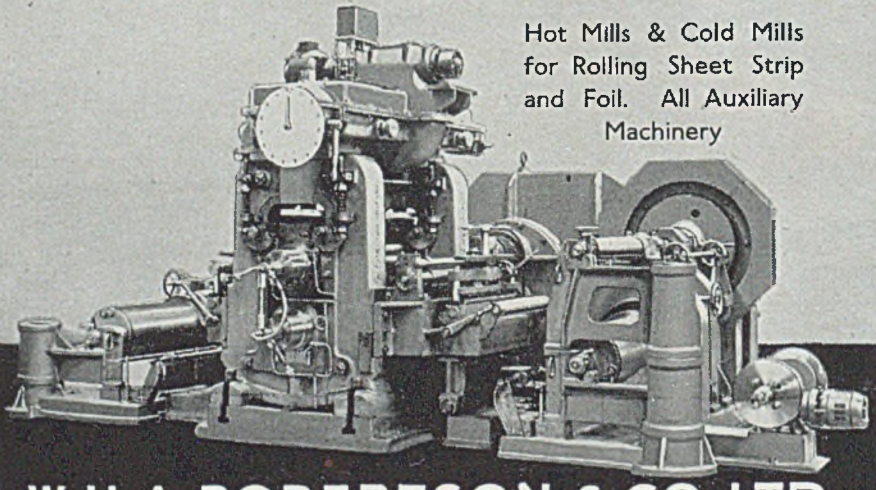
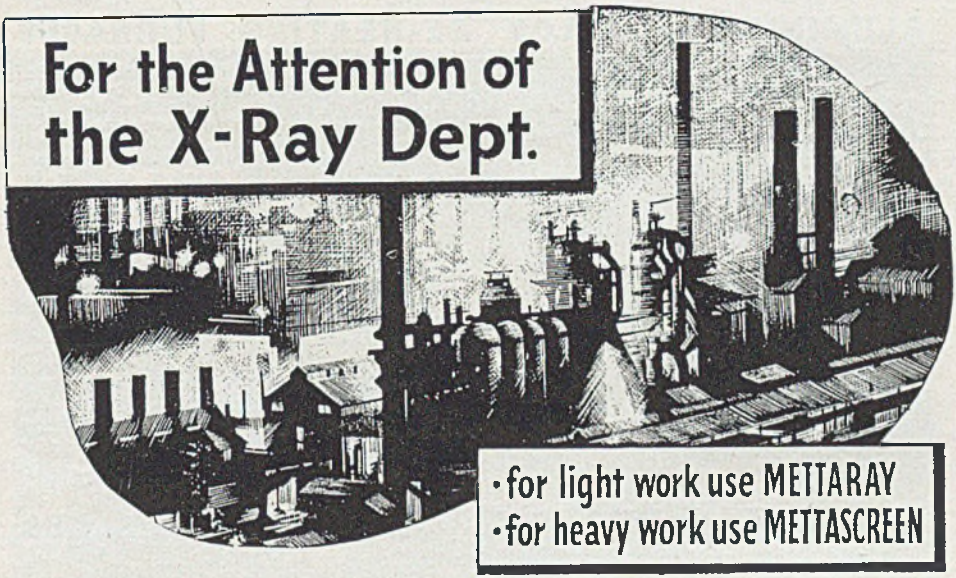


For the Attention of the X-Ray Dept.



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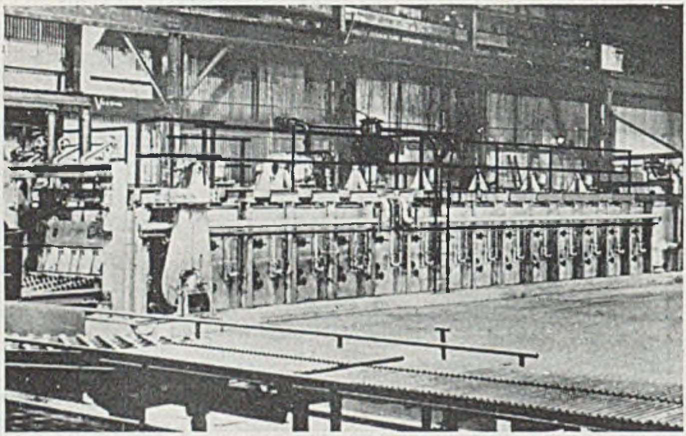

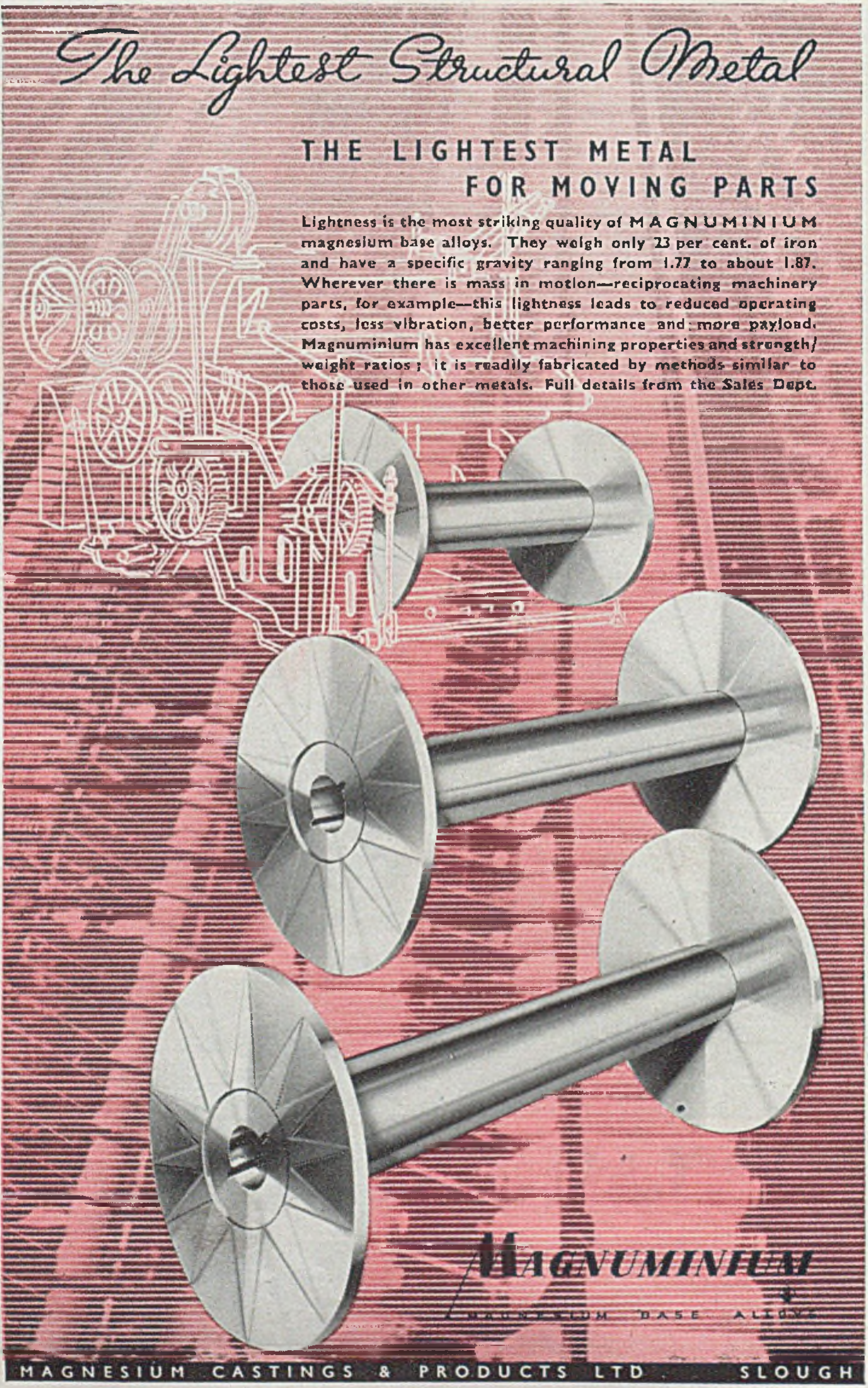

VOL. VII. No. 83. DECEMBER, 1944.

LIGHT METALS

Proprietors:
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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

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EDITORIAL OPINION

According to Prescription

ONCE again we publish in the present issue of "Light Metals" a summary of current light-alloy specifications, including, together with those for the aluminium-base alloys, those proper to magnesium-base alloys and aluminium-bearing copper-base alloys. Appropriately, too, in juxtaposition to this summary, appears an account on A.I.D. inspection in aluminium foundries. This article touches on the little-appreciated process of evolution undergone by tentative specifications before their final acceptance.

In common with all metal users, we must confess we have found ourselves, on more than one occasion, overwhelmed by the ominous mass of specifications with which we are now called upon to deal. Like most other metal users, too, we have often wondered, somewhat inanely, why so many are necessary; occasionally we have broken out into open rebellion and wished the whole lot to perdition. However, on more mature consideration, we are forced to the conclusion that the problem is too intricate to be solved in so cavalier a manner.

We appreciate the fact that, before it reaches us even in its present bulky form, the mass of data about which we complain must have been whittled down from something far bigger and much more incomprehensible. Consoling ourselves with our friends' misfortunes, too, we reflect that U.S.A., Germany, and, we presume, now, Russia, must be grappling with just this same problem. A period of many years will undoubtedly elapse before a final, simple, "handy" and international solution sees the light of day.

Equally significant, too, is the problem of trade names, whether for individual alloys or alloy groups. Certain of these, we know, have become household words and have acquired the force of a systematic nomenclature in their country of origin; only rarely, however, is this recognition extended beyond the national boundary. No very great stretch of imagination is required to realize the appalling muddles, disappointments, and quarrels which may arise as the result of this if post-war international trade reaches anything like the proportions we hope it will assume. Undoubtedly, there are people in this country fully conversant with the Japanese proprietary names for their own particular light alloys, and, yet again, others capable of giving roughly equivalent Japanese or Russian specifications corresponding to our own, but to the greater bulk of the metal-working industry, this knowledge is a closed book, and we can visualize the occurrence of ticklish situations.

The Civil Engineer

OPINION is often expressed that, in civil engineering fields, aluminium has not made the rapid headway that might have been expected of it. At first, we are often tempted, in spite of our better selves, to agree with this viewpoint, but, in so doing, we omit to take into account several factors.

On every side, massive structures of all types may be found executed in steel; assemblies of this type are increasing in number every day. Now, some 180 years has elapsed since the first iron bridge was erected. It was regarded at the time as a novelty and, from all contemporary accounts, was certainly not looked upon as likely to displace brick and stone. Not until after the passage of 30 or 40 years did engineers begin seriously to tackle steel bridges and similar structures with any degree of prophetic enthusiasm. To look farther ahead, visualize structural engineering in light alloys as having reached that stage of development arrived at by steel assemblies in the third quarter of the 19th century. At the moment, we tend to think of the light-metal structural age as possessing the outward and visible form of the iron age transmuted principally in colour and specific gravity, but the implications are, as we all know, vastly different. It is probable that in the 18th century progressive engineers visualized primitive metal bridges very much through the eyes of a dweller in the age of stone; only later did the capacity for flexibility of design in metal dawn upon them. Paxton, for all the harmless fun which may be heaped on him to-day, took a decisive step when he designed and built the Crystal Palace. Only the misfortunes of war prevented our seeing the first, large, all-aluminium bridge structure realized in practice, *and in Europe*.

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SPECIAL ARTICLES

REGULAR FEATURES

Light Alloys in
Rectifiers, Photocells and Condensers

The Discussion on Photocells Having Been Concluded on page 529 of "Light Metals" for November, Attention is Now Turned to a Detailed Consideration of the Theory and Practice of Electrolytic Condensers

DURING the past 20 to 40 years, the growing importance of electric power has become widely appreciated, and every effort has been made to ensure its availability at low cost. An "electric age" cannot be claimed, and, indeed, it would be most unwise to do so, because of the interdependence of the several services, fuel (e.g., coal and oil), steam and electricity. This is particularly to be noted with respect to control systems, and measuring and recording devices. Consequently, with whatever branch of engineering a technician be concerned, some appreciation of electrical components, the preciseness with which they function, and, therefore, the precision with which they must be manufactured is desirable. Condensers represent one group of such electrical components.

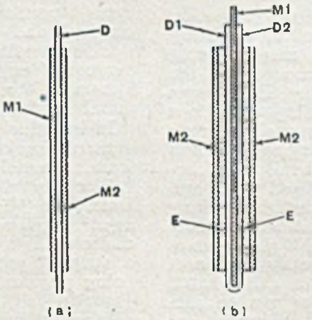

Fig. 102.—At the left (a) is shown the ordinary fixed condenser with paper or mica dielectric (D) between two metal electrodes (M1 and M2). At the right is shown the electrolytic condenser with electrodes (M1 and M2), the oxide film dielectric (D1 and D2) and the electrolyte (E).

To obtain, perhaps, a more general appreciation of this class of component, it can be compared to the radio valve. The same type of manufacturing conditions of cleanliness and exactitude, electrical characteristics of similar closeness with respect to tolerances, and production in quantities of similar order, are entailed. The use of condensers extends to all communication systems, telephonic, telegraphic, teleprinter and radio, to both the receiving and transmitting ends of the circuit; signalling systems, lamps, bells and buzzers, spark and spark-quenching devices, all embody them. Apparatus and equipment requiring the supply and discharge of large quantities of power over short time periods require them as essentials in their circuit design. Thus, resistance-welding machines of the electro-static type use condensers in which to develop, and from which instantaneously to discharge, the requisite power. The same system is used in some applications of vacuum evaporation of metals for speedy deposition. Again, it is used in the relatively recent development of fuse-joining of wires. This covers the joining of metal wires of a wide range of sizes and types, stainless steels, nichromes, aluminium, copper, etc., or combinations such as aluminium to copper, the joining of different diameters or sections to one another as well as of equal sections, or the joining of wires to tags. This last field applies not only to applications such as the joining of wire on drawing and reeling machines, and the selvidging of woven-wire cloth and mesh, but also, and perhaps most particularly in the electrical industry, for making joints in coils, resistances, heater windings, for terminating wire windings to tags and for cable jointing. Especially on the thicker gauges and large sections, energy supplied from condensers is almost essential. The electrolytic condenser plays a very important rôle in this field, which is relatively new and in an early stage of development and exploitation.

The various types of condenser can be grouped into two main categories, variable and fixed. Aluminium and its alloys are important in both classes, but particularly for fixed condensers. The fixed condensers can be subdivided into air- and oil-dielectric condensers, paper and mica condensers, and electrolytics. In the variable condensers, the operating capacity can be varied at will within the limits determined by specific designs.

The fixed condensers, on the other hand, are made to precise capacity values with no adjustment possible. The construction of all of them is on the same basic principle of a dielectric between two electrodes, with capacitance determined by the nature of dielectric, its thickness and the surface area of the electrodes. It is evident that only limited capacity values can be obtained with simple assemblies and that larger capacities can be secured by stacking and commoning components of the stack in series or parallel, or by rolling, using flexible electrodes and dielectrics. The first of these methods is used with mica condensers, in which mica is the dielectric, and the latter with paper condensers in which wax- or oil-impregnated paper is the dielectric medium and aluminium or tin foil, or metallized paper, comprises the electric material.

This part of the account will be confined to the electrolytic condensers. Obviously, there are reasons for the selection of one type in preference to another, and each has its own specific field of application, although in some instances there may be a little overlapping. Choice is, therefore, determined by specific advantages with respect to such electrical characteristics as electrical strength or breakdown voltage, power factor or power loss, capacity range in which available (or practical limits on capacity), temperature coefficient with respect to capacity or to power factor, etc. Other factors, such as general temperature limitations, physical size, stability under working conditions or under no-load conditions, amongst others, are also important criteria.

The electrolytics possess the following advantages:—

1. Low cost on a basis of electrostatic capacity.
2. In consequence of (1), relatively smaller space occupied and minimized weight.
3. Complete recovery of properties after an over-voltage load, rather than destructive breakdown.

The outstanding disadvantage is a restriction upon voltage, as efficiency falls off as operating voltage increases, because the energy-storing capacity of a condenser varies inversely as the square of the impressed voltage. Breakdown voltage is a function of processing conditions used in production for forming the dielectric film, and, in consequence, working voltage is a well-defined quantity, a feature in distinct contrast with the same property in fixed paper and mica condensers. In these, although working voltage is secured by design, that is, construction with respect to " mechanical " thickness of the paper or mica dielectric, a heavy margin of safety has to be allowed. On the other hand, whilst the paper and mica types can be produced to exceedingly close tolerances as regards capacity and power factor, and with respect to the temperature coefficients of these qualities, the electrolytics do not lend themselves to such accuracy of manufacture. This is on account of the chemical nature of the electrolyte, and such factors as influence of temperature upon electrolytic dissociation and pH of the electrolyte. Fortunately, in most applications of importance, the matter is not so serious as would at first sight be imagined, because the condensers are used for heavy loads. In this connection, information upon the closeness of characteristics to which electrolytic condensers can be supplied is of interest.

The usual commercial limits on capacity are plus 50 per cent. minus 20 per cent. of the nominal value. This refers to measurements at ordinary temperatures of 20 degrees C. plus or minus 5 degrees C., and under operating conditions, particularly of tropical service, variations well outside these limits are to be expected. Power factor at room temperatures is up to 15 per cent. for high-voltage condensers and 20 per cent. for low-voltage types.

Much work has been done on electrolytic condensers during the past 40 to 50 years. Production impetus probably reached its zenith from 10 to 15 years ago when the manufacture of valve-type radio receiving sets expanded rapidly, designs demanding relatively small-capacity electrolytics in large numbers. Scientific literature gives much information upon their design and functioning, technical literature gives some insight into their properties, construction and performance, whilst patent literature is extensive and covers electrolyte compositions, specific methods of construction and manufacturing processes.

Perhaps the starting point of electrolytic condensers can be traced in a contribution by Charles Wheatstone to the " Philosophical Magazine," No. 10, p. 145, 1855. This was entitled: " On the Position of Aluminium in the Voltaic Series," and dealt with polarization effects of aluminium. In the succeeding years it became established that numerous metals, when made anodic in appropriate electrolytes, acquired non-conducting films upon their surfaces, and that these films offered peculiar and valuable electrical properties. Bluff had recorded in the case of an aluminium anode in a dilute sulphuric acid electrolytes, the formation of a dark superficial skin. These observations led to much research and development, and, finally, to the production and application of electrolytic condensers of a wide range of types, particularly in relation to electrode material and electrolytes. By contrast, it is significant that commercial electrolytic condensers of any consequence are all of the class known as " aluminium electrolytics," the vital metal anode being of super-pure aluminium.

In introducing the subject of electrolytic condensers some notes and illustrations can be given from an article by Philip R. Coursey, entitled: " Electrolytic Condensers, Their Properties and Uses," in " The Wireless World," January 13, 1932.* In the paper and mica condensers, the dielectric is a separate material in the form of a strip of paper or sheet of mica, capable of being physically assembled between the metal (usually foil) electrodes. In the electrolytic condenser, the dielectric is not capable of separate production and assembly, because it consists of an exceedingly thin superficial film formed electro-chemically upon one of the metal electrodes. Further, the electrolyte or chemical solution in which this film is formed is also an essential constructional item of the condenser. It is necessary to provide electrical contact with the dielectric film. This is shown diagrammatically in Fig. 102. At (a) is represented the ordinary fixed condenser with the dielectric D of paper or mica between two metal electrodes M1 and M2; all interstices in the dielectric, and between it and the electrodes, are filled with oil or wax impregnant. At (b) is represented the electrolytic, in which M1 is the main metal electrode. On both surfaces of this electrode are the dielectric films D1 and D2, these being in intimate molecular contact with the metal.

The electrochemical process of producing the dielectric is referred to in the industry as " forming." The other metal electrode of the condenser is shown at M_1, M_2, and between the electrodes is the electrolyte E, E, which ensures complete continuity of contact electrically.

(To be continued.)

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* See also account by Pirie, "The Wireless World," 1937, October 1, p. 326, and October 8, p. 358.

NEWS—General, Technical and Commercial

THE editorials appearing in "Light Metals" for October and November have called forth the correspondence reproduced below:—

Magnesium Developments

"I have read with surprise the editorial on Magnesium appearing in the issue of 'Light Metals' for October, 1944. It is to be regretted that a journal purporting to promote interest in, and the interests of, light alloys should see fit to write so disparagingly of magnesium and the magnesium industry of this country. No facts are given, no authorities are named.

"You ignore the fact that for five years strict limitation has been imposed on the usage of magnesium by the authorities. The acute shortage dictating this policy occurred *in spite* of the efforts and warnings of the magnesium producers and fabricators. Further, war conditions imposed a pretty complete censorship on the activities and developments of the magnesium industry, for which it is in no sense to blame.

"I write impartially, being equally interested and occupied in the development and fabrication of aluminium and magnesium alloys. I hope also I can write authoritatively, having, I think, pioneered, with my company, the development and expansion of elektron-magnesium alloy fabrication in this country.

"Beginning in 1921, when there was no magnesium fabricating industry existing, by 1939 we had built up an imposing production, entering successfully a wide range of industries. Much of the fabricating technique was developed here, including the successful manufacture of gravity die castings on a large scale. You will doubtless be surprised to learn that this effete industry transmitted to Germany pre-war and to U.S.A. up to to-day much new knowledge and experience, and that by 1939 England had built up a magnesium alloy fabrication and application probably exceeding in volume, range of use and technical knowledge that obtaining in U.S.A., and even Germany. Yet I have no recollection that you have informed yourself, prior to writing your article, of the activities of my company and its associates, who probably produce 75 per cent. of this country's magnesium fabrications, and whose output reaches several thousand tons per annum. Instead you quote an anonymous person 'famous in the light alloy industry,' and even then not verbatim.

"Equivocal phrases such as 'cautious in providing testimonials for magnesium,' 'doubt existing in high places,' 'cheerful prognostication . . . wants foundation and rings falsely,' 'lacking developmental and creative force,' and so on, seem, even with their context, a serious indictment of the sincerity, enterprise and energy of those engaged in the magnesium industry.

"The very solid achievements of the relatively short period of 20 years in creating and developing a large and successful industry from zero could never have been made without the qualities which you seem to think lacking in those persons engaged in the magnesium industry.

"You set magnesium against aluminium. This is a very narrow view which has never been held by my companies. We know the two metals to be more complementary than antagonistic, having wide experience and interest in both. Magnesium is, like all other materials, pre-eminently suitable for many applications. For other uses it offers no advantages compared with alternatives, or may be definitely unsuitable.

"Responsible and experienced magnesium fabricators have formed their policy regarding technical publicity and application on the sound and honest lines dictated by full recognition of the principles enunciated.

"Nowhere do you refer to the responsibility of the prospective user who has to be 'satisfied with crumbs.' Speaking from a wide experience of over 20 years, I can assure you that too often progress has been retarded by conservatism and lethargy on the part of the designer and constructor, despite the tenacity and energy of the fabricator and his willingness to put all resources at the constructor's disposal. Too often when indifference has been partly overcome, difficulties or troubles encountered with a novel medium have caused abandonment of further trials.

"Now, I understand from your editorial, U.S.A. and Germany are held up as models to follow. Yes, in the case of U.S.A., in so far as there is ample evidence of both the will and determination on the part of engineers there to use to the full the special advantages of magnesium, and to persist till success is gained, whatever difficulties and temporary failures have to be overcome.

"The magnesium interests of which I have full knowledge have never failed to give full technical assistance, or to pursue undaunted a new development. But if the prospective user demands immediate and full success on a new application as a condition of continued interest, the fabricator certainly is not to blame. Where full and continued co-operation has been maintained as it has in many important directions, success of an impressive character has been achieved. Witness the innumerable 'planes of all types incorporating highly stressed magnesium components with unqualified success.

"If prospective users are really serious, and care to apply to the right quarters, they will not need to be satisfied with crumbs; they'll get a full meal or nothing, according as their ideas are sound or not. If they don't know where to apply, it would seem that our publicity media, of which, Sir, 'Light Metals' is a part, are not as widely read as could be wished.

"Finally, that section of the magnesium industry with which I am connected has nothing to be ashamed of—quite the contrary. Its members have sound reasoned confidence in future development, and the experience and staff to give all possible co-operation in the preparation of suitable designs and logical applications.

"May I end by saying that I think you owe the industry a debt which you may partly repay by publishing this letter."

E. PLAYER,
Managing Director, Sterling Metals, Ltd.

[It was certainly not our intention to underestimate the part played by the British magnesium industry in bringing the ultra-light alloys to their present high state of development. Moreover, we have always endeavoured, by every possible means, to give magnesium alloys due prominence, and that in spite of the fact that aluminium, the senior metal, tends so frequently to overshadow the former. We have always maintained that the research and development work in connection with magnesium carried out in this country has always been abreast with, and considerably in advance of, similar work carried out in Germany and U.S.A., and have openly stated that, in this connection, the British magnesium industry should, in justice to itself and to the national cause, sing its own praises far more loudly than has hitherto been the case. Finally, in agreement with Mr. Player, we, too, have absolute confidence in the future of the ultra-light alloys.—ED.]

Britain and Magnesium

"In 'Light Metals' for October and November you broached the opinion that there is available in this country a considerable amount of information about magnesium and its potential uses which might well be published for the benefit of the public, but which is, in fact, not made readily available.

"You obviously deplore this situation and trust that in due course it will be improved, as it has already given rise abroad to much misunderstanding as regards technical progress made in this country in connection with the ultra-light alloys.

"In this regard it is rather interesting to note that in the 'Daily Express' for November 15 is a paragraph headed 'Saucepans from the Dead Sea'' (!) attributed to Mr. Moise Novomesysky, managing director of Palestine Potash. Here it is stated that magnesium is 'much stronger than aluminium,' but has a great drawback for domestic use as it tends to corrode. Mr. Moise Novomesysky, however, believes that *American research* will solve that problem within two years and that magnesium will then 'catch on.'

"It would, therefore, seem that whatever progress the industry in England has made with respect to the surface protection of magnesium has not been broadcast sufficiently loudly outside our own shores. The writer has had bitter experience of this situation in a slightly different direction: the problem of combating light-metal industrial fires, too, was first successfully solved in this country, but the work done has never been accorded the prominence given to far less efficacious systems developed in the States."

G. H. DURSTON,
For Durston, Lang and Co., Ltd.

[At the present time when, for the sake of our Export Trade, it is so essential that the technical prestige of this country be given every support, it is to be regretted, as Mr. Durston indicates, that a false impression of mediocrity regarding British scientific and technological achievement should be circulated. We hope, and indeed know, that it will not be left solely to American workers to solve vital problems connected with the surface protection of the ultra-light alloys and to develop compositions of inherently high corrosion resistance.—ED.]

The Late Mr. H. W. Healy

WE regret to announce the sudden death recently of Mr. H. W. Healy, M.I.E.E., M.I.Mech.E., M.I.P.E. Mr. Healy became known as an executive engineer of a very high order some years ago, when he held many important positions with the Gramophone Co., Ltd., Hayes, Middlesex. Mr. Healy's connection with the light metal world was in the double capacity of user and producer, for, until 1943, he was managing director of Parnall Aircraft, Ltd., and its foundry subsidiary, Magnal Products, Ltd.

Mr. Healy was a man of inspiring personality. He was the best type of industrial psychologist—an unconscious one. He looked upon life as a glorious adventure, and he often expressed refreshingly unorthodox views on the human element in industrial relationships. He had wide interests which were exemplified in his conversation, lectures and broadcasts.

A business associate of many years has written the following brief appreciation:—

"The death of Mr. H. W. Healy has taken from me a friend with whom I have worked in harmony for 25 years. During times of stress he was there to encourage, help, and, also, to drive. His cheerful crack, ' How's the fun and games?' always gave heart and encouragement. He was a man on whom you could rely. To all he has achieved I give my tribute. He was more alive than the century in which he lived, and whenever we were parted during the period I have known him, I felt the sense of loss. The engineering world will miss one of whom, as of few others, it can be said, ' He was a man.' "—Sam Nortcliffe.

Civilian Aluminium Products in U.S.A.

SEVEN manufacturers of aluminium cooking utensils in the U.S. have been authorized by the War Production Board to produce 664,500 pieces during the fourth quarter, a few days after the fourth quarter had begun. Two manufacturers' applications to begin manufacture of civilian aluminium articles were denied by the Board on the ground that production at these particular plants would interfere with war production.

Of the seven approvals for fourth-quarter production four were to manufacturers who had been producing aluminium ware during the third quarter. These were the Hayward Non-ferrous Foundry, Hayward, Cal., 6,000 pieces; San Francisco Die Casting Co., 42,000 pieces; Tray Service Co., Dallas, Tex., 5,000 pieces; J. C. Williams Aluminium Casting Co., Dallas, Tex., 2,500 meat tenderizers of aluminium. The three new authorizations are: Farber and Shlevin, Brooklyn, New York, 35,000 household trays; Leyse Aluminium Co., Kewaunee, Wis., 115,000 dinner pails (262,000 for the first quarter of 1945); West Bend Aluminium Co., West Bend, Miss., 180 tons of aluminium ware (500 tons in the first quarter of 1945).

Magnesium Controls in U.S.

SPEAKING at the first annual meeting of the newly formed Magnesium Association held recently at the Waldorf-Astoria, New York, Dr. Willard H. Dow, president of Dow Chemical Co., predicted early " relaxation " of present war-time controls over magnesium metal, and he added that " shortly all the magnesium controls will be removed."

R. P. Lansing, vice-president, Bendix Aviation Corp., warned the meeting of coming cutbacks in aircraft production, and estimated that magnesium producers would have to find civilian markets for about 700 tons of fabricated magnesium metal, compared with present capacity of 7,000 tons. This is a reduction in the industry's size to 10 per cent. of war-time capacity. The aviation industry is viewing the future with optimism, when it hopes to retain a civilian industry in the billion-dollar class, compared with its present war-time size of $20,000,000,000.

The U.S. magnesium ingot producing capacity amounts to 270,000 tons annually. Actual production, according to Lansing, has been cut back from a high of 16,000 tons a month to an output of 8,000 tons to 14,000 tons. The Government has a magnesium metal stock pile of about 40,000 tons. " When the war ultimately ends," he said, " we are faced with a tremendous production and fabrication capacity and comparatively small markets. Without attempting to forecast, if it were reasonable to expect that we will continue to produce after the war military aircraft at a rate of even 5 per cent. of present production, then such production would provide a market for about 2,000 tons a year." However, he said he believed commercial aircraft should provide demand for an equal amount of magnesium metal. By expanding other demands he estimated a peace-time market of about 7,000 tons of magnesium metal annually.

Aluminium Hopper Cars

THE need for lighter-weight and, therefore, faster-moving freight rolling stock on U.S. railroads has long been recognized. Only when freight trains can travel in proper ratio to the speed of Diesel-electric streamline passenger trains can curves be graded up for the 75- to 125-mile speeds possible with modern equipment. In consequence, the recent order placed by the Missouri Pacific Lines with the American Car and Foundry Co. for 25 aluminium hopper cars is significant, although it was not placed with potentially higher-speed operation in mind at the present. Purpose was to reduce total weight, so that heavier trains could be hauled.

The hopper cars were designed by the American Car and Foundry Co. in co-operation with the engineering staffs of the Missouri Pacific and the Aluminum Co. of America. Each car will have a capacity of 6¼ tons more than the present steel hopper cars, but they will not impose any more weight on the axles or call for any increased power from the locomotive hauling them. Aluminium alloy is being used for the entire hopper car body except the centre sill and bolster, which are of steel. Empty weight of the cars will be about 17 tons, compared with an average of 22 tons for steel hopper cars. This is a saving in deadweight of 26 per cent.

Prior to the present construction of aluminium hopper cars Aluminum Research Laboratories at New Kensington, Pa., have been conducting tests since 1932 on the effects of various commodities on aluminium. Sulphur and coal have found to have little, if any, affect on the alloy used.

A.I.D. INSPECTION IN ALUMINIUM FOUNDRIES

E. Carrington Summarizes the Aims and Practice of A.I.D. Inspection for Light-alloy Castings, and Briefly Outlines the Established System for the Development of Official Specifications

IN all factories where aircraft parts are made, such terms as " A.I.D. Inspector," " A.I.D. Control," " A.I.D. Supervision," are met with. In many cases, however, many of those working in the factory do not know what these expressions mean, and, in fact, tend to look upon everything connected with A.I.D. with a certain amount of suspicion, because the only purpose of the A.I.D. inspector appears to be to find fault with their work! This, of course, is very far from the case, and as A.I.D. supervision has definitely come to stay, it is desirable that the workpeople should be able to see to what extent the A.I.D. inspector is helping them to make first-class products which may be incorporated in aircraft, thus eliminating risk to the crew.

In the early days, flying was, of course, hazardous, due to the large factor of " ignorance " involved; but one has only to consider the great airborne operations recently carried out in Belgium to realize that aeroplanes are now as safe as any other modes of conveyance. This is very largely due to the enormous amount of work carried out by the Air Ministry in its Department of Technical Development (D.T.D.) and its Aeronautical Inspection Department (A.I.D.). Every part of every aircraft and methods of treatment and assembly are inspected, either by an A.I.D. inspector or by a factory's inspector. In this way the quality of our aircraft has reached such a high standard that our airmen are able confidently to work their machines all out, just as they work themselves all out, and to build up that decided air superiority which is helping so much to make our operations successful. A.I.D. inspection applies to all our aircraft, wherever they are made. Aircraft made in America for us are inspected under the supervision of our A.I.D. inspectors just like those made in this country. The present notes are only concerned with inspection in aluminium foundries.

In the foundry there is an inspector who is on the staff of the foundry. He is responsible for the release of castings thought to be satisfactory. He may simply be in charge of dimensional checking, and send samples for analysis, bars for physical testing, and castings for X-ray examination, to outside test houses which have been approved by A.I.D. At the other end of the scale, he may be a qualified metallurgist, who is in charge of the laboratory, test house and X-ray department. In other foundries the duties of the chief inspector will, of course, be between these two extremes. In all cases, however, he must be approved by A.I.D., and A.I.D. Memo. No. 1, Issue 2, says: " The chief inspector should be immediately responsible to a director or some other senior official of the firm, and shall not be under the control of those directly responsible for production. In other words, the chief inspector shall be in such a position that his decisions are not liable to be over-ruled in the interests of output."

Whether the tests be carried out in the foundry or in an outside test house, it is the chief inspector's duty to collect all the details and then to release those castings which he considers to comply with the specification and drawing. This is done by means of release notes. On these are entered the customer's name, the part number and description of the castings, the batch number, the number of castings and the specification number. At the bottom is a certification, with wording laid down by the Air Ministry, to the effect that all castings entered on the release note have been inspected and are correct to specification and to the drawing. Originally there were four release notes, one being sent to the customer, one to the customer's A.I.D. inspector, one to the foundry's A.I.D. inspector, and one for the foundry's file. Now only two are used, one of which is filed and the other sent to the customer.

With this arrangement it is obvious that castings to the same part number might have widely varying standards of inspection in different foundries. This may lead to castings which are to be highly stressed being passed when they have a slight defect, or castings which will not be stressed at all being scrapped when they could be used. Some means had, therefore, to be found of enabling the inspectors to find out what was wanted, either from their customers (who, in their turn, would have to be sure that they knew), or from those responsible for the design of the aircraft. An organization had to be set up which could find out all necessary details, could lay down definite standards and methods of procedure for inspection, and could see that these were carried out. An authoritative organization of this kind would have to be under the control of the Air Ministry itself. Two departments were set up—the Department of Technical Development (D.T.D.), which decided upon specification and design, and the Aeronautical Inspection Department (A.I.D.), which looked after inspection.

A.I.D. opened district offices in various parts of the country, and, from these, supervizing inspectors were sent to the various foundries in the district. The arrangement differs according to the inspection organization and the type of castings made in the foundry. The A.I.D. inspector may be a resident inspector, and, as his name implies, spend all his time in one foundry. In other cases, a supervizing inspector calls periodically on several foundries, but is always ready to come along at short notice whenever the chief inspector requires his advice or assistance.

The A.I.D. inspector can—and does—assist in the foundry in quite a number of ways. As before stated, the foundryman often looks upon him as an unnecessary nuisance, but the writer has worked with quite a number of them and has always found them to be most helpful.

With the exception of some pressure castings which are for dust covers or for other purposes where strength is not required, all aircraft castings are made to a definite specification, and this must be complied with in every way. From time to time, firms have developed a casting alloy with outstanding qualities in certain directions. They send particulars and samples to the Air Ministry, and ask if the alloy may be included amongst the Ministry's specifications. The alloy is thoroughly tested, and, if found satisfactory, is given a specification number by the Directorate of Technical Development. Examples are:—D.T.D.245, D.T.D.424. Copies of the specifications may be obtained from H.M. Stationery Office, York House, Kingsway, London, W.C.2. These are, however, looked upon as provisional specifications, which may be replaced later by better ones. In some cases an alloy comes into general use. A specification is then issued for it by the British Standards Institute (B.S.I.). This new specification may have modifications or alterations which it has been thought advisable to introduce in the light of past experience with the alloy. When the B.S.I. specification is issued, the corresponding D.T.D. specification becomes obsolete, and all future orders, including those for aircraft parts, should give the B.S.I. specification. Examples of alloys which have changed from D.T.D. specifications to B.S.I. specifications are Y alloy, B.S.I. L35, and Wilmil or Alpax, 2L33. B.S.I. specifications may be obtained from the British Standards Institute, 28, Victoria Street, London, S.W.1.

The specification gives the limits of chemical composition, and the minimum tensile and elongation figures to be obtained from a standard test sample. If heat treatment is required, time and temperature limits are specified, together with any special details, such as quenching in hot water, etc. The size of the mould and the pattern for the test bar are shown, and a drawing is given showing the exact size of the test bar. If some castings are supplied as cast, and others heat treated, or if there are two alternative heat treatments, separate specifications are issued. It is thus possible to find what should be done to each batch of castings and what results may be expected.

If there be any queries as to a specification, or if a foundry find that it has difficulty in making a casting to a particular specification and would like to use another one, the supervising inspector will be able and willing to help. He will approach either the designs department or the customer's supervising inspector, to clear the matter up. Hence, when the job is started there should be no doubt whatever as to what is wanted.

Apart from these specifications, castings are divided into three classes. Class I contains castings the failure of which would cause the aircraft to become out of control. Class II contains castings which are highly stressed, but the failure of which would not cause the aircraft to become out of control. Class III contains lightly stressed or unstressed castings. Whilst, of course, the higher-class alloys are generally used for Class I castings, there is no absolute rule. 2L33, for example, is widely used for Class I, II and III castings. It is the duty of the supervising inspector to see that the foundry knows to which class each batch of castings belongs, and that the amount of testing carried out is sufficient for that particular class.

The inspection department should check all metal entering the foundry for use for aircraft castings. It will all be covered by release notes giving quantity, batch number, and alloy. The metal is stacked in a locked, bonded store, and each batch is stacked separately and labelled. A card index shows when metal is received and when it is issued to the foundry. Periodically, the supervising inspector examines the stock and checks the metal against the release notes.

When samples are taken for analysis, or test bars cast for physical testing, it is important that they shall be representative of the metal being used to make the castings. If metal is added to the melt indiscriminately and samples taken at any time, many of the castings may have properties materially different from those of the samples. Metal is therefore added in definite, weighed-out charges, containing predetermined percentages of scrap derived from the manufacturer's own production, and samples are taken when each of these charges has been melted. The size of the charge depends, of course, upon the size of the furnace. When a large furnace is used to feed a number of bale-out furnaces, one sample is taken from each charge put into the large furnace, or one sample is taken per day, whichever is the more frequent, but test bars will be required from each bale-out furnace, especially if the castings are to be heat treated. In the case of running jobs, in the die shop, a small amount of metal will be added after the pouring of, perhaps, every other casting, but in this case also a weighed-out batch is supplied, and samples are taken at times decided upon after a talk with the supervising inspector.

The preparation of test bars should also carefully be supervised. Three are required for each batch of castings. If the first bar fails, the other two must be pulled. If these pass, the batch is passed. If only one passes the batch should be scrapped, but in borderline cases, or in cases where the quality of the test bar is suspected, the supervising inspector will discuss the matter with those responsible for design, or with the customer's A.I.D. inspector, and will give the foundry's inspector a ruling. It is sometimes possible to help him to form a decision by pulling small test pieces, cut from the castings themselves, on a

Hounsfield or other testing machine of suitable capacity, but the results obtained are not accepted in place of those obtained from an A.I.D. standard test bar. Whilst it is important that castings should not be passed if tensile tests show the material to be defective, it is equally so that good castings should not be scrapped because of faulty bars. Hence, great care should be taken in pouring the test bars.

The specification says that the test bar shall be at an angle of 30 degrees from the vertical when pouring starts. The details of procedure subsequently followed vary fairly widely in different foundries, but the essential requirement is a slow, steady, unbroken pour. The metal should actually be poured down the thin tube of aluminium oxide which forms during pouring, and which must not be broken. The time taken to fill the parallel part of the mould should be 10 to 15 secs. The heads may be filled more quickly so that the feed metal will be reasonably hot. Definite pouring temperatures should be decided upon for the various alloys, and these should strictly be adhered to. A variation of 10 or 20 degrees in the pouring temperature would make little alteration in the quality of the bars, but if small differences were allowed, larger ones would soon creep in, and the tensile figures would soon deteriorate. As an example, the specification figures for D.T.D.304 are 18 tons/sq. in. and 4 per cent. elongation. If the test bars are cast at 660 degrees C. they may be expected to give 19 to 21 tons/sq. in. and 6 to 8 per cent. elongation. If cast at 750 degrees C. the figures will probably be 14½ to 15 tons and 3 to 3½ per cent. If the casting temperature is 850 degrees C., especially if the melt has been "stewed" at this temperature, the figures will probably be down to 12½ to 13 tons and 3 per cent. Even if the metal at 850 degrees C. be allowed to cool to 660 degrees C. in the ladle and be then poured, the results are not likely to reach the specified figures. Macro etching of the fractured bars would show the grain size of those cast at 850 degrees C. to be many times as large as those cast at 660 degrees C. The grain size of the bars cast at 660 degrees C., but stewed, is not much larger than that of those cast at 660 degrees C. without stewing, but the metal does not recover its original properties. Careful control of metal temperatures, as well as casting temperatures, is therefore essential.

The inspector is required to supervise the segregation of scrap. He will see that separate bins are provided for each alloy, marked with the alloy's specification number and painted with its code colour. If any bin becomes rather full, either more scrap will be used per charge or all the scrap will be melted, well mixed and ingotted. It will then be put back into the store to await analysis. Any batch of this kind should have a red label marked "Not to be used." If, on analysis, the composition of the ingots complies with specification requirements, they are released for use. Should the composition need adjusting, then special laboratory action is necessary, and the ingots should be clearly labelled to that effect.

In a die foundry the supervising inspector will personally inspect any die which has been made to an Air Ministry order. When it has been stamped up correctly, and the customer has accepted the first castings as dimensionally correct, the supervising inspector will release the die and authorize payment. This release cannot be carried out by the foundry's own inspector.

Another important branch of the inspection department which is often guided by the supervising inspector is the X-ray department. When the use of castings for aircraft was first contemplated, some method had to be found of making as sure as is humanly possible that all castings which were despatched from the foundry were sufficiently sound for use, and would add nothing to the element of risk which the pilot had to put up with in his operational duties. While "cut up" or "break up" tests are of invaluable assistance when carried out on sample castings, for the assessment of the degree of soundness achieved by a given foundry technique, some other form of testing is necessary to ensure continuity of quality in castings submitted for use. Radiological inspection is the solution to this problem. This was developed intensively. At first, A.I.D. approved X-ray laboratories were made available, but soon most foundries had their own outfits.

In the case of engine castings, which represent the largest bulk of aircraft castings, radiography is only used during development work, for it is possible to test these castings directly, when the engine is undergoing its running tests. This sort of test is not available for airframe castings.

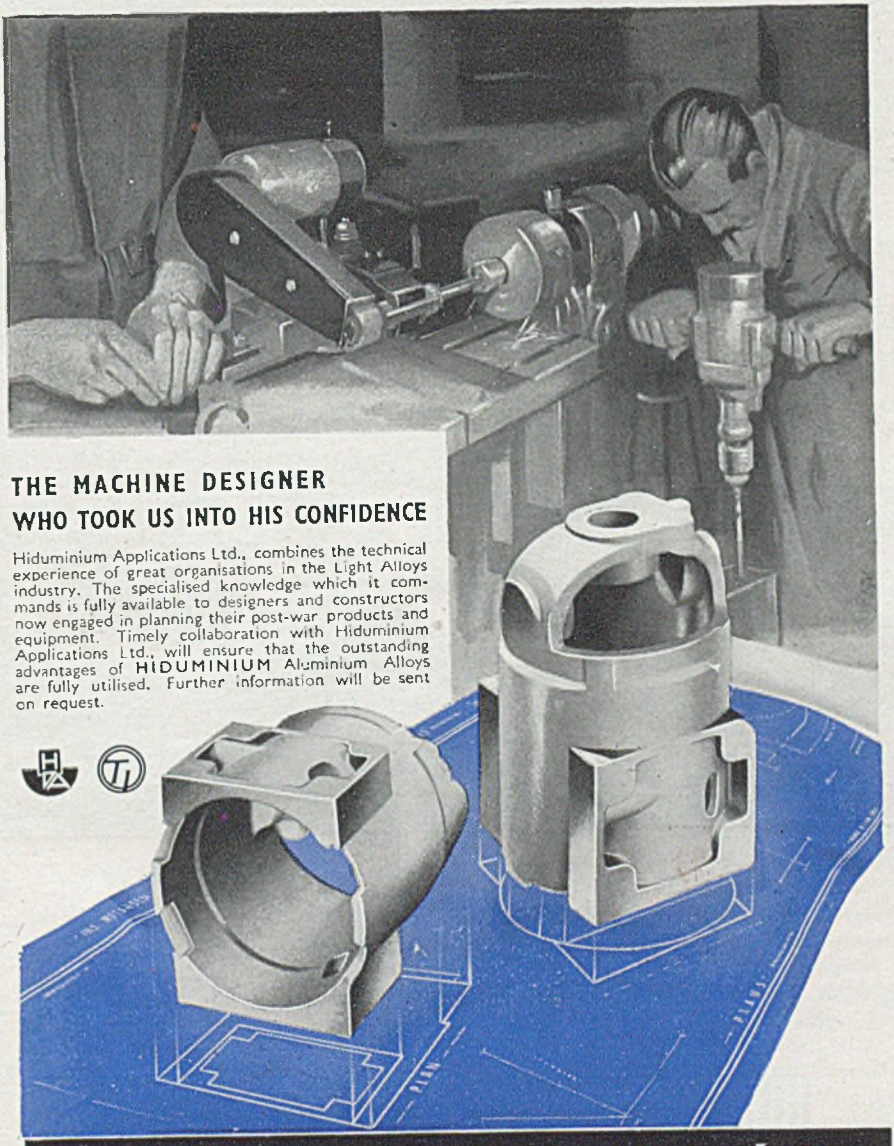
By the aid of radiography, high-strength castings were made which to a large extent replaced forgings and parts built up from extrusions, sheets, etc. Gradually, a technique was evolved, and now all foundries work to a specified procedure. It is a simple matter, however, for the metallurgist, who will generally be in charge of the X-ray department, to couple with this A.I.D. controlled procedure a scheme of inspection which includes non-A.I.D. castings and serves as a guide for the foundry management. In this way, X-ray examination serves as a guide for correct technique, and as an inspection tool, to make sure that faulty castings do not leave the foundry.

A.I.D. instructions are that until a definite foundry technique has been decided upon, every Class I and Class II casting must be radiographed. When 20 *consecutive* castings have been found to be satisfactory under X-ray, the castings are said to have obtained radiographic approval. The foundry technique must then on no account be changed without consulting the X-ray department. Should modification of the foundry technique be necessary, a further run of castings is to be examined, and radiographic approval re-established. When approval has been obtained, 100 per cent. of Class I castings will still be radiographed, but the number of Class II castings to be radiographed will be reduced. It may be reduced to as low as 2 per cent., but the actual percentage will be decided upon when the faults found in the castings have been considered. Class III castings need not be radiographed, but most foundries will examine representative castings, in order to see if it will be possible to improve the foundry technique. In addition, many Class II and Class III castings will be screened, to make sure that there are no major defects.

A.I.D. gives definite instructions as to the method to be used for X-ray examination of castings. On the drawings, the stressed parts of the castings are marked, and, of course, these portions must be given special attention. Castings are divided into two classes. For those in the first class, the radiographic procedure is specified in detail. The portions to be radiographed, and the number of shots, are given, and the position of the casting on the table, and the angle at which the X-ray strikes the table are specified. All castings in this class must be radiographed exactly as instructed. In the second class, a technique has not been laid down, but is left to the radiographer's initiative.

The results obtained are divided into three classes. Castings which are quite satisfactory are despatched, and released in the usual way, the release note being endorsed to the effect that all, or a specified percentage, of the castings have been radiologically examined, and found to be free from any serious form of defect. Borderline cases are despatched, but the radiographs are also despatched, and the customers' supervising inspector will decide as to whether the castings shall be used or scrapped. Castings with major defects are, of course, scrapped.

The evaluation of radiographs requires a good deal of experience and collaboration with the micrographer. Castings which X-ray examination shows to be defective are cut up and examined macroscopically and microscopically. In this way a technique is built up which enables the radiologist to pass or reject a casting simply by radiological examination.



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In order to assist the foundry management, the first few off from any new pattern or die should be very roughly fettled and sent to be radiographed at once. They should be given precedence and as soon as they are ready the films should be shown to the foundry foreman and any defects pointed out. If necessary the castings should be cut up, in order to ascertain as nearly as possible the cause of the failure. When satisfactory foundry technique has been developed full details should be entered on a foundry technique card, so that if the production of that casting be resumed after a stop, all conditions can be repeated and initial scrap avoided.

Another branch of inspection in which the supervising inspector will be interested is the search for cracks. Some aluminium alloys are very hot short, and may give a high percentage of scrap due to cracks, especially if die castings are made. Some cracks are readily seen through a low power glass. Others can only be found after suitable tests have been carried out. There are two usual tests for cracks; the chalk test and the test using a fluorescent liquid and ultra-violet light. For the chalk test the castings are heated for 20 to 30 minutes at 95 degrees C. in a mixture of paraffin and lard oil. The heat opens the cracks and allows the penetrating oil to enter. The castings are dried and rubbed with french chalk, which, of course, gives them an even, white coating. As they cool down to air temperature, the cracks close up again and squeeze out the liquid, which produces a dark mark on the layer of french chalk.

The other method consists in immersing the castings in a hot, fluorescent liquid. This liquid is then allowed to drain off, and the castings are placed in a bath of carbon tetrachloride, which washes the fluorescent liquid from the surface of the castings, but not from the cracks. The castings are allowed to dry, and are then viewed under ultra-violet light. Cracks appear as bright green lines.

In addition to supervising the testing of the castings, the supervising inspector will also keep an eye on the apparatus used. The tensile machine, for instance, is required by the Air Ministry to be tested and the calibration checked by a competent authority. Again, it is very important that heat treatment shall be carried out at the temperatures given in the specification. The supervising inspector will therefore see that the automatic temperature controllers and recorders are showing the correct temperature. The foundry's own inspector will, of course, check them periodically and is required systematically to record such checks.

We have seen, then, that the supervising A.I.D. inspector is available for assistance when doubts crop up concerning procedure, at any stage of production, or the results obtained when any of the tests are carried out. This does not mean that he acts as foundry manager or chief inspector. He has nothing to do with the actual making of the castings, and only carries out actual inspection for release of castings if asked to do so. He will carry out routine inspection of some of the castings already passed, to satisfy himself that the standard set by the foundry's inspection department is satisfactory. Apart from that, his duties are to help and advise and to see that all requirements decreed by the Air Ministry are carried out satisfactorily.

In one way he can sometimes assist the foundryman. A casting may be difficult to make because it has originally been made as a forging or a built-up part. There may be abrupt changes of section or sharp corners, or some other detail, which makes it difficult to produce as a casting. It is often possible to redesign the casting, and to produce a new one which is quite satisfactory and is also relatively easy to cast. Sometimes the foundry can approach the designers directly and obtain permission to alter the shape of the castings. On one occasion the writer and his associates redesigned a troublesome wing brace. The makers of the aircraft gladly accepted the design and many hundreds of satisfactory castings were made.

In some cases, especially if the job be

a sub-contract, the supervising inspector can help in this work by getting in touch with the designers and ensuring that proper authority is obtained for any recommended modification.

The Air Ministry has gone to a great deal of trouble in order to make as sure as is humanly possible that all castings which are used in aircraft are sound. They have had a great deal to do with the development of methods of control and inspection, and especially with that new inspection tool, X-ray examination.

It is hoped that this account has demonstrated that the supervising A.I.D. inspector is not a man whom the Air Ministry unnecessarily employs to come into the foundry to find fault. Let it be understood that one of his duties definitely is to find fault if it be there, but he generally does so helpfully and tactfully. In general, however, he helps in every way possible, and his help is not restricted to the matter which comes within A.I.D. regulations. The standard required by aircraft castings, which is probably higher than that required by any other class of castings, is maintained by the Air Ministry, and its representatives, the A.I.D. inspectors, backed by the skill and care of all progressive aluminium foundrymen.

Current Light-alloy Specifications

Summary of Specifications with Chemical Compositions, Current to October, 1944

D.T.D.—Specifications for Aluminium-base Alloys

No.	
128	Aluminium-alloy forgings (for sealing rings for cylinders).
130A	Aluminium-alloy bars, extruded sections and forgings (3-in. max. dia.)—solution treated and aged.
131B	Aluminium-alloy sand- or die-castings (heat treated)—suitable for pistons, etc.
133B	Aluminium-alloy sand- or die-castings —not suitable for pistons.
147	Light alloy airscrew forgings (Fairey Reed type).
150A	Light alloy airscrew forgings (detachable blades).
165	Aluminium-magnesium alloy castings.
182A	7% Magnesium-aluminium alloy sheets and strips (annealed).
184	Light alloy airscrew forgings and stampings (detachable blades and complete airscrews).
186A	7% Magnesium-aluminium alloy tubes (hard).
190	7% Magnesium-aluminium alloy tubes (annealed).
213A	Aluminium-manganese alloy sheets and coils.
220A	Wrought light aluminium alloy tubes.
231	10% Silicon-aluminium alloy castings.
238	Aluminium alloy sand- or die-castings (as cast)—suitable for pistons, etc.
240	Silicon-aluminium castings (heat treated).
245	Silicon-aluminium alloy castings (fully heat treated).
246A	Aluminium-alloy crankcase forgings (softened).
250	Aluminium-alloy sand- or die-castings —not suitable for pistons.
255	Aluminium-alloy die castings—suitable for pistons.
264	Aluminium-alloy sand- or die-castings —not suitable for pistons.
269	Aluminium-alloy sand- or die-castings.
272	Aluminium-silicon alloy sand- or die-castings—not suitable for pistons.
273	Aluminium-alloy tubes.
276	Aluminium-silicon alloy sand- or die-castings—not suitable for pistons.
287	Aluminium-alloy sand- or die-castings —not suitable for pistons.
294	Aluminium-alloy sand- or die-castings —not suitable for pistons.
297	7% Magnesium-aluminium alloy bars, extruded sections and forgings (softened).
298	Aluminium-alloy sand- or die-castings —not suitable for pistons.
300	Aluminium-magnesium alloy sand- or die-castings — not suitable for pistons.

No.
303 5% Magnesium-aluminium alloy wire and rivets.
304 Aluminium-alloy sand- or die-castings —not suitable for pistons.
309 Aluminium-alloy sand- or die-castings (heat treated)—not suitable for pistons).
310B Soft aluminium-alloy tubes—suitable for oil, petrol, gas starters and general purposes.
313 Aluminium-alloy sand- or die-castings (as cast)—not suitable for pistons.
324 Silicon-aluminium alloy forgings for engine cylinders and pistons.
327 Aluminium-alloy wire and rivets.
346 Soft aluminium-alloy sheets and strips.
356 Wrought light aluminium-alloy sheets and strips.
361 Aluminium-alloy sand-castings (heat treated)—not suitable for pistons.
363A Aluminium-alloy extruded bars and sections (6 ins. max. dia.).
364A Aluminium-alloy bars, extruded sections and forgings (3 ins. min. dia.).
390 Aluminium-coated aluminium-alloy sheets and coils.
404 Hard-drawn high-tensile 7% magnesium-aluminium-alloy wire and rivets.
410 Aluminium-alloy bars and forgings (3 ins. min. dia.).
423A Aluminium-alloy bars, extruded sections and forgings (3 ins. max. dia.).
424 Aluminium-alloy castings for general purposes.
428 Aluminium-alloy castings for low-stressed parts.
440 11/15 Aluminium-alloy tubes—suitable for structural and high-pressure use.
443 10/17 Aluminium-alloy bars, extruded sections and forgings.
450 10/17 Aluminium-alloy tubes—suitable for structural purposes.
460 18/22 Aluminium-alloy tubes—suitable for structural purposes.
464 Aluminium-alloy tubes.
478 99% Secondary aluminium notched bars and ingots for remelting.
479 Secondary aluminium-alloy notched bars and ingots for remelting.
520 23/27 Aluminium-alloy tubes.
543 Aluminium-alloy sand- or die-castings (heat treated)—suitable for cylinder heads.
546 Aluminium-coated high-tensile aluminium-alloy sheets and coils—solution treated and artificially aged.
603 Aluminium-alloy sheets and coils (solution treated).
610 Aluminium-coated aluminium-alloy sheets and coils (solution treated).
646 High-tensile aluminium-alloy sheets and coils (solution treated and artificially aged).

B.S.—Specifications for Aircraft Materials

No.
6 L 1. Aluminium-alloy bars, extruded sections and forgings (3 ins. max. dia.) (heat treated).
5 L 3. Aluminium-alloy sheets and coils (heat treated).
2 L 4. Hard aluminium sheets.
3 L 5. Aluminium - zinc - copper - alloy castings.
3 L 8. 12% Copper - aluminium - alloy castings.
4 L 11. 7/1 Aluminium-alloy castings.
2 L 16. Half-hard aluminium sheets.
2 L 17. Soft aluminium sheets.
2 L 24. Y-aluminium-alloy castings.
4 L 25. Aluminium-alloy forgings (including pistons and cylinder heads).
2 L 30. 98% Aluminium notched bars and ingots (for remelting).
3 L 31. 99% Aluminium notched bars and ingots (for remelting).
2 L 33. Silicon-aluminium castings.
L 34. 99% Aluminium bars and sections.
L 35. Y-aluminium-alloy castings (heat treated).
L 36. Aluminium rivets.
2 L 37. Aluminium-alloy rivets.
2 L 38. Aluminium-coated aluminium-alloy sheets and coils.
2 L 39. Aluminium-alloy bars and forgings (3 ins. min. dia.) (heat treated).
2 L 40. Aluminium-alloy bars, extruded sections and forgings (3 ins. max. dia.) (heat treated).
2 L 42. Aluminium-alloy forgings (including pistons and cylinder heads).
L 44. Soft aluminium-alloy extruded bars and sections (3 ins. max. dia.).
L 45. Aluminium-alloy bars and forgings (3 ins. min. dia.).
L 46. Soft aluminium-alloy sheets and coils.
5 T 4. Aluminium-alloy tubes.
4 T 9. Aluminium tubes.

B.S.S.—British Standard Specifications

359 98% Aluminium notched bars and ingots for remelting purposes, rolling slabs and billets.
360 99% Aluminium notched bars and ingots (for remelting purposes).
361 7% Copper-aluminium-alloy castings.
362 12% Copper-aluminium-alloy castings.
363 Zinc-copper-aluminium-alloy castings.
385 Pure aluminium tubes.
386 Pure aluminium bars and sections.
395 Wrought light aluminium-alloy sheets and strip.
396 Wrought light aluminium-alloy tubes.
414 Wrought light aluminium-alloy sheets and strip.
477 Wrought light aluminium-alloy bars.
478 Wrought Y-alloy bars.
532 Light aluminium-alloy forgings.

533 Y-alloy forgings.
702 Silicon-aluminium-alloy castings.
703 Y-alloy castings (as cast).
704 Y-alloy castings (heat treated).
1080 Aluminium-alloy bars for the manufacture of fuses and fuse parts (War Emergency Specification).

Light Metals Control L.A.C. Specifications

L.A.C. 10 Secondary aluminium alloy suitable for pistons other than aero and heavy-duty pistons.
L.A.C. 112 Secondary aluminium casting alloy especially suitable for pressure and gravity die castings.
L.A.C. 113A General purpose secondary aluminium sand-casting alloy suitable for use where ductility is not important, e.g., gearboxes and casings.

D.T.D.—Specifications for Magnesium-base Alloys

59A Magnesium alloy castings.
88B Magnesium alloy forgings, including stampings and pressings—not suitable for pistons.
118 Magnesium alloy sheets—suitable for welding.
120A Magnesium alloy sheets—suitable for welding.
136A Magnesium alloy castings—suitable for pressure work.
140A Magnesium alloy castings—for lightly stressed parts.
142 Magnesium alloy bars.
259 Magnesium alloy bars.
281 Magnesium alloy castings (heat treated)—suitable for pressure work.
285 Magnesium alloy castings (fully heat treated).
289 Magnesium alloy castings (heat treated).
325A Magnesium alloy ingots and castings.
348 Magnesium alloy tubes for lightly stressed parts—suitable for welding.
350 Magnesium alloy castings (as cast).
628 Magnesium alloy ingots and castings.

D.T.D.—Specifications for Copper-base Alloys Containing Aluminium

135 Aluminium-nickel bronze forgings for exhaust valve seats.
160 Aluminium-bronze for valve seats.
164A Aluminium-nickel-iron bronze bars, forgings and stampings.
174A Aluminium-bronze die castings.
197 Aluminium-nickel-iron bronze bars, stampings and forgings.
253A Aluminium-nickel-silicon brass tubes.
283A Aluminium-nickel-silicon brass sheets (annealed).
323 Aluminium-nickel-silicon brass tubes (medium pressure).
367 Aluminium-nickel-silicon brass wire and rivets.
412 Aluminium-bronze sand or die castings.

CURRENT LIGHT ALLOY SPECIFICATIONS

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Ag	Cd	Remarks
D.T.D. Specifications, Aluminium-base alloys.															
128	R	0.05-0.15	0.50 max.	2.0 -3.0	—	0.5 -1.0	0.80-1.2	—	—	0.02-0.10	—	—	—	—	—
130A	R	0.65-1.2	0.55-1.25	1.8 -2.5	—	0.6 -1.4	0.60-1.2	—	—	0.05-0.15	—	—	—	—	—
131B	R	0.7 -1.7	2.0 max.	1.3 -2.5	—	0.5 -1.7	0.8 -1.3	—	—	0.25 max.	—	—	—	—	—
133B	R	0.05-0.30	1.5 -2.80	0.8 -2.0	—	0.8 -1.75	0.8 -1.40	—	—	0.05-0.25	—	—	—	—	—
147	R	0.40-0.70	—	3.5 -4.5	0.40-0.70	—	0.75 max.*	—	—	—	—	—	—	—	—
150A	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti 0.3 max. (if present)
165	R	3.00-6.00	—	—	0.25-0.75	—	0.6 max*	—	—	—	—	—	—	—	Total impurities 1.0 max.
182A	R	6.5 -10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—	—	—
184	R	0.4 -1.0	1.0 max.	1.5 -3.0	—	0.5 -1.5	0.8 -1.4	—	—	0.02-0.12	—	—	—	—	—
186A	R	6.5 -10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—	—	—
190	R	6.50-10.00	—	—	0.60 max.	—	0.75 max.	—	—	—	—	—	—	—	—
213A	R	—	0.6 max.	0.15 max.	1.5 max.	—	0.75 max.	—	—	—	—	—	—	—	—
220A	R	0.4 -1.0	1.0 max.	1.5 -2.5	—	0.5 -1.5	0.8 -1.5	—	—	0.12 max.	—	—	—	—	—
231	R	—	8.0 -12.0	—	0.50 max.	—	0.60 max.	—	0.10 max.	0.20 max.	—	—	—	—	Other elements excl. mod. agents 0.10 max. Total mod. agents (Na, W, Cr, Co, B, Ca) 0.30 max.
238	R	1.4 -1.8	2.0 max.	1.5 -2.5	—	0.5 -2.0	1.2 -1.5	—	—	0.02-0.12	—	—	—	—	—
240	R	0.60 max.	10.0 -13.0	—	0.60 max.	—	0.60 max.	—	—	—	—	—	—	—	Total other metallic impurities 0.20 max.
245	R	0.60 max.	10.0 -13.0	—	0.60 max.	—	0.60 max	—	—	—	—	—	—	—	Total other metallic impurities 0.20 max.
246A	R	0.6 -1.2	1.0 max.	1.5 -2.5	—	0.5 -1.5	0.8 -1.5	—	—	0.12 max.	—	—	—	—	—
250	R	0.5 -1.0	1.0 -1.4	2.0 -3.0	—	1.0 -2.0	1.0 -1.4	—	—	—	—	—	—	—	Ce 0.05-0.2; Cb 0.05-0.3 (if present); Cr 0.05-0.2 (if present)
255	R	0.5 -1.0	1.0 -1.4	2.0 -3.0	—	1.0 -2.0	1.0 -1.4	—	—	—	—	—	—	—	Ce 0.05-0.2; Cb 0.05-0.3 (if present); Cr 0.05-0.2 (if present).
264	R	—	10.0 -13.0	0.1 max.*	0.5 max.*	2.5 -3.5	0.6 max.*	—	0.1 max.*	0.2 max.*	—	—	—	—	—
269	R	0.1 -0.3	0.7 -0.9	4.0 -4.6	0.3 max.	—	0.5 -0.7	—	—	0.25 max.	—	—	—	—	—
272	R	0.4 -0.6	4.5 -5.5	1.0 -1.5	—	—	0.6 max.	—	—	0.25 max.	—	—	—	—	—
273	R	0.8 -1.8	0.5 max.	3.5 -4.8	0.3 -1.5	—	0.4 max.	—	—	—	—	—	—	—	—
276	R	0.4 -0.6	4.5 -5.5	1.0 -1.5	—	—	0.6 max.	—	—	0.25 max.	—	—	—	—	—
287	R	0.05-0.2	0.75-2.5	1.0 -2.0	—	1.0 -1.75	0.25-1.3	—	—	—	—	—	—	—	Ce (if present) 0.05-0.3; Cr (if present) 0.05-0.3; Cb (if present) 0.05-0.3
294	R	0.2 -1.5	2.5 max.	2.0 -4.5	0.5 max.	—	0.8 max.	—	—	0.4 max.	—	—	—	0.5-2.5	—
297	R	6.5 -10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—	—	—
298	R	—	0.25 max.	4.0 -5.0	—	—	0.25 max.	—	—	0.25 max.	—	—	—	—	Impurities (Ni, Mg, Mn and Zn) 0.2 max.
300	R	9.5 -11.0	0.25max.*	0.15 max.*	—	—	0.3 max.*	—	—	—	—	—	—	—	Other impurities (Ti, Mn and Ca) 0.25 max.
303	R	4.5 -5.5	0.5 max.*	—	0.6 max.*	—	0.5 max.*	—	—	—	—	—	—	—	—
304	R	—	0.25 max.	4.0 -5.0	—	—	0.25 max.	—	—	0.25 max.	—	—	—	—	Impurities (Ni, Mg, Mn and Zn) 0.2 max.
309	R	0.3 -0.8	2.0 -3.0	0.8 -2.0	—	0.5 -1.5	0.8 -1.4	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
310B	R	1.0 -3.0	0.7 max.*	—	1.5 max.	0.5 max.†	0.7 max.*	0.5 max.†	—	0.2 max.*	—	—	—	—	—
313	R	0.3 -0.8	2.0 -3.0	0.8 -2.0	—	0.5 -1.5	0.8 -1.4	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
324	R	0.8 -1.5	11.0 -13.0	0.7 -1.3	—	0.7 -1.3	—	—	—	—	—	—	—	—	Impurities (Fe, Mn, Ti) 0.6 max.
327	R	0.2 -0.5	0.7 max.*	1.5 -3.0	0.5 max.*	0.7 max.*	0.7 max.*	—	—	0.3 max.*	—	—	—	—	—
346	R	0.5-1.25	0.75-1.25	—	0.5 -1.0	—	0.75 max.	—	—	—	—	—	—	—	—
356	R	1.0 max.	1.0 max.	3.0 -4.5	1.2 max.	—	1.0 max.	—	—	—	—	—	—	—	—
361	R	—	0.25 max.	4.0 -5.0	—	—	0.25 max.	—	—	—	—	—	—	—	Ti (if present) 0.25 max. Impurities (Ni, Mg, Mn, Zn) total 0.25 max.
363A	R	4.0 max.	0.6 max.	3.0 max.	1.0 max.	—	0.6 max.	1.0 max.	4.0-8.0	0.3 max.	—	—	—	—	—
364A	R	1.0 max.	1.5 max.	3.0 -4.5	1.2 max.	—	1.0 max.	—	—	—	—	—	—	—	—
390	R	0.6 -1.8	0.7 max.	3.5 -5.0	0.3 -1.2	—	0.7 max.	—	—	—	—	—	—	—	Coating: Al 99.7 min.
404	R	6.5 -10.0	0.5 max.*	—	0.6 max.*	—	0.5 max.*	—	—	—	—	—	—	—	—
410	R	0.65-1.2	0.55-1.25	1.8 -2.5	—	0.6 -1.4	0.60-1.2	—	—	0.05-0.15	—	—	—	—	—
423A	R	0.5 -1.25	0.5 -1.25	1.0 max.	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—	—	—
424	R	0.15 max.	3.0 -6.0	2.0 -4.0	0.7 max.	0.35 max.	0.8 max.	—	0.20 max.	0.20 max.	—	—	—	—	—
428	R	0.1 max.*	2.0 -4.0	6.0 -8.0	—	—	1.0 max.*	—	2.0-4.0	—	—	—	—	—	Ni + Sn + Pb + Mn 1.0 max.*
440	R	1.0 -3.0	0.7 max.*	—	1.5 max.	0.5 max.†	0.7 max.*	0.5 max.†	—	0.2 max.*	—	—	—	—	—
443	R	0.5 -1.25	0.75-1.25	1.0 max.	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—	—	—
450	R	0.5 -1.25	0.75-1.25	1.0 max.	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—	—	—
460	R	0.5 -1.25	0.75-1.25	1.0 max.	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—	—	—
464	R	1.0 max.	1.0 max.	3.0 -4.5	1.2 max.	—	1.0 max.	—	—	—	—	—	—	—	—
478	99 min.	—	0.50 max.	0.20 max.	—	0.25 max.	0.60 max.	—	0.10 max.	—	—	nil	—	—	—
479	R	0.4 -1.0	0.7 max.	3.5 -4.5	0.4 -0.7	0.25 max.	0.8 max.	—	0.2 max.	—	0.05 max.	nil	—	—	—
520	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
523	*Material to latest B.S. Specification L.1 or DTD 423A.*														
543	R	1.3 -1.7	2.0 max.	1.5 -2.5	—	0.5 -2.0	0.8 -1.3	—	—	0.02-0.12	—	—	—	—	—
546	R	1.0 max.	1.5 max.	3.5 -4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—	—	Coating: Al 99.5 min.
603	R	1.0 max.	1.5 max.	3.5 -4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—	—	—
610	R	1.0 max.	1.5 max.	3.5 -4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—	—	Coating: Al 99.5 min.
646	R	1.0 max.	1.5 max.	3.5 -4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—	—	—
B.S.I. Aircraft materials.															
6L.1	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
5L.3	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
2L.4	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
3L.5	R	—	0.70 max.*	2.5 -3.0	—	—	0.80 max.*	—	12.5-14.5	0.20 max.*	0.10 max.*	—	—	—	—
3L.8	R	—	0.70 max.*	11-13	—	—	0.80 max.*	—	0.10 max.*	0.20 max.*	0.10 max.*	—	—	—	—

CURRENT LIGHT ALLOY SPECIFICATIONS—*Contd.*

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Ag	Cd	Remarks
B.S.I. Aircraft materials—contd.															
4L.11	R	—	0.70 max.*	6-8	—	—	0.80 max.*	—	0.10 max.*	0.20 max.*	0.10 max.*	1.0 max†	—	—	—
2L.16	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
2L.17	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
2L.24	R	1.2 -1.7	0.60 max.*	3.5 -4.5	—	1.8 -2.3	0.60 max.*	—	—	0.20 max.*	0.05 max.*	—	—	—	Si + Fe 1.0 max.* Sn + Zn 0.10 max.*
4L.25	R	1.2 -1.7	0.6 max.	3.5 -4.5	—	1.8 -2.3	0.6 max.	—	—	0.3 max.	—	—	—	—	Si + Fe 1.0 max.
2L.30	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
3L.31	99 min.	—	0.50 max.	0.03 max.	—	—	0.60 max.	—	0.03 max.	—	—	—	—	—	—
2L.33	R	—	10.0-13.0	0.1 max.*	0.5 max.*	—	0.6 max.*	—	0.1 max.*	0.2 max.*	0.1 max.*	—	—	—	—
L.34	99 min.	—	0.50 max.	—	—	—	0.60 max.	—	—	—	—	—	—	—	Fe + Si 0.90 max. Other metallic impurities 0.10 max.
L.35	R	1.2 -1.7	0.60 max.*	3.5- 4.5	—	1.8 -2.3	0.60 max.*	—	—	0.20 max.*	0.05 max.*	—	—	—	Si + Fe 1.0 max.* Sn + Zn 0.10 max.*
L.36	98.0 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	0.2 max.	—	—	—	—	Fe + Si 1.7 max. Other impurities 0.2 max.
2L.37	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	0.25 max.	0.7 max.	—	0.1 max.	—	0.05 max.	nil	—	—	Ti (if present) 0.3 max.
2L.38	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	0.25 max.	0.7 max.	—	0.1 max.	—	0.05 max.	nil	—	—	Ti (if present) 0.3 max. Coating: Al 99.5 min.
2L.39	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
2L.40	R	0.3 -1.5	1.5 max.†	1.5 -4.0	1.0 max.†	2.0 max.†	0.3 -1.5	0.2 max.†	—	0.2 max.†	—	—	—	—	Ce 0.3 max.,† Nb 0.3 max.†
2L.42	R	1.2 -1.8	1.3 max.	1.5 -3.0	—	0.5 -1.5	1.0 -1.5	—	—	0.2 max.	—	—	—	—	—
L.44	R	1.0 -3.0	0.7 max.*	—	1.5 max.	0.35 max.†	0.7 max.*	0.5 max.†	0.1 max.	0.2 max.	0.05 max.	nil	—	—	—
L.45	R	0.3 -1.5	1.5 max.†	1.5 -4.0	1.0 max.†	2.0 max.†	0.3 -1.5	0.2 max.†	—	0.2 max.†	—	—	—	—	Ce 0.3 max.,† Nb 0.3 max.†
L.46	R	1.0 -6.0	0.7 max.	1.0 max.†	1.5 max.	1.5 max †	1.5 max.†	0.5 max.†	0.1 max.	—	0.05 max.	nil	—	—	—
5T.4	R	0.4 -0.8	0.7 max.	3.5 -4.5	0.4 -0.7	—	0.7 max.	—	—	—	—	—	—	—	Ti (if present) 0.3 max.
4T.9	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.7 max.
B.S. Specifications															
359	98.0 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.10 max.
360	99.0 min.	—	0.50 max.	—	—	—	0.60 max.	—	—	—	—	—	—	—	Fe + Si 0.90 max. Other metallic impurities 0.10 max.
361	R	—	1.00 max.*	6.00-8.00	—	—	1.00 max.*	—	0.10 max.*	—	—	—	—	—	Total other metallic impurities 0.10 max.
362	R	—	1.00 max.*	11.0-13.0	—	—	1.00 max.*	—	0.10 max.*	—	—	—	—	—	Total other metallic impurities 0.10 max.
363	R	—	1.00 max.*	2.50-3.00	—	—	1.00 max.*	—	12.50-14.50	—	—	—	—	—	Total other metallic impurities 0.10 max.
385	98.0 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.10 max.
386	98.0 min.	—	1.0 max	—	—	—	1.0 max.	—	—	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.10 max.
395	R	0.40-0.70	—	3.50-4.50	0.40-0.70	—	0.75 max.*	—	—	—	—	—	—	—	—
396	R	0.40-0.70	—	3.50-4.50	0.40-0.70	—	0.75 max.*	—	—	—	—	—	—	—	—
414	R	1.20-1.70	0.60 max.	3.50-4.50	—	1.80-2.30	0.50 max.	—	—	—	—	—	—	—	—
477	R	0.40-0.70	—	3.50-4.50	0.40-0.70	—	0.75 max.*	—	—	—	—	—	—	—	—
478	R	1.20-1.70	0.60 max.	3.50-4.50	—	1.80-2.30	0.50 max.	—	—	—	—	—	—	—	—
532	R	0.40-0.70	—	3.50-4.50	0.40-0.70	—	0.75 max.*	—	—	—	—	—	—	—	—
533	R	1.20-1.70	0.60 max.	3.50-4.50	—	1.80-2.30	0.50 max	—	—	—	—	—	—	—	—
702	R	—	10-13	0.10 max.	0.50 max.	—	0.60 max.	—	0.20 max.	0.10 max.	—	—	—	—	Total other metallic impurities (excluding Na) 0.10 max.
703	R	1.2 -1.7	0.60 max.*	3.5 -4.5	—	1.8 -2.3	0.60 max.*	—	—	—	0.05 max.*	—	—	—	Si + Fe 1.0 max. Sn + Zn 0.10 max.
704	R	1.2 -1.7	0.60 max.*	3.5 -4.5	—	1.8 -2.3	0.60 max.*	—	—	—	0.05 max.*	—	—	—	Si + Fe 1.0 max. Sn + Zn 0.10 max.
1080	R	0.25-0.75	—	2.5 -4.0	0.2 max.*	0.05 max.*	0.75 max.*	—	0.2 max.*	—	—	0.1-0.5	—	—	Sb 0.3-1.0. Fe + Si 1.2 max.*
Light Metals Control. L.A.C. Specifications.															
10	R	0.15-0.35	0.6 max.*	9.0-10.5	0.6 max.*	0.5 max.*	0.3-1.0	—	0.1 max.*	—	0.1 max.*	0.1max.*	—	—	Fe + Mn 1.4 max. Zn + Sn + Pb 0.2 max.
112	R	0.3 max.	7.0-13.0	2.0- 3.0	0.5 max.	1.5 max.	1.0 max.	—	1.2 max.	—	—	—	—	—	Total other impurities 0.5 max.
113A	R	0.1 max.*	1.3 max.	2.5- 4.5	0.3 max.*	0.5 max.*	1.0 max.*	—	9.0-13.0	—	—	—	—	—	Ni + Sn + Pb + Mn 1.0 max.*
DTD Specifications. Magnesium-base alloys.															
59A	8.5 max.	R	0.4 max.*	0.4 max.*	0.5 max.	—	0.1 max.*	—	3.5 max.	—	0.4 max.*	0.4max.*	—	—	—
88B	11.0 max.	R	—	—	1.0 max.	—	—	—	1.5 max.	—	—	—	—	—	Total impurities 1.5 max.
118	0.2 max.	R	0.4 max.	0.2 max.	2.5 max.	—	—	—	0.2 max.	—	—	—	—	—	Impurities 0.5 max.
120A	9.0 max.	R	0.4 max.	0.3 max.	1.0 max.	—	—	—	1.5 max.	—	—	—	—	—	—
136A	9.0 -11.0	R	—	—	0.5 max.	—	—	—	3.5 max.	—	—	—	—	—	Total impurities including Cu, Pb, Fe and Si 1.5 max.
140A	0.2 max.	R	0.4 max.	0.2 max.	2.5 max.	—	—	—	0.2 max.	—	—	—	—	—	Impurities 0.5 max.
142	0.2 max.	R	0.4 max.	0.2 max.	2.5 max.	—	—	—	0.2 max.	—	—	—	—	—	Impurities 0.5 max.
259	11.0 max.	R	—	—	1.0 max.	—	—	—	1.5 max.	—	—	—	—	—	Total impurities 1.5
281	9.0 -11.0	R	—	—	0.5 max.	—	—	—	1.0 max.	—	—	—	—	—	Impurities including Cu, Pb, Fe and Si 1.0 max.
285	9.0 -11.0	R	—	—	0.5 max.	—	—	—	1.0 max.	—	—	—	—	—	Impurities including Cu, Pb, Fe and Si 1.0 max.
289	8.5 max.	R	—	—	0.5 max.	—	—	—	3.5 max.	—	—	—	—	—	Impurities including Cu, Pb, Fe and Si 1.0 max.
325A	3.5 -5	R	—	—	0.10-0.40	—	—	—	0.5 max.	—	—	—	—	—	Impurities including Cu, Pb, Fe and Si 0.50 max.
348	7.5 max.	R	—	—	1.0 max.	—	—	—	1.5 max.	—	—	—	—	—	Total impurities (Si, Cu and Fe) 1.5 max.
350	2.0 -6.0	R	—	—	0.6 max.	—	—	—	—	—	—	3.0-10.0	0.25-4.0	—	Impurities including Cu, Ni, Fe and Si 0.5 max.
628	5.75-7.25	R	—	—	0.10-0.40	—	—	—	0.75-1.50	—	—	—	—	—	Impurities including Cu, Ni, Fe and Si 0.50 max.
DTD Specifications. Copper-base alloys containing aluminium.															
135	9.75-10.5	—	—	R	—	1.0 -1.5	—	—	—	—	—	—	—	—	Total impurities 0.3 max.
160	9.0 -9.8	—	—	R	—	—	—	—	—	—	0.15 max.*	—	—	—	Total impurities (including Pb) 0.75 max.
164A	9.0 -10.0	0.1 max.*	0.1 max.*	R	2.5 max.†	1.0 -3.0	0.5 -2.5	—	0.5 max.*	—	0.05 max.*	0.2max.*	—	—	—
174A	7.5 -10.5	—	—	R	3.5 max.†	4.0 max.†	1.5 -3.5	—	—	—	—	—	—	—	Total impurities 0.3 max.
197	8.0 -12.0	—	—	R	—	4.0 -6.0	—	—	—	—	—	—	—	—	Total impurities 0.3 max.
253A	0.7 -1.2	—	0.8 -1.3	81.0-86.0	0.10 max.*	0.8 -1.4	0.25 max.*	—	R	—	0.05 max.*	0.10 max.*	—	—	—
283A	0.7 -1.2	—	0.8 -1.3	81.0-86.0	0.10 max.*	0.8 -1.4	0.25 max.*	—	R	—	0.05 max.*	0.10 max.*	—	—	—
323	0.7 -1.2	—	0.8 -1.3	81.0-86.0	0.10 max.*	0.8 -1.4	0.25 max.*	—	R	—	0.05 max.*	0.10 max.*	—	—	—
367	0.7 -1.2	—	0.8 -1.3	81.0-86.0	0.10 max.*	0.8 -1.4	0.25 max.*	—	R	—	0.05 max.*	0.10 max.*	—	—	—
412	8.0 -12.0	—	—	R	2.5 max.†	3.0 -6.0	3.0 -6.0	—	—	—	—	—	—	—	Impurities 0.3 max.

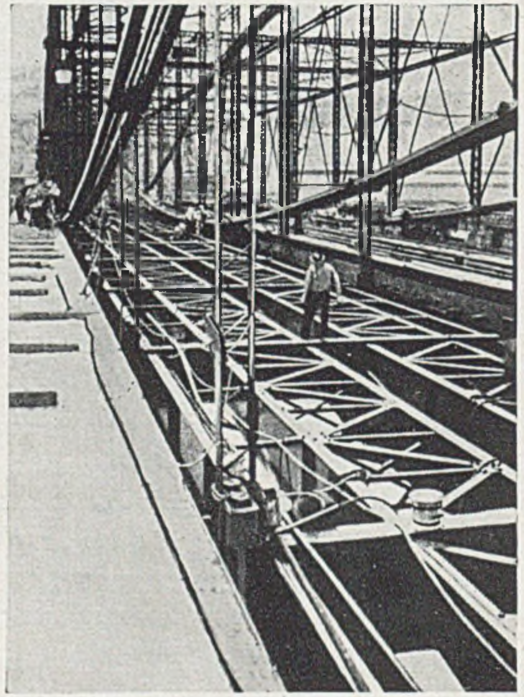
* Denotes elements classified as impurities.

† Denotes elements which may be present at option of manufacturers.

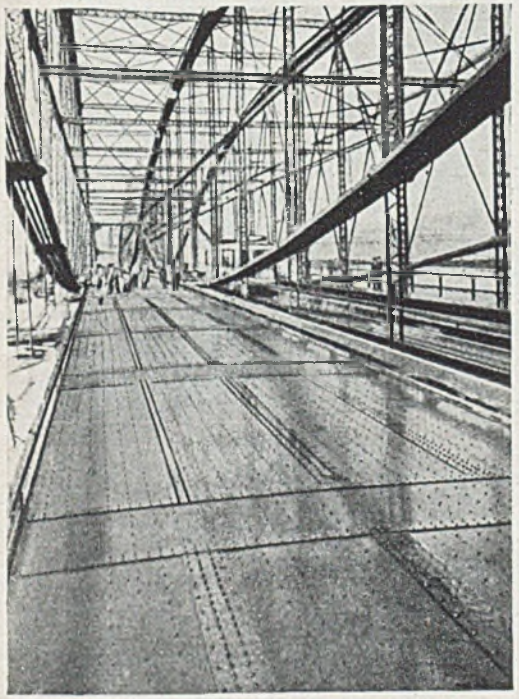
LIGHT ALLOYS IN CIVIL ENGINEERING

CIVIL engineering is, and must always be, pre-eminently a field for materials which are strong, abundant, frequently bulky and, above all, economical both in first cost and in maintenance. Those which most obviously satisfy these requirements are bricks, concrete, timber, cast iron and steel. At first sight, it is difficult to see in what way the use of light metals can be of advantage here, or how the greater expense of light-alloy construction can be justified; nevertheless, in certain specific applications, alloys of aluminium and magnesium have already rendered invaluable service. It is, in fact, rather surprising that so little attention has been devoted by the Technical Press to a consideration of the contributions which may be made by the light and ultra-light alloys in particular applications in civil engineering. With the grave problem of a rebuilding programme in mind, it is believed that the present moment is opportune to rectify this omission.

It is not proposed to discuss further the smaller items of architectural or structural engineering, such as aluminium glazing bars, doors, kick plates, spandrels and mouldings, which are, on the whole, rather better known, but to confine attention to the larger members which are present for load-bearing purposes only, and to other aspects of civil engineering in which the value of light metals is not so well known.



ALUMINIUM work on tramway side of the Smithfield Street bridge, Pittsburg, U.S.A. ("The Engineer," July 27, 1934.)

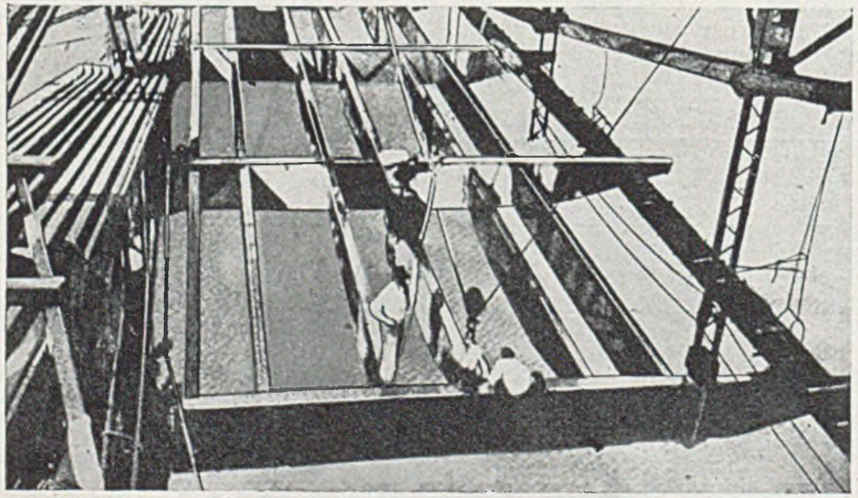


THE Smithfield Street bridge, showing aluminium floor ready for covering. ("The Engineer," July 27, 1934.)

There is, unfortunately, not a great deal of information relative to the design of light-alloy structural units which has been made generally available. Some of the researches which have been carried out on the design of aluminium and magnesium-alloy air frames are obviously applicable to structural members. Some information is contained in the technical publications issued by the principal aluminium and magnesium-alloy producers and suppliers in England, America and Germany. More recently, in this journal, Dudley* has made a theoretical study of the behaviour of light-alloy beams under various conditions of loading, and has deduced a number of formulæ relative to the design of light-metal structures.

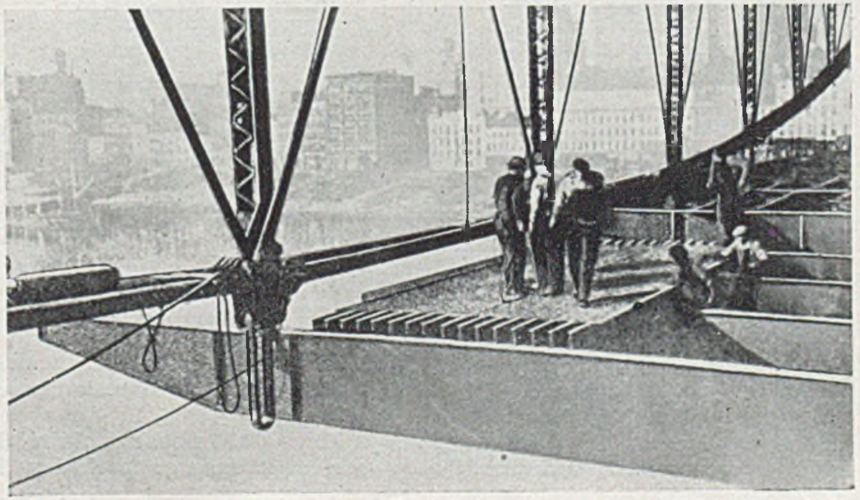
Value of Light Alloys

The value of light alloys in immobile structures lies usually in one or more of four factors, namely, the high strength-



Survey of Some Notable Achievements in Aluminium Constructional Work

AT the left are illustrated aluminium beams and stringers incorporated during the reconstruction of the Smithfield Street bridge. At the right, a floor panel in the Smithfield Street bridge is shown in the process of location. ("The Engineer," July 27, 1934.)



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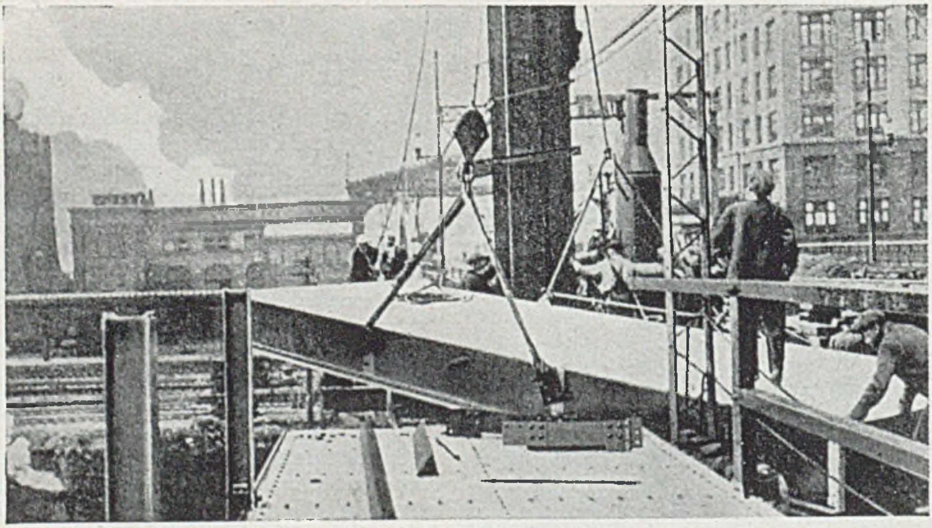
* "Light Metals," 1942/5/497; 1943/6/81, 158 and 480.



FURTHER view of the Smithfield Street bridge. Here, the last aluminium-alloy panel is being placed into position on the footway at the East side.

to-weight ratio of these materials; their resistance to corrosion and decay; the readiness with which they respond to certain fabricating operations; and the ease, compared with bricks, concrete, ferrous and other non-ferrous metals, of transportation to the site and of handling during erection. With this in mind, the applications of light metals in civil engineering may be considered under a number of well-defined heads:—

First, applications where the high strength-to-weight ratio of the light alloys, and particularly of the high-strength aluminium alloys, allows a reduction of dead weight on the foundations or lower members of a structure. Amongst larger structures, this is perhaps best illustrated by the use of light metals in bridge building, particularly where reconstruction is necessary to relieve the dead loading of ageing and deteriorating trusses and other stressed members. Among smaller items, aluminium has been adopted in many instances in the construction of large street and other types of lanterns, one of the main purposes being to reduce weight and thereby to allow the use of less massive and cheaper supporting structures.

Secondly, applications where the reduction in weight which can nearly always be achieved by the judicious use of light metals is of value in simplifying control of massive units or the handling of smaller items. Instances of such applications in large equipment range from massive structures, such as flood-gates weighing 28 tons in aluminium as compared with 78 tons in steel, to flood-prevention equipment for retail stores, where the need for easy manipulation and rapid fixing of anti-flood bulkheads has led to the adoption of aluminium as the chief material of construction. Among smaller items, light alloys have been employed in the construction of surveying instruments, road profilometers, road rammers, ladders and platforms for high-level repair work, in each case with a welcome reduction in weight and corresponding ease of handling. Also under this head may be considered mobile structures, where a reduction in weight results in a direct reduction in fuel consumption and in road wear, and in an improved performance of the vehicle.

Thirdly, those spheres of use where the ease of forming or machining the light alloys is an attraction. Many of the aluminium alloys are capable of producing sound castings with very little trouble. The magnesium-base alloys and the higher-strength aluminium alloys require more careful treatment, but good results can be obtained in experienced hands. Alloys are available for forging, for the production of seamless tubes and for deep drawing and pressing. Certain aluminium and magnesium alloys, and pure aluminium especially, are readily formed into shape by spinning, a process which has been much employed for suitable designs required in only small quantities.

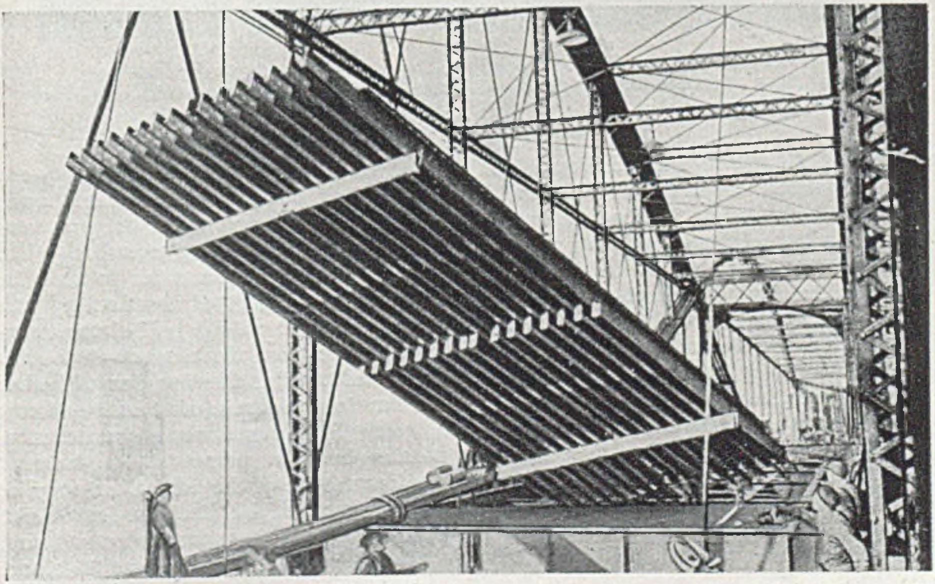
Linked up with all the other factors is the overall, fair corrosion resistance of aluminium and its alloys. Although attacked by many chemicals and especially by alkalies, the light alloys show a vastly superior resistance to the commoner corroding materials and atmospheres than the " non-stainless " ferrous metals; in fact, often superior and seldom inferior to other common non-ferrous metals. Moreover, this resistance can be greatly increased by suitable surface protection, such as by anodizing or by painting. Among outstanding examples, where advantage has been taken of this resistance to corrosion, may be instanced road signs and advertisements, traffic beacons, rolling shutters, ventilation and air-conditioning equipment and refuse-collection vehicles. In the last instance, the non-absorbent properties of aluminium and the absence of corrosion products which might favour the existence of bacteria or vermin make for much better sanitary conditions.

Finally may be considered applications which depend on certain special characteristics of aluminium, for example, its use in reflectors and as a coating for pavement lights to give good and permanent reflectivity without the fragility of glass; and the use of aluminium foil as a heat insulator, for instance, in tanks used for holding tar and bitumen in molten form for road-repairing purposes.

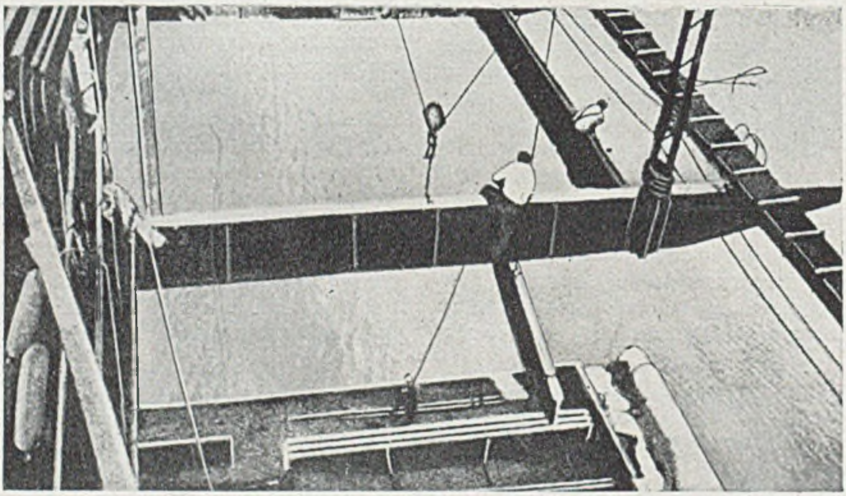
The Smithfield Street Bridge

As an illustration of the first type of application, we may consider the use of

THIS view of the Smithfield Street bridge shows a portion of the aluminium roadway being positioned. Note the size of the light-alloy unit.



light alloys in bridge construction and reconstruction. The first major application of aluminium alloys in bridge building, and the most notable achievement of light metals in this field to date, was the aluminium floor and balustrading system of the reconstructed bridge over the Monongahela River at Pittsburg. The suggestion to use light alloys in this connection came from the Aluminum Co. of America, which concern carried out a great deal of development work in order to ensure success in this new field. It may be that the entire satisfaction which has been obtained from the light-metal construction is one of the reasons why so little song has been made of what must be regarded as a most notable achievement, marking the commencement of a new era in civil engineering with far-reaching repercussions in all branches of constructional engineering. Since then, American interest in aluminium bridge construction has not waned, and it is reported that an American consulting engineer, Moisseiff, in collaboration with Alcoa, has produced a complete set of specifications for bridge design and construction in aluminium alloys.

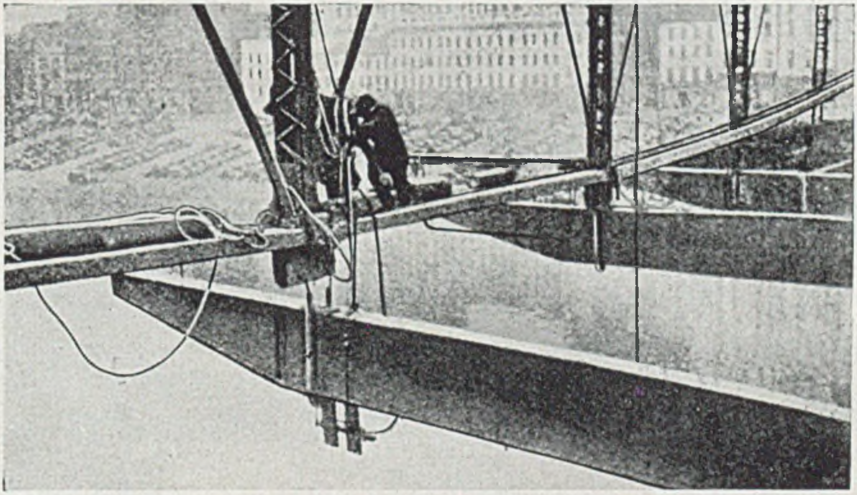


ERECTING a 36-in. aluminium-alloy stringer during the reconstruction of the Smithfield Street bridge. ("The Engineer," July 27, 1934)

The bridge over the Monongahela River, known as the Smithfield Street Bridge, was originally built of steel and wrought iron in 1882 to link Pittsburg proper with what is known as the South Side, on the opposite shore of the Monongahela River. It had two over-water spans of 360 ft. each, composed of two fish-belly trusses at 25-ft. 8-in. centres, the roadway being freely suspended from the trusses. In 1890 a third truss was erected outside the existing spans to provide a further roadway, increasing the total width by 20 ft. 8 ins. Twenty-one years later further enlargement again became necessary, and the upstream trusses were moved outwards 4 ft. 6 ins. At the same time, in order to suit the tramway rails, part of the flooring was remodelled, but on one half of the structure the original flooring of 1882 was maintained. This flooring was of timber built up to a thickness of 11 ins., and cost a great deal for annual maintenance, besides being a perpetual fire hazard. The magnitude of the fire hazard may be gauged from the fact that the first bridge across the river was destroyed by fire, whilst, during the summer of 1932 alone, five fires started in the floor system of the bridge, any one of which would have destroyed the structure if it had not been promptly discovered and extinguished.

Being, in effect, an extension of one of Pittsburg's principal thoroughfares, this bridge was used by pedestrians, motorcars and trolleycars in ever-increasing volume, due especially to the rapid expansion of the South Side. In 1926, a careful examination showed that the bridge was being overstressed by the increased traffic on an ageing and deteriorating structure, and measures to strengthen it had to be undertaken. In 1928, steel bars were welded to the faces of the outside eye bars of both the centre and up-stream trusses, thus easing the live-load stresses and, presumably, the dead-load stresses also. It became evident, however, that it was only a matter of time before something drastic would have to be done, and the demolition of the existing bridge and the construction of a new one seemed the most likely solution.

In 1932 a further investigation showed that substantial repairs of the trusses would have to be carried out without delay and that the timber floor would have to be renewed. This work would render the bridge fit to carry the existing live load, but, with no substantial increase in the design-strength of the structure, there was no room for traffic expansion. The fire hazard of the timber floor and the heavy maintenance costs would also remain undiminished. An obvious solution was to replace the upper part of the structure, that is to say, trusses, flooring and balustrading, with something lighter, less susceptible to fire hazards and which required less maintenance, and it was at this point that light alloys came under consideration.

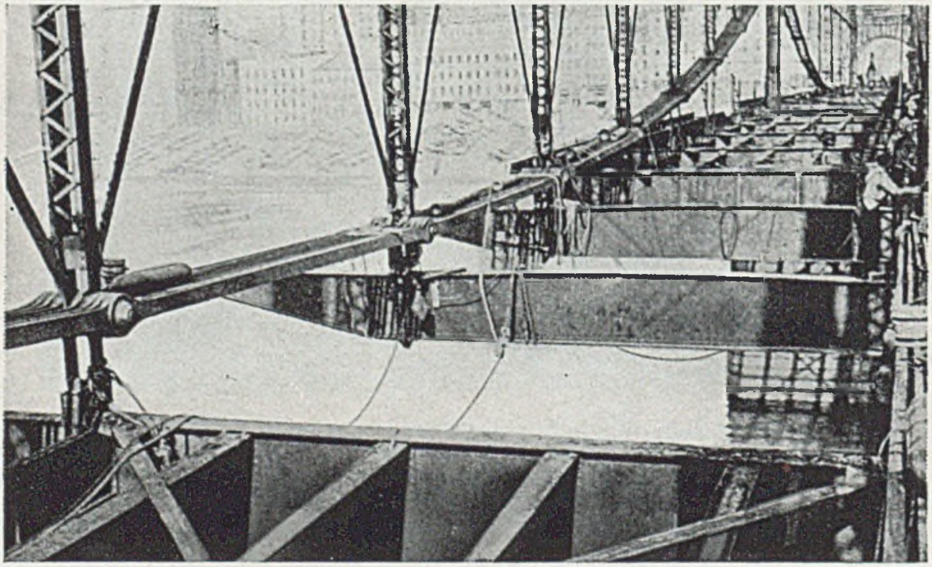


VIEW during the early stages of the reconstruction of the Smithfield Street bridge, showing location of a light-alloy floor beam. ("The Engineer," July 27, 1934.)

It was agreed that the useful life of the bridge could be greatly prolonged by reducing the loading on the trusses and the piers. The first suggestion, therefore, was to maintain the existing main structure of the bridge, replacing the heavy existing roadway with its supporting floor beams and stringers by a lighter structure consisting of a wooden decking over aluminium alloy floor beams and stringers. The alloy it was proposed to use was one of the duralumin type known as 17ST, which had been well tried over a number of years in such applications as railway coaches and wagons, motorcars, dragline booms and cranes, and designs were prepared on the basis of this alloy. Before fabrication had commenced, however, Alcoa was able to offer another alloy, known at 27ST, which appeared to possess certain advantages, chiefly in respect of improved mechanical properties and greater corrosion resistance. Particulars of these alloys and of two others which were also employed in the bridge reconstruction are given in Table I.

Meanwhile, intensive study was being devoted to the design of a satisfactory floor decking in aluminium alloy, and eventually one of the battle-deck type succeeded in satisfying all requirements and was chosen for use in the bridge. This was an important step, in one design largely eliminating the fire hazard, maintenance charges and high dead weight of the wooden decking. It was also decided to utilize light alloys in a railing design which would have the required strength, be pleasing in appearance, not expensive to produce and simple to erect. It was felt that not only would this still further reduce weight, but also, if constructed in one of the more corrosion-resistant aluminium alloys, it would considerably reduce maintenance costs. Surprising though it may seem, maintenance costs on bridge hand railings, compared with similar charges on the rest of the structure, are out of all proportion to the original prime costs.

The final design, then, was for a battle-deck-type roadway with its supporting floor beams and stringers and its balustrading all in aluminium alloy, and it was estimated that, compared with steel and wood contruction, this would result in a saving of 751 tons of dead weight, or over 1 ton per linear foot of bridge. This achievement appears all the more remarkable when it is considered that the corresponding structure in iron and wood weighed some 1½ tons per foot, or three times as much as the light metal construction. This light construction was considered to be sufficient to prolong the life of the main structure by at least 25 years. The total cost was $276,436, of which the outlay for structural aluminium



TAKEN during the reconstruction of the Smithfield Street bridge, the illustration reproduced here shows two aluminium floor beams on the highway side of the bridge.

PICTURED here are sections of roadway floor for the Smithfield Street bridge during the course of fabrication on the works of the Fort Pitt Bridge Company.

amounted to $192,000. This may seem a large sum of money for the reflooring of a 720-ft. bridge, but when it is considered in relation to the estimated cost of $1,935,000 for a new bridge, it must be conceded that the use of light alloys in this application has proved to be a wise economy. The general contract was given to Walter S. Rae, and the fabrication of the structural aluminium was subcontracted to Alcoa; actual fabrication being carried out at the Fort Pitt Bridge Works.

Materials Employed

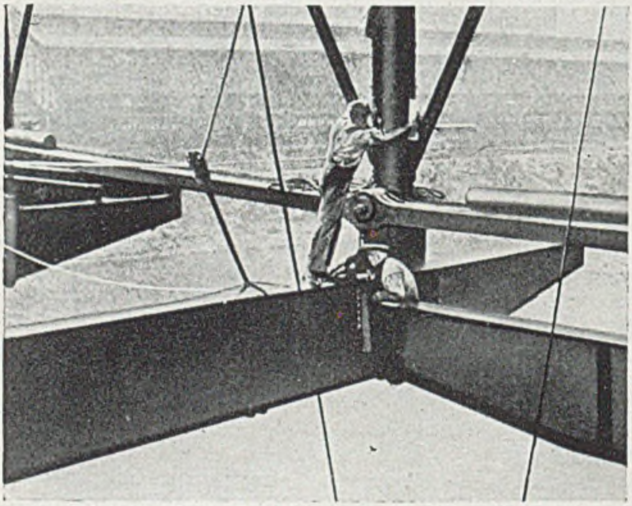
Some mechanical properties of the alloys employed have already been given in Table I. From this it will be seen that the alloy 27ST is comparable in many respects to silicon steel; in fact, if due allowance is made for its lower modulus of elasticity, it may be designed for similar stresses. It is harder than the usual run of light alloys and is, therefore, not easily damaged either in the workshop or on the site, and it can be numbered without any doubt among the more valuable structural materials available to the bridge engineer, particularly as it is available in a wide variety of structural shapes as well as in the form of plates of varying width and thickness. The material is both heat-treated and artificially aged. Therefore, it cannot be welded or cut by a torch without loss of strength, but it can be punched, sheared and drilled easily and is not injured by hot riveting. While only limited amounts of forming can be carried out on the alloy at room temperatures, it can be heated to 200-220 degrees C. without harm, and at these temperatures forming is greatly facilitated.

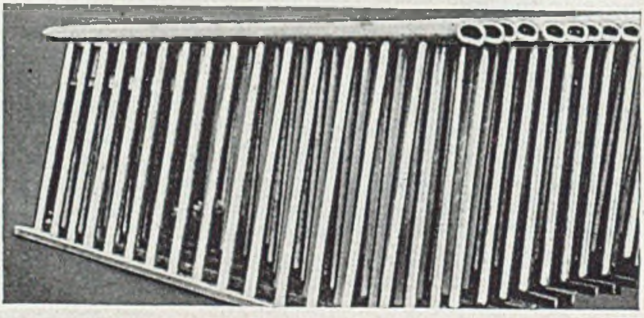
Since then a further Alcoa alloy has been described which would appear to be even more suitable for bridge building. With a composition of 4.5 per cent. Cu, 0.8 per cent. Mn, 0.8 per cent. Si, remainder aluminium, it has an ultimate tensile strength of 29 tons/sq. in. and shear strength of 17 tons/sq. in. Yield strength is 22 tons/sq. in. in tension and compression and 13 tons/sq. in. in shear. The modulus of elasticity is 10,300,000 p.s.i. in tension and compression and 3,800,000 p.s.i. in shear. Elongation is given as 11 per cent. 4SH is an unheat-treatable alloy of intermediate strength and corrosion resistance available in a variety of tempers. 53ST is a heat-treated alloy with exceptionally good cold working properties, of good strength, high resistance to corrosion, and easily welded.

Constructional Details

The roadway system can clearly be seen from the accompanying illustrations. The bridge provides a double track of rails for street cars, a 22-ft. roadway for vehicular traffic, and on either side a 12-ft.

pathway for pedestrians. Construction followed the normal lines as used for steel except that every opportunity was taken to reduce weight in the aluminium structure, even at the expense of more costly fabrication, and that advantage was taken of the light weight and ease of handling of light-alloy structural assemblies to make more use of partial shop fabrication than is possible with ferrous metals—in topical parlance, an example of prefabrication applied to bridge building made possible by the adoption of light alloys for structural units.





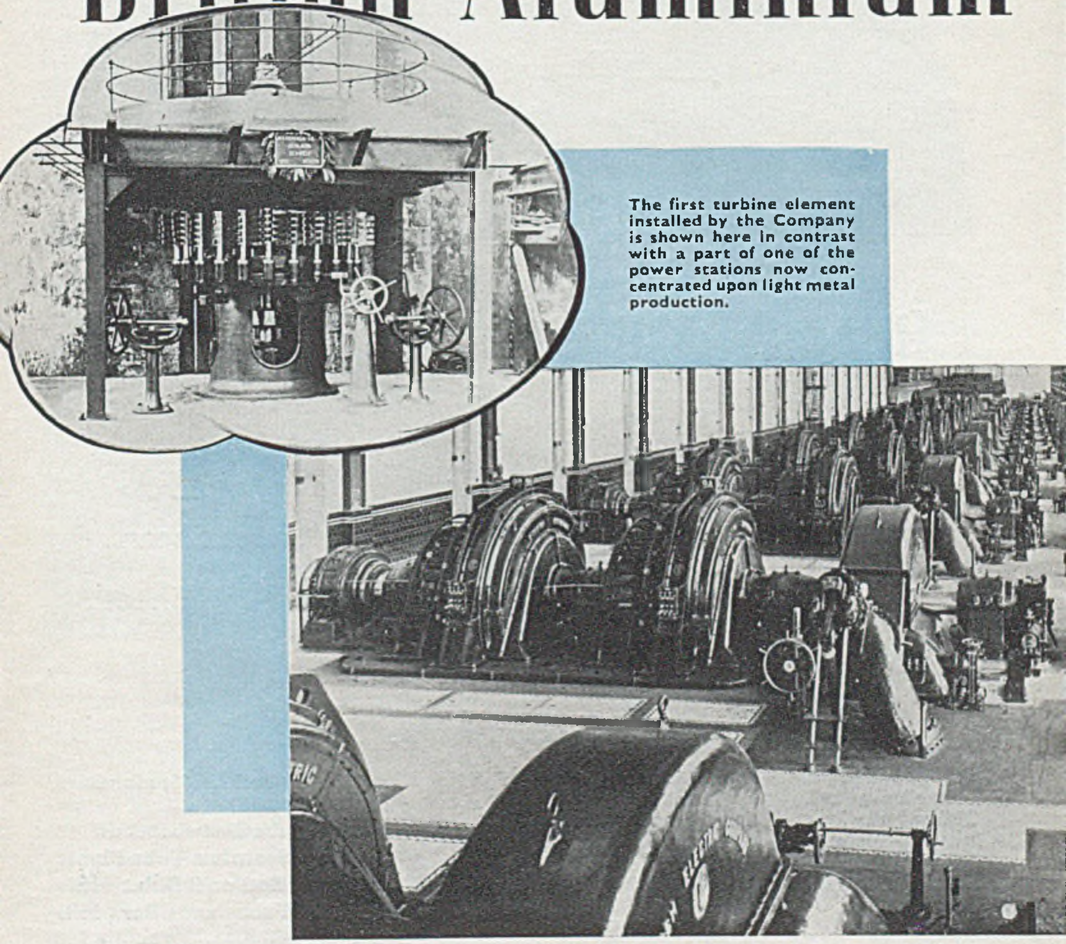
ABOVE. Aluminium stringer on the roadway section of the Smithfield Street bridge being hoisted into place; it is 27 ft. 5 ins. long and weighs 1,200 lb. At the right are shown handrail panels for the Smithfield Street bridge made up of aluminium channel and tubes. The panels are each 9 ft. $2\frac{1}{2}$ ins. long. ("Civil Engineering," March, 1934.)

The main floor beams are suspended at intervals of 27 ft. 6 ins., and consist of built-up girders 42 ins. deep under the crown of the vehicle roadway and 39 ins. deep under the street car roadway. They are built up from $\frac{1}{2}$-in. aluminium alloy plates with four flange angles of 4 × 3 × $\frac{3}{8}$ in. These beams project beyond the two outer suspension trusses to carry the footpaths as cantilevers. Longitudinal stringers connect with the main girders, the majority being 36 ins. deep. In the street car section, the rails are carried directly on the stringers. In the roadway section, the flooring consists of deck plate construction, the plates being $\frac{7}{16}$ in. thick riveted to 7-in. channels spaced at 8-in. centres. These rest on the main floor beams and on intermediate bearers strung between the longitudinal stringers.

The joists have an effective span of 9 ft. $2\frac{1}{2}$ ins., and at the centre of each joist span there is an 8-in. channel, which is rigidly secured to each of the joists. This channel acts as a distributing member, so that a wheel load is absorbed by several joists, and in this way the whole floor system is made to behave like a deep slab. The highway aluminium alloy deck is surfaced with a cold-laid asphaltic concrete mixture $1\frac{1}{2}$ ins. thick. This constitutes the wearing surface and is anchored to the underlying figured surface of the aluminium plates, the rivet heads and

The Jubilee of

British Aluminium



The first turbine element installed by the Company is shown here in contrast with a part of one of the power stations now concentrated upon light metal production.

On December 18th, 1944, The British Aluminium Company, Ltd., celebrates its Jubilee. In the past half century the aluminium industry of this country has risen from modest beginnings to its present high standing, progressively developing the water power of the Highlands for the electrolytic reduction of the metal. In Great Britain and the Empire the Company's undertakings cover all sections of the industry, from bauxite mining, through alumina factories, aluminium reduction, casting, rolling, extrusion and drawing, a complete chain of service to the manufacturer of aluminium and its alloys.

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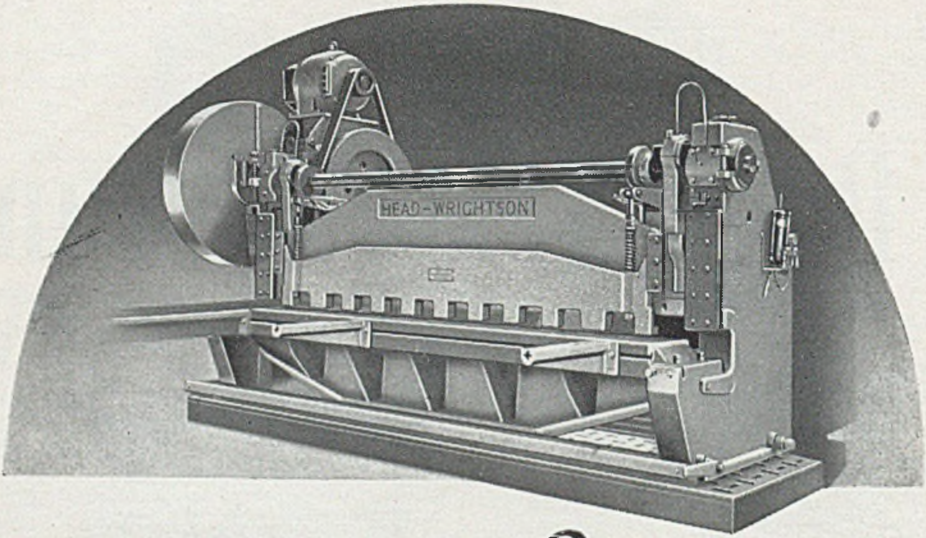

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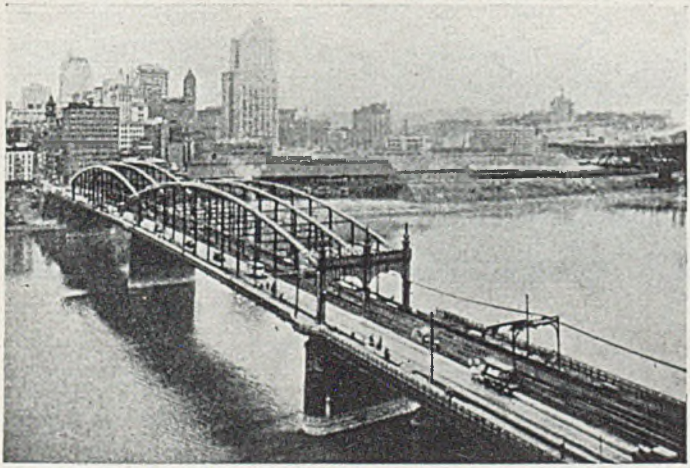
THORNABY-ON-TEES

34-L

ENGINEERS TO THE EMPIRE

diamonds preventing any creeping of the asphalt under traffic conditions.

The floor beams, stringers and lateral bracing of the railway section of the bridge were shop fabricated as far as possible to facilitate their erection. The floor of the highway half of the bridge was fabricated in sections 11 ft. wide and 27 ft. 7⅝ ins. long. Two such sections composed a floor panel, leaving a 4 ft. space over each floor beam which was afterwards covered by a tread plate which was field reamed and riveted to ensure continuity of the system. This procedure was only made possible by the lightness of the aluminium-alloy structural units.



OVERHEAD view of the Smithfield Street bridge after reconstruction and widening. The transformation effected here was made possible only by the extensive use of aluminium alloys.

The footways were similarly built up, and consisted of ¼-in. aluminium alloy plates reinforced by 2 × 2-in., angles riveted to the underside, the whole resting on 6-in. channels carried by plate girder stringers between the main floor beams of the bridge. They were shop fabricated in panels 27 ft. 7⅝ ins. long and about 8 ft. wide, and were erected as units.

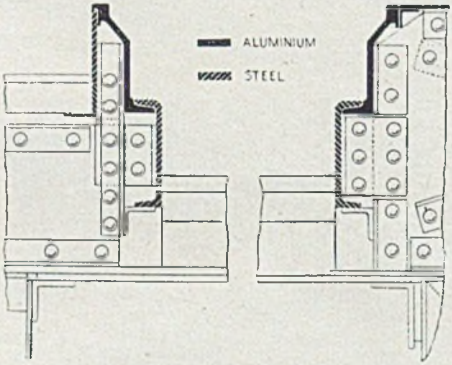
The Battle Deck Floor System

The light-alloy floor system was only adopted after comprehensive tests had been made on built-up panels 11 ft. wide by 13 ft. 10 ins. long, involving measurement of stresses and deflections in every part of the structure under H-20 loading, and a service test which consisted of driving an H-20 truck across the test panel 6,300 times in one direction. Its evolution forms the subject of an interesting study, illustrating the advantage of utilizing practical tests as well as computations whenever possible.

As originally designed, the flooring was made up of shop-fabricated panels, each 5 ft. 6 ins. wide and 13 ft. 10 ins. long. Two panels were made up and joined together in the field to form a panel 11 ft. by 13 ft. 10 ins. long, which was placed in position over a pit of the same length dug in a roadway where the behaviour of the panels could be studied. One of the two constituents of this panel consisted of tread plate ½ in. thick, supported by and riveted to 8-in. channels spaced 11 ins. apart, with a channel under each edge, the rivets being spaced 9 ins. apart. The other utilized 7/16-in. tread plates but was otherwise identical. These two constituents were joined by riveting together the adjacent channels under the edge of the plates. Two 8-in. distributor channels, spaced 4 ft. 7 ins. from each end, were added, situated below and at right angles to the joists, to which they were rigidly attached by short angles and rivets. The purpose of these channels was to provide some distribution of concentrated wheel loads, since it was apparent that differential deflection of adjacent joists under heavy wheel loads would lead to high stresses in the plate and disintegration of the asphalt surface. The only alternative was to multiply the floor beams, and space them more closely together, a procedure which was obviously undesirable. An intermediate supporting channel was also added across the centre of the panel, since it was felt that the unsupported 13 ft. 10 ins. span was too flexible to be satisfactory.

The success of the distributing channels was proved by accurate measurement of the deflections obtained under various conditions of loading. Deflections of the whole system acting as a simple beam with static and moving loads in the centre were respectively 0.55 in. and 0.60 in., or 1-302 and 1-277 of the span. This deflection was scarcely noticeable and was entirely satisfactory in service. The maximum stresses recorded are given in Table II.

In its original design, however, this test panel was not satisfactory. Since it had been decided to limit the stresses to 6.7 tons/sq. in., it was necessary to use either a thicker plate or to reduce the joist spacing. The latter proved to be the more economical, and an 8 ins. spacing and shorter span were decided upon. The distributor channel was considered to be understressed, but it was not reduced in size, since its effectiveness was dependent on its stiffness. A further improvement which was made as the result of test observations was provided by the substitution of a double butt strap splice for the riveting of the joists in adjacent sections. This was found to result in improved continuity.



EXCELLENT use is made of the malleability and shock-resisting powers of aluminium in the Michigan Avenue Bascule bridge, Chicago. Light-metal kerbs, whilst causing no damage to car tyres, successfully withstand all normal service stresses.

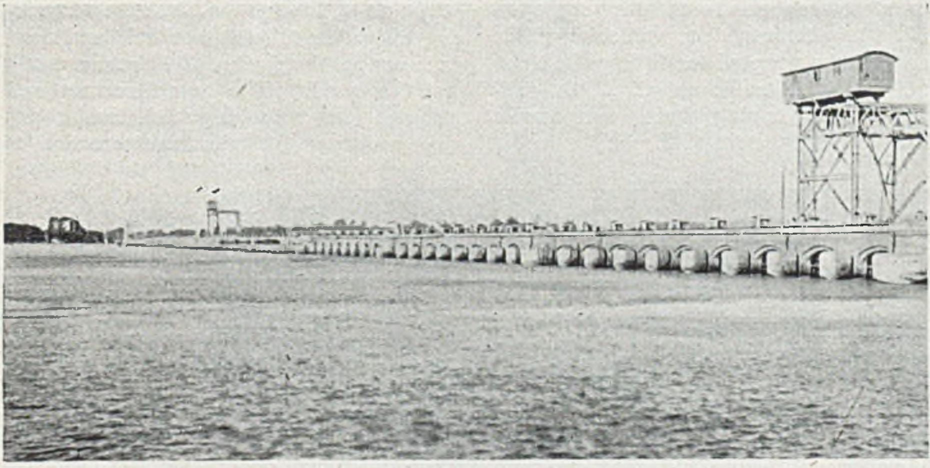
Pedestrian Hand Railings

A somewhat unusual construction was evolved for the railings for the pedestrian footpaths in order to take full advantage of the adaptability of light alloys to economical methods of mass pre-fabrication and simple erection and, at the same time, to provide an attractive design with the required strength. The form adopted consisted of 5-in. H-beam posts riveted to the facia girders, a 5-in. oval tubular top rail with a $\frac{1}{8}$-in. wall reinforced at the ends where it rested on a seat welded to the top of the post, and a 4-in. channel bottom rail which rested on angle seats riveted to the web of the posts. The top and bottom rails were connected by 1$\frac{1}{2}$-in. round tubular balusters spaced 6$\frac{3}{4}$ ins. from centre to centre. The balusters were inserted in holes punched in both top and bottom rails, where they were fastened by expanding them in the same way in which a boiler tube is expanded into the shell.

The railings were made up into prefabricated panels each 9 ft. 2 ins. long and weighing 45 lb. To erect them, the posts were first set in position and riveted to the girders, after which the panel was placed in position, the bottom rail bolted to its seat, the cap placed on the post over the top rail and four $\frac{1}{2}$-in. aluminium rivets were driven home. So simple was the method of erection that, after the posts had been erected, the 72 panels for one side of the bridge were moved from a storage place on one of the approaches and erected in 1 hr. 8 mins. Painting was not required as corrosion-resistant alloys were employed. Strength would appear to be entirely adequate, as the top rail was found to withstand a horizontal load of 362 lb. per linear foot without the stresses exceeding the yield value.

Fabrication

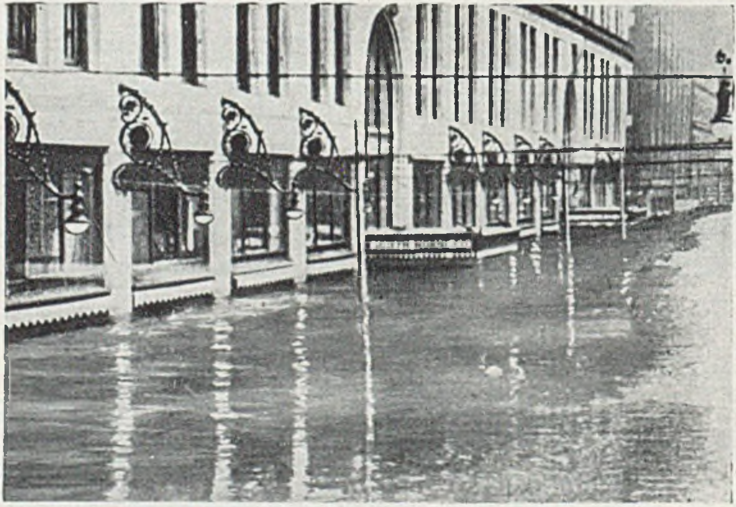
Not the least interesting side to the use of light metals in this application is the manner in which fabrication and erection were simplified. It has already been described how the flooring and balustrading were both partially prefabricated in the workshop into units which required little more than erection and fixing on the site. The elimination of much field work in this way greatly simplified erection and would not have been possible with steel as similar pre-fabricated units in this metal would have been too heavy to transport and handle satisfactorily on the site. Particularly was this true as reconstruction had to be commenced at the centre of each span, and the units had, therefore, to be loaded on to barges and ferried out to the desired position under the bridge. This was necessary because the Pauli-type trusses of the bridge are so designed that the wind load on the floor system is transmitted to the piers at each end of a truss and to the centre panel of each truss. The floor between the centre panel and the piers providing no lateral stiffness, reconstruction had to begin at the centre of each span and proceed thence towards the two ends.



SHOWN above and at the right are views of the Assuit barrage, Egypt. Although the relevant parts of the structure were, here, constructed in steel, this work has been cited as an instance where light metals could usefully have been employed, mainly for the purpose of reducing the dead weight of moving parts.

The value of pre-fabrication also

showed itself in the slightness of the interruption which reconstruction imposed on traffic over the bridge. The work of reconstruction was commenced on October 6, 1933, and on October 24 of the same year the bridge was again made available to all three kinds of traffic. In that time, with some minor exceptions, the structure had been fully equipped with a new floor system, vehicular traffic had been interrupted for 18 days and rail and pedestrian traffic not at all, the railway tracks having been temporarily moved from one side of the bridge to the other and, as expeditiously, back again.



VIEW in Pittsburg, March 18, 1936, showing premises of Joseph Horne Co. with flood water rising to a height of 10 ft. on the main floor. The steel bulkheads originally provided for use in such an emergency as this could not be set up in time.

In the fabricating shops, very little in the way of special equipment was needed for dealing with the light metal. The methods and machinery normally employed for dealing with ferrous metals proved to be quite satisfactory for the new material, provided care was taken to ensure that clean cuts were obtained on plates and angles subjected to shearing. Bending was performed on horizontal bulldozers, and punching on single, rack and automatic spacing machines. The dies and punches had a radial clearance of 1/32 in., and were kept sharp and well lubricated. Standard tools were used for drilling, reaming, milling and chipping. A small hand saw of the type used for cutting hardwoods was employed for trimming the ends of angles and coping channels when necessary.

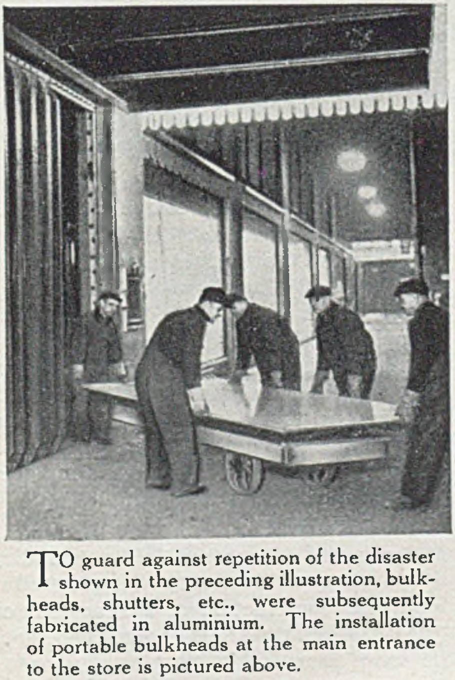
The rivets were of steel, $\frac{5}{8}$ and $\frac{3}{4}$ in. in diameter, hot driven with No. 80 pneumatic hammers and 70-ton squeeze riveters. Defective rivets were removed by drilling a hole of about the diameter of the rivet through the head, then knocking off the head with a chisel, and next backing out the rivet. Rivet busters could not be used. The same course was adopted for removing defective rivets driven during the subsequent erection of the floor structure. The aluminium-alloy parts were easily scribed and centre punched, and lent themselves readily to layout work. The material stood the usual run of shop handling without serious damage, but the precaution was taken of covering the cable slings with rubber hose to protect exposed surfaces.

Care had to be taken in shaping the aluminium members, because of the difference in the coefficients of expansion of aluminium and steel; but this was offset to some extent by the lower modulus of elasticity of the former, a factor which made for easier fitting. Protection against corrosion was provided by first cleaning the metal surface with dilute acid, rinsing well and then painting with an iron oxide-zinc chromate pigment in a phenolic-resin vehicle.

Aluminium in Other Bridges

Although the most famous, the Smithfield Street bridge is by no means the only example of light-metal bridge construction. Medium-strength aluminium alloys of high corrosion resistance have been employed for posts, railings and panels which form the component parts of pedestrian railing or balustrading systems of several American bridges, perhaps the best example of which is the Arlington Memorial bridge, Washington.

Light-alloy balustrading was fitted on the International Highway Bridge over the Rio Grande, but for a different reason than those given hitherto. The river in this locality is subject to severe flooding, and torrents of water sweeping down the river regularly did considerable damage to the concrete railings which were first erected. A railing sufficiently strong to withstand flood water being considered impracticable, it was decided to fit one composed of sections 10 ft. long, which could be removed to a place of safety when flooding appeared imminent. Light weight was essential to enable them to be moved in time, and an all-aluminium construction was evolved built up from rolled and extruded sections.



TO guard against repetition of the disaster shown in the preceding illustration, bulkheads, shutters, etc., were subsequently fabricated in aluminium. The installation of portable bulkheads at the main entrance to the store is pictured above.

FOR protecting the shop windows of Joseph Horne and Co. aluminium sheet was employed. One such unit is here shown being located for bolting up.

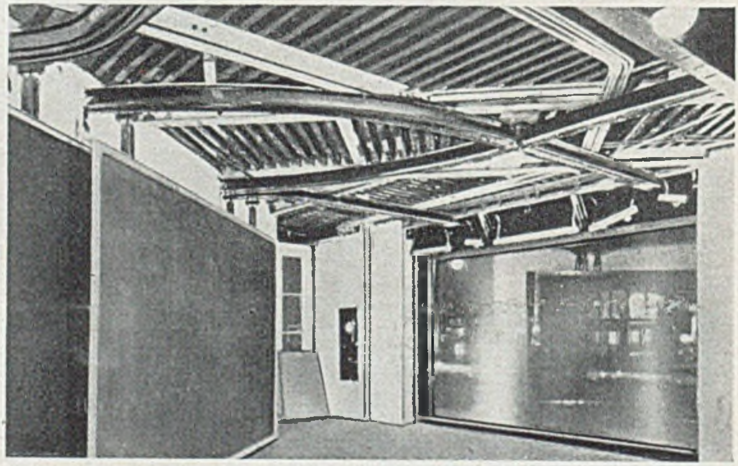
Portability par excellence in bridge unit construction has been achieved by British and American army engineers, who are known to have made good use of aluminium in emergency or pontoon bridges. One such design, stated in 1937 to be standard equipment of the U.S. army engineers, was based on the use of a number of light-weight boats or pontoons anchored across the river, with stringers and planking across to provide the bridge flooring. Construction was entirely in aluminium except for the gratings in the boats, the stringers and planking, which were in wood. Each boat was 26 ft. 6 ins. long, with a 5-ft. beam over the gunwale, and weighed 1,200 lb. complete, compared with 2,000 lb. (plus the considerable weight of absorbed water) for a wooden construction. In emergency it could be used to accommodate 20 soldiers.

At the shore end the roadway was supported by an "H" frame or trestle, consisting of two tubular steel columns supporting an aluminium alloy cross beam.

In the Michigan Avenue bascule bridge, Chicago, excellent use has been made of the malleability and shock-resisting powers of aluminium in the construction of kerbs, which, whilst causing no damage to car tyres, successfully withstand all the stresses encountered in service. This bridge carries probably the heaviest traffic in the world. Until a short time ago timber was used for the construction of the kerbs at the centre and sides of the roadways, but proved to be neither adequate nor safe. Hence, in the new upper deck of the structure, extruded aluminium shapes in a steel framing have been used to obtain the desired contour of the kerb, the wearing surface being of asphalt. It is claimed that this combination of steel framing and extruded aluminium will stop a car's tyres without damage to hub caps or fenders.

An approach to all-aluminium bridge construction was made in 1935, when it was reported that a proposed reconstruction programme for the Brooklyn Bridge envisaged the use of no metal other than aluminium, except for the rivets.

Another ambitious scheme was proposed in Italy shortly after the outbreak of the European War. In a paper presented at the light metals conference held at Milan, 1939-40, the Italian Minister-Director, D. de Simone, presented details of a road bridge to be built over the Tiber at Rome for the 1942 International Exhibition. The bridge was to have three arches, the smaller ones at the head and foot being in ferro-concrete, whilst the big centre arch, with a span of 377 ft., to traverse the entire distance between the banks of the river, was to be constructed in an aluminium-copper-magnesium alloy known as Superduralumin. The total length of the proposed bridge was 754 ft., its overall width being 119.5 ft., whilst the height of the roadway above the water was 78 ft. The height of the four parallel arched main girders was 83.7 ft. The complete weight of the whole structure was to amount to some 1,200 metric tons. The explanation for this ambitious project is, perhaps, to be found in the fact that, at that time, the amount of iron permitted for use in Italian buildings was limited to one-tenth of that allowed in 1935.

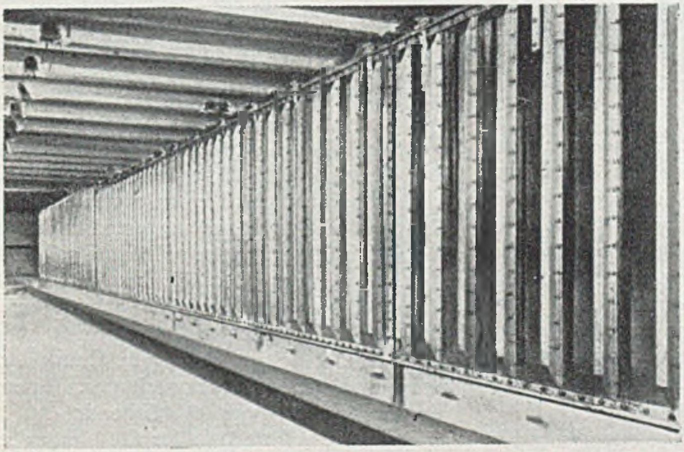

OVERHEAD track system in main corner window of Joseph Horne and Co. Ball-bearing trolleys mounted on the track support the rolling-type light-alloy bulkheads.

Dam Construction

Amongst a number of outstanding engineering achievements in connection with the construction of a new dam on the Ohio River near Gallipolis, Ohio, none is more remarkable than the use of a structural aluminium alloy for the emergency bulkheads or so-called flood gates. The function of emergency bulkheads is to shut off the water from one pair of gates in order that maintenance inspection or repairs may be carried out. Actually, in this case, the use of the word gates is a little misleading, as each gate consisted, in fact, of eight large steel cylinders 125 ft. long and each more than 20 ft. high, movable vertically between concrete pillars. Obviously, only one gate can be closed at a time, and in all such cases it is usual for economic reasons to construct only one set of emergency bulkheads, and to make provision for storing them on the shore and for transporting them to a position just upstream of the gate it is required to close. Normally, in the case of large dams, this entails the provision of a heavy service bridge over the entire length of the dam and storage sheds and heavy cranes for transportation and manipulation, which is a very expensive business.

The Gallipolis dam is a large one, built only a year or two before the war in replacement of a number of smaller dams, to provide a deeper channel for navigation, and preliminary designs showed that the normal bulkhead arrangements would be unusually expensive. Each bulkhead unit would weigh 78 tons in normal structural steel, a figure which could be reduced to 44 tons if high-strength nickel-alloy steel were employed. On the other hand, by making use of the high-strength aluminium alloys the weight could be further reduced to 28 tons, at which figure manipulation would require only light bridging and small cranes. It is, however, important to note that a bulkhead unit must be heavy enough to seat itself by gravity with a full head of water passing through the opening, and tests were made with a full-scale unit to ensure that correct functioning would be obtained.

As a result, it was decided to construct the bulkheads in aluminium alloy in seven similar sections, each measuring 128 ft. by 13 ft. 10 ins. by 4 ft. and weighing 28 tons, of which 20 tons was light metal. Each unit was composed of two horizontal trusses, with the skin plate on the downstream side, and, to prevent jamming, the units were provided with rollers at each end.



LOADING platform at Joseph Horne and Co., Pittsburg, showing complete barricading for protection against flood waters from the Allegheny river.

The alloy chosen was the same as that employed for the more highly stressed components of the Smithfield Street bridge, namely, 27ST. This alloy is, naturally, highly resistant to corrosion, although, in addition, in this case it was protected by a zinc-chromate/iron-oxide primer covered by two coats of aluminium paint. Arising out of the low modulus of elasticity of the aluminium alloy in comparison with steel, it was found that the deflection of the lowest unit under a full head of water was approximately 8 ins., and, therefore, provision had to be made to ensure a parallel bearing of the rollers against the masonry bearing plates for all deflections up to this maximum. This was done by providing a swivelling roller housing, which, like the rollers, was constructed of steel.

The whole of the dam, together with its auxiliary equipment, was designed in the United States Engineering Office at Huntingdon, West Virginia. The dam itself was built by the Dravo Contracting Co., Pittsburg, whilst the emergency bulkheads were constructed by the Nashville Bridge Co., Tenn.

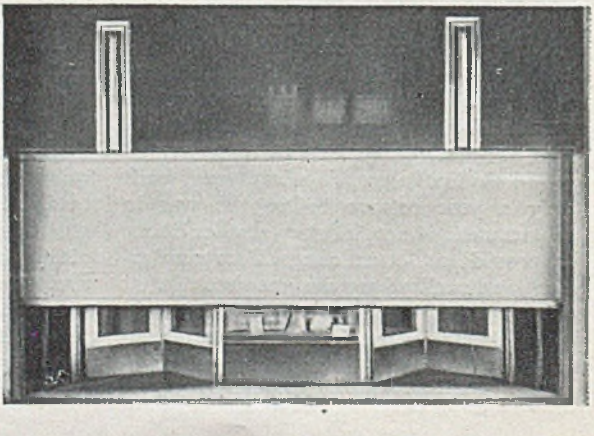
Similar aluminium bulkheads were also supplied for use on the Emsworth dam. The gates themselves were of steel, 100 ft. long and weighing 126 tons each. In emergency, or for repair purposes, one set of gates may be replaced by a sectional aluminium bulkhead, each section of which is 105 ft. long by 12 ft. wide by 6 ft. 6 ins. high. It weighs only 15 tons, so that a light travelling crane is all that is necessary to pick it up and drop it into place. A civil engineer has suggested to us that the gates themselves might well have been constructed in light alloy.

Flood Prevention Equipment

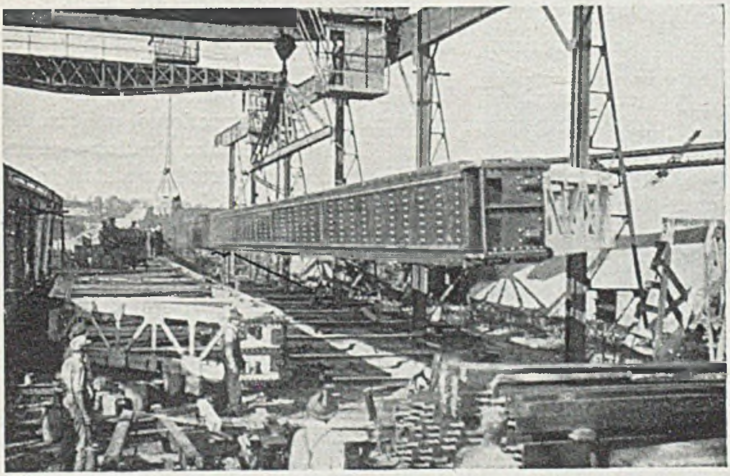
Disastrous flood damage experienced by Pittsburg's largest store, Joseph Horne and Co., has caused the directors to take certain steps by which their premises could be protected against disastrous inundation. After an unpleasant experience in 1907 the company had installed a pumping and draining system, which proved efficient in keeping the building free from water during subsequent flood periods, when the river rose to a level higher than the basement floor. Steel plates were provided for buckling on the outside of the building to keep out flood water which had reached the level of the street, but they proved to be very cumbersome, requiring, in fact, a crew of 15 to 20 men for the handling of each. The equipment was stored in a warehouse across the river, and at every threat of flood it was brought out and held in readiness on the sidewalks for use. Although floods of great magnitude did not occur during the 28 years subsequent to 1907, the water on several occasions rose to a height which necessitated the laborious preparation of the equipment.

Then came the record flood of 1936, unfortunately so suddenly that there was not sufficient time to install the equipment, and some $1,500,000 damage resulted. In the light of this disaster new equipment was designed for rapid handling by a small crew of men. The lightness of aluminium suggested that this metal might well prove to be the solution to the problem of quick handling. A series of experiments were carried out, and, as a result, new equipment was designed, consisting chiefly of aluminium sheet and structural alloy shapes. There are, in all, five types of bulkhead:

First, the rolling type for the protection of display windows, consisting of a single sliding wall of metal built up from aluminium alloy sheet and sections. These are hung on four-wheeled ball-bearing



VERTICAL sliding-type aluminium bulkhead at one of the entrances of Joseph Horne and Co.'s store. One of the parts is here shown dropping into place.



COMPONENTS for emergency bulkheads used in connection with the construction of the dam on the Ohio River near Gallipolis, Ohio. These are shown in course of fabrication at the works of the Nashville Bridge Co., Tennessee.

trolleys mounted on ceiling tracks extending from the place of storage at the rear of the window space to a flanged steel frame located at a distance of 10 ins. from the plate-glass window. To equalize water pressure on both sides of the window, small inlets are located below the windows to allow the water to rise between the glass and the aluminium simultaneously with the rise outside. There are 16 bulkheads of this rolling type, each being 9 ft. in height and ranging in length from 8 ft. to 24 ft. Two men can move a bulkhead into position and bolt it into place within five minutes.

Secondly, the vertical sliding-type bulkheads which are fitted to safeguard certain of the entrances. They are counterbalanced and easily dropped into position for use.

Continuous overhead hinged bulkheads are used to keep out flood water from the loading bay. When not in use these are supported just below the ceiling, and, in case of an emergency, they are simply dropped into the vertical position and bolted tight with a high-speed electric wrench.

Portable vertical compression bulkheads are provided for customer entrances, where it is obviously undesirable to have non-ornamental auxiliary equipment visible. Four sections are provided for each door, each section consisting of ¼-in. plate 5 ft. long by 12 ft. high, used in conjunction with edging bars and stiffening channels.

Lastly, there are fixed compression-type bulkheads fitted at certain main-floor sites. These are constructed in aluminium, bronze and steel, are semi-anchored to the floor, and are sufficiently heavy to remain in position during inundation.

Although Pittsburg has not had to endure any further floods on the 1936 scale, there is already ample testimony to the success of these aluminium bulkheads. Incidentally, the corrosion resistance of the metal has led to a wide use of aluminium and its alloys on the first floor. Drawers and panels of aluminium in the back of the showcases have been grained to match the rest of the woodwork.

In the ventilation tower of the U.S. Lincoln tunnel, which links New York with New Jersey, aluminium louvres and screens have been fitted to prevent the inrush of snow, sleet, rain, birds and insects, whilst not detracting from the visible warning of fire, which is given by the observance of smoke issuing with the exhaust air. The value of aluminium in this connection is mainly one of noncorrodibility, and, as louvres are only lightly stressed, an alloy containing only a small proportion of alloying constituent, and avoiding copper, is used to obtain maximum corrosion resistance.

Road Signs and Advertisements

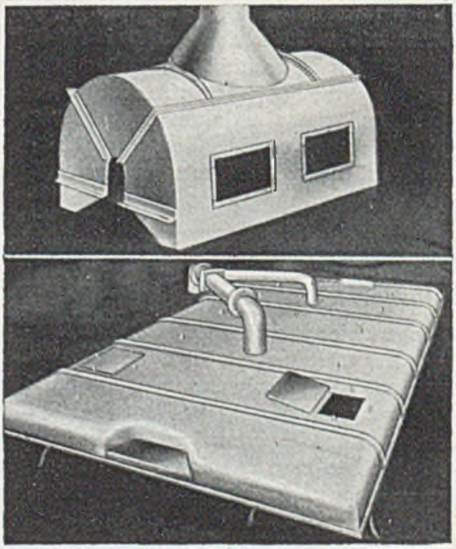
Because of its resistance to corrosion, aluminium has been chosen for the construction of various types of road signs where rusting would be disadvantageous and any maintenance undesirable. In a few cases, and especially in countries enjoying a dry climate, the metal has been left in its natural finish, which is not unattractive, but generally, however, additional protection is given by the application of a weather-resistant paint, which is suitably based on zinc chromate or iron oxide. The behaviour of this combination of a weather-resistant paint on a basis of aluminium is highly satisfactory under conditions of outside exposure, and undergoes very little deterioration with time.

SHOWN at the left are units for air conditioning plant constructed in aluminium, which has proved admirably suited to withstand the particular service conditions encountered in equipment of this type. Below are illustrated two further assemblies for an air-conditioning and ventilating system. Light alloys, again, are employed.

Perhaps the most commonplace example of this combination is the seamless aluminium traffic beacon, thousands of which have been installed up and down the country. While other metals have been employed for this purpose, the rustless light-weight aluminium type still finds favour and proves the cheapest in the long run.

Aluminium bolts and nuts have been employed with advantage for the fixing of porcelain enamelled iron road signs. When steel bolts and nuts are used, even though they may be heavily painted or plated, sooner or later red rust is formed, which discolours the sign and stains it indelibly. With aluminium no coloured corrosion product is formed, and the danger of discoloration is avoided.

In Germany, reflectors of polished Hydronalium sheet have been fitted to traffic-light beacons. In Königsberg it has been found an advantage to use aluminium for the construction of unlit traffic signs. These signs take the form of an aluminium disc supported on a steel tube. The high reflectivity of the metal surface enables it to be seen in the dark by approaching traffic, dazzle being prevented by suitable embossing of the disc. It was found that, by the use of aluminium, lighter steel supports could be employed, and also that the disc retained its reflectivity very well. This is particularly interesting as the climate at



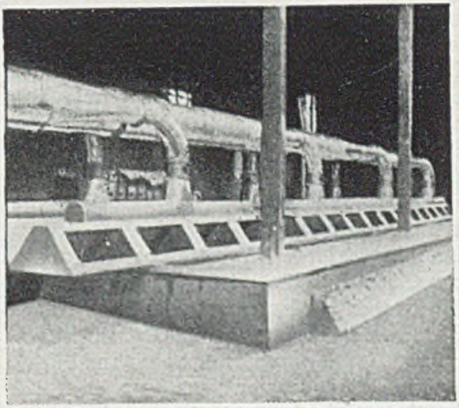
Königsberg is a marine one and is, therefore, very good testing ground for a corrosion-resistant metal.

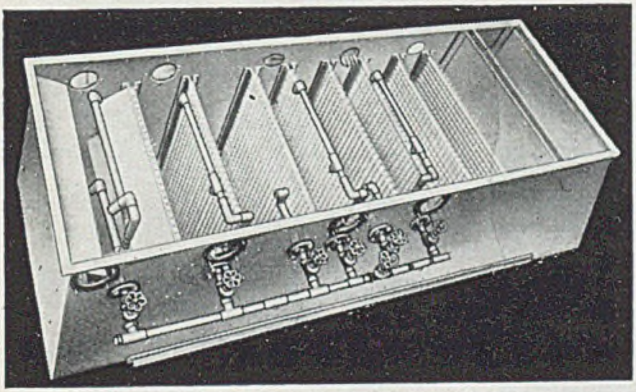
The Keystone Dairy Co., of Parnassus, U.S.A., have erected six highway advertising signs in the form of huge milk bottles cut from 14-gauge 3S-H sheet, whilst 200 plaques of aluminium cast with raised letters have been placed alongside the North Carolina highways to indicate places of historic interest.

Air Conditioning

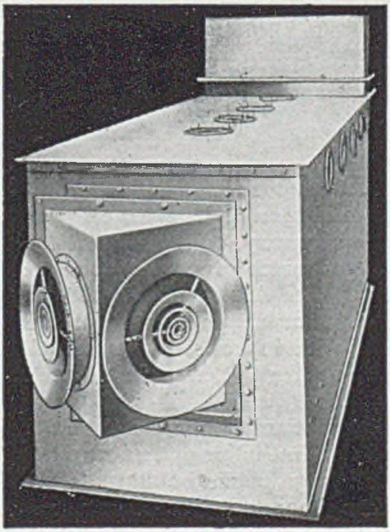
On the more practical side, considerable use has been made of aluminium and its alloys in various forms of air conditioning and ventilating equipment, its value in this connection being mainly that of considerable resistance to corrosion, and that when corrosion does occur the product is colourless and small in bulk.

In some instances, however, weight saving is not unimportant. Thus, in large air-conditioning plants, the liberal use of light metals frequently enables the apparatus to be installed in an old building without the necessity for putting in additional foundations, whilst transport and erection problems in confined spaces are greatly simplified owing to easier manhandling. The economy under these three heads frequently far exceeds the extra expense of light metals in the equipment. To reduce the inertia of moving parts (important from vibration point of view in buildings, particularly old ones), alu-



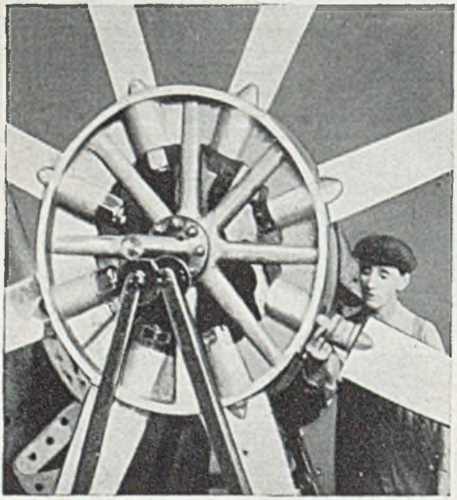


SHOWN above, to the left, and below, are further examples of assemblies designed for air conditioning and ventilating. Ease of fabrication into complicated forms, high resistance to corrosive attack by a variety of media, and good heat-transfer properties are some of the qualities called for in materials used for these purposes.



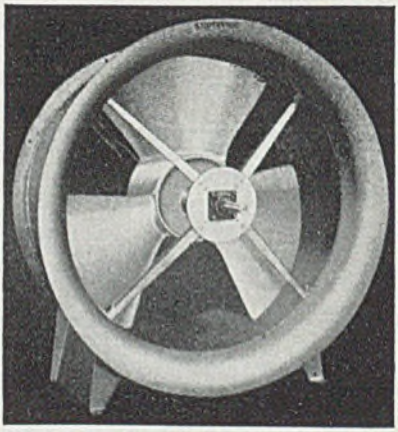
minium and also magnesium alloys have been used with success, and are becoming increasingly popular in all branches of civil engineering. Note, for example, the use of ventilating and air-conditioning equipment for coal mines and underground railways.

In Great Britain, a signal success in the use of aluminium in ventilation equipment has been achieved by the Anemostat concern, some of the products of which are illustrated. Many municipalities have introduced Anemostat ventilation equipment in large numbers of trams and buses. Anemostat equipment has been installed in the engine-rooms of several of the largest ships afloat, with results which have been very highly commended in shipping circles and in the press. These installations contain many fittings of aluminium of spun and welded construction. Where necessary, these are anodized and dyed to match any particular colour system. The Anemostat air diffuser is a circular fitment in aluminium sheet, which, with its series of conical planes, breaks up the volume of air, producing draught-free ventilation.



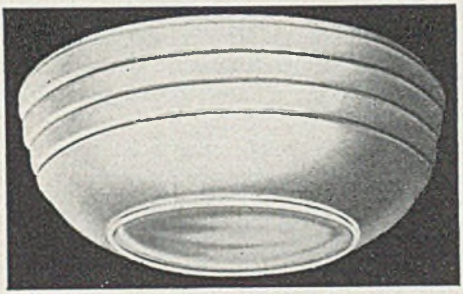
Air conditioning in municipal buildings, hospitals, institutions, theatres, cinemas and all large public buildings is proving another important industry where the light metal finds favour on account of its physical and mechanical properties.

Also illustrated is a cast aluminium Axiflo pressure fan produced by the B. F. Sturtevant Co. (America). Designed to meet the demand for a compact and inexpensive fan of the axial flow or thrust type, the fan possesses pressure characteristics comparable to those of a centrifugal-type blower. Its principal use lies in the movement of large volumes of air against resistances, such as wind, dust friction, filters and baffles. It combines the economical operation of the propeller-type fan with the high-performance characteristics of the centrifugal fan.



PICTURED above is the Axiflo pressure fan in which a cast-aluminium fan wheel is employed in conjunction with an aluminium fan casing. At the left is a 13 ft. diameter ventilating fan manufactured by the Foster-Wheeler Corp. It is built up from magnesium-alloy sand castings and weighs 650 lb. Still larger units have recently been constructed in ultra light alloy.

The fan wheels are solid, integrally cast, heat-treated aluminium alloy for high strength and low weight, and, where corrosive fumes are to be handled, the fan casing is also made of aluminium. The light weight of aluminium plus its resistance to the weather and to most corrosive atmospheres are combined in this fan to permit low cost movement of air against resistance.



CIRCULAR pavement light with metallized lateral face. Light transmission is notably increased by this practice. (After Long, "Journ. Soc. Glass Tech." 1937/21/435.)

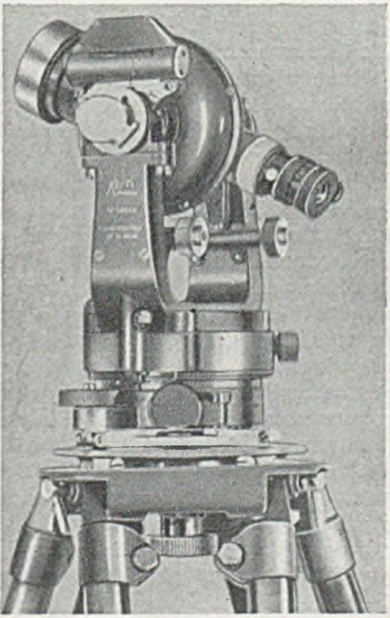
Even more interesting is the large ventilating fan, 13 ft. in diameter, which has been fabricated by the Foster-Wheeler Corporation. This unit is built up from magnesium-alloy sand castings and weighs 650 lb. Attention should be paid to the method of assembling the blades in the hub, which makes for economical fabrication with reliable service. Larger units have since been constructed in the ultra-light alloys.

In America use has been made of aluminium in air-conditioning units employing a modified system of electrical dust precipitation, which has been developed by the Westinghouse research laboratories. The dust particles in the air are given an electrical charge, being drawn through a series of cells consisting of aluminium plates, which are alternately at a high potential and earthed. The charged dust particles adhere to these plates, whilst purified air passes on. A demonstration equipment installed in a Chicago building comprised 369 units, each of which contained 111 aluminium plates, 8 ins. by 9 ins. in size. It is claimed that the system gives very satisfactory results. In one suite of Chicago offices more than 100,000 lb. of aluminium have been used in the construction of one of these Westinghouse electric air conditioner units. With a grid voltage of 5,000, it is claimed that 99 per cent. dust precipitation is obtained with a volume of 272,700 cubic ft. of air passing through the plant per minute. The process and the aluminium equipment has stimulated interest among many research workers in Great Britain, who have for a considerable period been trying to find an efficient means of preventing fog, or excessive pollution of the atmosphere, by electrical precipitation.

An aluminium ventilating plant of German origin is illustrated. With its hoods and trunking, it is reminiscent of fume-removal plant as used in the chemical industry, and for which aluminium has proved to be equally satisfactory.

Refuse Collection

America, Switzerland and Italy have all taken advantage of the corrosion resistance of aluminium alloys to produce light-metal refuse-collector vans, which are superior in sanitary properties and general performance to anything constructed in wood or steel. It is believed



DOUBLE quadrant theodolite type DK1 by Kern and Co., Ltd. This instrument, which is of very massive construction, is notably lightened by the replacement of all conventional brass parts by others of aluminium. Such weight reduction is appreciated by engineers in the field.

that Switzerland was the first in the field here. The Zurich municipal authorities put an experimental van into use in 1930, and by 1934 they were steadily replacing the older galvanized-iron vehicles, over which aluminium showed decided advantages. Light metal was used for the van bodies and also for the fabrication of cans for holding slaughter-house and butchers' refuse. These were found to be far more resistant to corrosion than galvanized iron, and capable of more thorough deodorization without damage to the metal.

The Italian vans were put into commission in 1936 for the collection of household and shop refuse, aluminium being chosen for its corrosion resistance, light weight and clean appearance.

Refuse collection in New York must necessarily be on a large scale, and 315 huge dump trucks have been fitted for the purpose with aluminium side doors, roof doors and tail gates, consuming 180,000 lb. of aluminium in all.

To those who might be inclined to question the suitability of aluminium for this purpose in view of its softness in comparison with steel, it may be remarked that aluminium alloys are giving good service in the transportation of coal, where conditions are far more onerous. In addition to obtaining better service and sanitation, aluminium produces a lighter vehicle, which needs less power to drive and causes less wear on tyres and roads. The use of light metals to reduce unladen weight in mobile equipment is fast becoming standard practice in all branches of the transport world. An unusual example, of interest to civil engineers, is that of a portable mixing machine for use in road making and repair, in which the frame of the motor, the end bells and the lower housing of the mixer are all of aluminium alloy to produce a lightweight and portable machine.

Light Metals in Highway Illumination

It has been previously remarked how the employment of light metals may enable the use of lighter supporting structures, which may result in a financial saving exceeding the extra cost due to the use of the light metal. The larger types of lanterns, both for gas and electricity, which are suspended over highways or in other situations, are typical examples where light metals may be employed to advantage. Weight saving is, however, not the only benefit which aluminium has to confer in this application. Being situated in exposed positions, subjected to a heating effect which is sometimes considerable, and, in the case of gas lamps, being exposed to the products of the combustion of gas, the corrosion resistance of the metal is an important factor, and it is to be noted that aluminium and its alloys stand up very well to these corrosive conditions. Aluminium is a good conductor of heat, and thereby assists in keeping the lantern cool. It is also a very good reflector material, being more robust and serviceable than silvered glass, whilst being almost as efficient in light reflection. In cases where reflection is required without glare, satin or frosted-finish metal may be adopted.

It is not surprising, therefore, to find that some considerable use has been made of the light metals in illuminating installations on civil engineering works. Light-metal sheet in unalloyed aluminium or in aluminium-manganese alloy, castings in aluminium-silicon alloy and, to a smaller extent, forgings in the stronger aluminium alloys are now employed to an increasing extent in the big lamps used for street and civic lighting and for the illumination of large structures such as dams. They have given every satisfaction in service, and the extra initial cost has been saved several times over by the reduced maintenance charges alone. The B.T.H. Mercra H lantern installed in Bromford Lane, Birmingham, towards the end of 1934 is just one instance of a street lamp incorporating aluminium alloy, the light metal being used for the trunk of the lantern.

Cast aluminium was employed for the fabrication of four lanterns installed in the Boulder Dam intake towers. These lanterns, which combine the functions of beacons and ventilators, are large domed structures, 10 ft. 6 ins. high, hexagonal in shape and measuring 6 ft. 5 ins. across the flats. Each weighs 1,500 lb. and is built up from 68 aluminium castings varying in section from ⅜ to ½ in., casting being performed in green sand moulds, skin dried. Each lantern is lit by six 300-watt flood lamps, and incorporates many interesting features of design.

A particularly striking application of aluminium reflectors is in the lighting of what is known as Pennsylvania's "Dream Highway," which is claimed to be not only the safest but also the most colourfully lit motor highway in the world. Three different colours are employed, yellow sodium vapour illumination being employed at terminal approaches, and outside the traffic interchanges, blue-green illumination from mercury vapour lamps for the interiors of the tunnels, and white light from incandescent lamps in the buildings at the interchanges. The mercury vapour units give an illumination of 3½ ft.-candles on the road and provide adequate visibility along the tunnels for more than 1,000 ft., this being sufficient to allow safe driving at speeds of more than 60 m.p.h. Motorists approaching a tunnel first pick up the yellow approach lighting which starts at about 1,500 ft. from the tunnel entrance. The spacing of the lights becomes closer towards the tunnel, so that the illumination gradually builds up to that prevailing in the tunnel.

Table 1.—Aluminium Alloys Used in Smithfield Street Bridge.

Alloy	4 S.H.	53 S.T.	27 S.T.	17 S.T.
Ultimate strength	18.7	16	26.6	26
Yield point	17	13.4	22.4	15.6
Elongation in 2 ins	3	12	12	20
Brinell hardness	80	80	118	100
Where used	Tubing for hand-rail	Rolled shapes for hand-rail	All floor members	Basis of design

Table 2.—Maximum Stresses Recorded in Tests on Original Flooring Test Panel.

8-in. distributor channel	3.7 tons per sq. in.
8-in. joist	7.9 tons per sq. in.
7/16-in. tread plate	9.5 tons per sq. in.
½-in. tread plate	7.7 tons per sq. in.

Portable Equipment

The low density of the light and ultra-light alloys is, of course, most advantageously employed in the construction of portable equipment, and there are a number of instruments used in civil engineering which have taken advantage of this property and which are the more easily handled for so doing.

Illustrated is a double-quadrant theodolite constructed of aluminium alloys. The advantage of light-alloy fabrication for instruments such as these is obvious and need not be enlarged upon. In connection with instruments of this type, however, it may be of interest to note that one of the earliest uses which was found for aluminium was in the fabrication of an engineer's transit. This was in 1876, and constituted probably the first assembly of aluminium fabricated parts in the U.S.A. It was built by W. and L. E. Gurley, of Troy, New York, of aluminium tubing which had been bought in Paris by Wm. Gurley, and of castings which they made themselves from aluminium metal costing $1.30 per oz.! In 1909 it was returned to the makers for repair and was promptly exchanged for a new instrument. It now resides in the museum of its makers. This instrument had been in constant use and had given trouble-free service between 1876 and 1909, which is excellent testimony for the metal, bearing in mind that the aluminium of 1876 was very crude in comparison with the pure metal and alloys of closely controlled composition which are available for the use of instrument makers and civil engineers of to-day.

Also from America comes news of a road-checking equipment which has been constructed in aluminium alloy. Its introduction followed a decision of the Oregon, U.S.A., Highways Department that irregularities in road surfaces should not exceed 0.07 in. in 10 ft., and its purpose is to record the contour of the road on a suitable chart. To enable the apparatus to be handled by one man, light alloys have been used exclusively in the construction of the inner frame. The instrument consists essentially of an 11-ft. section of an aluminium girder—a 7-in. aluminium I beam—supported on levelling screws, which is set to span the portion of the road to be tested. A sliding carriage which runs along the girder carries a double-ended arm, one end of which rests on the road surface whilst the other end carries a pencil and chart on which a record of the road profile can rapidly be traced. The use of aluminium enabled an instrument to be produced weighing only 55 lb. which can be handled easily by one man.

The State of Utah has a standard snow sampler for use in surveying operations, consisting of a tube carrying a cutter at the lower end. The tube is fabricated from 22-gauge aluminium sheet and has an external diameter of 1¾ in. The cutter is of steel.

A petrol-operated road rammer, the main casting of which was made of magnesium, has given satisfactory performance over many years despite the high impact and shock stresses to which it is subjected.

Unloading Booms

Because of its low density and softness there is a popular tendency to relegate the use of light metals to parts which are small or only lightly stressed. Nevertheless, it is frequently in the support of heavy loads that light metals prove of the greatest advantage. In the mechanical world, engineers have built cranes, dredgers and such like in which the judicious incorporation of light metals has enabled greater loads to be carried and capacities to be increased. Somewhat similar is the use of aluminium in the construction of a boom for use in the unloading of cargo vessels, mainly carrying coal, plying on the North American Great Lakes. Compared with an existing steel structure, it was found that, by using aluminium, the boom could be increased in length by 46 per cent., whilst the load on the ship was only increased by 30 per cent. Thus, a boom was constructed 225 ft. 6 ins. in overall length with a working radius of 218 ft. to replace a steel boom of 150 ft. working radius. The total weight of the aluminium portion was 13 tons, and it is used to support a load of 16 tons. Generally speaking, in structures of this type, the use of aluminium enables the length of the boom to be increased by 35 per cent. without increasing the loading of the ship.

Details have been given of an interesting type of construction for aluminium ladder and stage equipment manufactured by the Aluminium Ladder Co., of Philadelphia. The ladder is constructed of two parallel aluminium alloy sections between which are attached rungs of aluminium alloy tubing. As two of these ladders are used with the rungs pointing outwards at right angles to the surface against which the ladder is placed, the rungs serve the additional purpose of support for the stage. This, too, is made of aluminium, and is of corrugated construction for stiffness. It is fitted with clips to prevent it from slipping out of position. Above the uppermost rung, the two ladder sections converge and are bent to form a hook by means of which the ladder may be hung from a parapet or open-top tank. The ladder weighs only 1½ lb. per foot run. The stage weighs 3 lb. a foot and is both light and sturdy.

Aluminium construction has also been employed for the construction of a vertically extending platform designed for the repair of street lighting fixtures and overhead cables. The platform, which is 4 ft. wide, is made wholly of aluminium and weighs 630 lb., compared with 1,645 lb. for a similar structure in steel.

As a final example of the diversity of ways in which light metals are of interest to the civil engineer may be mentioned an application in which the heat insulating properties of crumpled aluminium foil are employed to advantage as a medium for thermal insulation.

HEADING CAPACITY OF RIVET WIRE

Describing the Theory and Practice of a New Testing System Designed to Meet Production Requirements. After Rajakovics and Teubler, "Aluminium" (Germany), 1942/24/5; 160

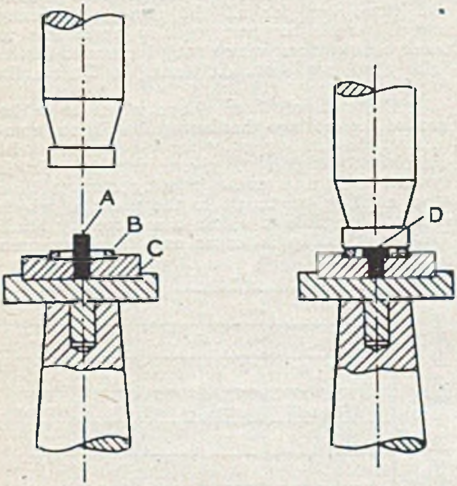


Fig. 1 (above).—Apparatus for heading test pieces to a determined head height in a single stroke: A, unheaded wire; B, adjustment ring; C, heading die; D, head wire.

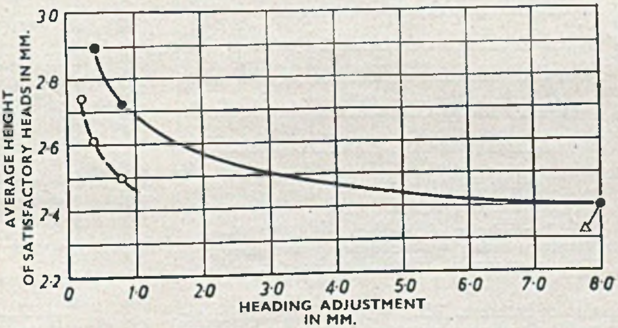


Fig. 2 (right).—Effect of heading stroke on apparent heading capacity of age-hardened duralumin 681H rivet wire, 6 mm. diameter. Wire, projecting 9 mm. from heading die upset to give flat head: continuous line, upset from 9 mm. in steps of 0.6, 0.8 and 8 mm.; broken line, initial height to height of upset from 9 mm. to 3.9 mm. in one stroke, and further headed in steps of 0.2, 0.6 and 0.8 mm.

FOR the adequate assessment of the quality of light-alloy wire for rivets it is necessary to determine not only shear strength but also the heading properties. Various factors to be considered when investigating shear strength have already been considered by Rajakovics and Blohm in "Aluminium" (Germany), 1939/21/219,* but conditions governing heading qualities are still largely unknown.

Current Tests for Heading Properties

According to technical specifications laid down by the Reich Verband der deutschen Luftfahrtindustrie, a wire is defined as headable when it is capable of being upset to form a flat head of given dimensions without the occurrence of fissuring or of visible grain growth. An accompanying table showing the relationship between wire diameter and permissible head diameter is reproduced from the specifications referred to in which it is laid down that the heading test shall be carried out under a press.

In the case of age-hardening alloys which cannot be headed in the fully hardened state, special significance is attached to the time period during which the material may still be headed after solution treatment, that is, before age-hardening has proceeded too far. The duration of this period is obviously dependent on the temperature at which the material is stored after solution treatment, as discussed by Rajakovics and Blohm in "Z. Metallkunde," 1939/31/137. The shortest time interval for storage at room temperature in the case of an aluminium-copper-magnesium alloy, according to D.I.N.1713 was set at two hours. In the case of the rivet alloy Duralumin LN93, the interval may be as long as four hours.

Apart, however, from the specified minimum time period during which the heading operation may be carried out, the total period during which it is possible to head these rivet wires

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*For complete list of references see "Aluminium" (Germany), 1942/24/5.

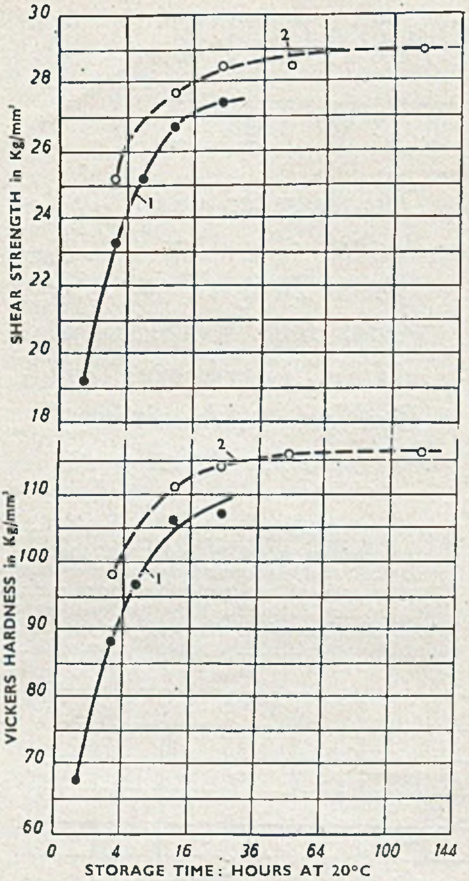

Fig. 3.—Variation of shear strength and Vickers' Hardness during age-hardening, of two wires in Duralumin LN.93, 6 mm. diameter.

is also of interest. Hitherto this has been determined by testing a number of samples at various time intervals after solution treatment. Clearly, at a certain stage, satisfactory heads will not be obtainable, and, at this point, the required maximum period may be fixed. Unfortunately, this method suffers from the disadvantage that by reason, say, of minute variations in position, varying degrees of segregation, etc., permissible time intervals varying for any given wire from 6-24 hours may readily be obtained. This difficulty can be overcome only by continuous testing of a very large number of samples in any one batch.

Heading Limit

To avoid the uncertainties described, the authors have devised a new test system to determine what may be described as the "limit of headability"; this term embracing also the time factor.

If a test piece at a given time interval after solution treatment be subjected to heading not only until a head of given diameter be obtained, but also until the first signs of fissuring appear, then the height or diameter of the head obtained gives a good indication of the capacity of the material for plastic deformation, and thus for its heading capacity. This method is specially advantageous for testing the headability of those alloys where this quality is independent of storage time, i.e., for all the non-age-hardening alloys. It is, however, equally applicable to those compositions which may be headed in the fully aged condition, for example, Duralumin 681H.

In the case of those alloys which must be headed before age hardening has been completed, the limiting point for heading must be determined within a given period. It is evaluated from a curve relating storage time after solution treatment to the point at which it is still possible to obtain a satisfactory head. This relationship is linear and the maximum

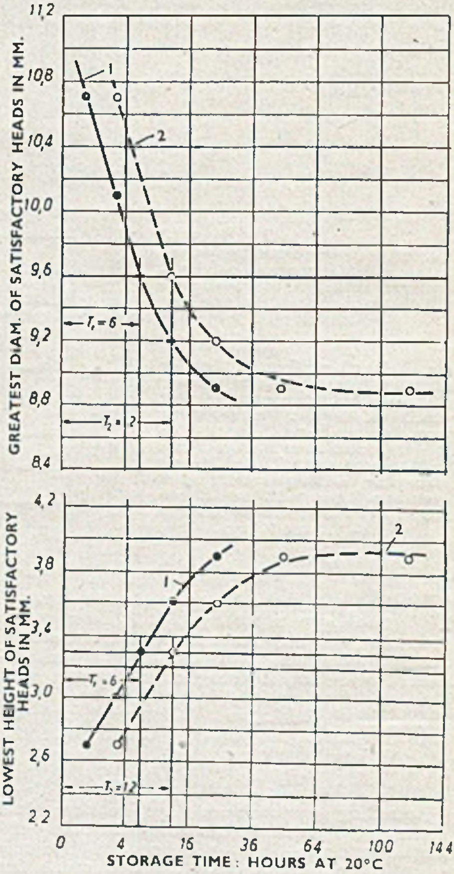

Fig. 4.—Variation of heading capacity (expressed in height of head and diameter of head) with age-hardening for two 6-mm. diameter wires in Duralumin LN.93.

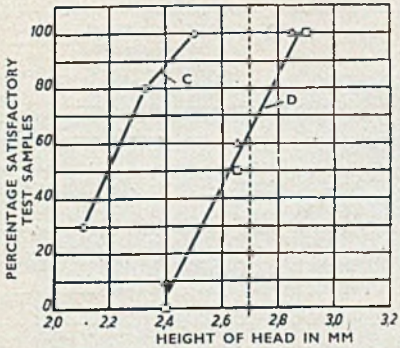

Fig. 5.—Influence of speed of deformation on heading capacity of rivet wire in Duralumin LN.93. 5 mm. diameter, upset to give flat head, material tested 6 hours after quenching from 505°C. Shear strength on wire, 24.1 Kg./mm.^{2}, 7.3 mm. of wire allowed for formation of head.

permissible storage time may be deduced with sufficient accuracy for all practical purposes.

Influence of Degree of Upsetting

Before adopting the new test method to be described for evaluating the limit of headability of rivet wires, it was thought necessary, first, to see whether upsetting in stages, or in one continuous stroke, produced any difference in the point at which fissuring first occurred. To investigate this point Duralumin 681H in the form of 6 mm. diameter wire was chosen. As this alloy may be headed in the fully hardened state it is clear than any effect due to storage time is automatically eliminated. The mean shear strength of the wire examined was 24.6 kg./mm.^{2} The wire was first subjected to heading in a pneumatic heading machine to give a head of 9 mm. dia., a steel die being used for the purpose; this being done in one series in a single stroke of 2.9 mm. and then in a second series in stages of 0.2, 0.4 and 0.8 mm. until the first signs of fissuring appeared.

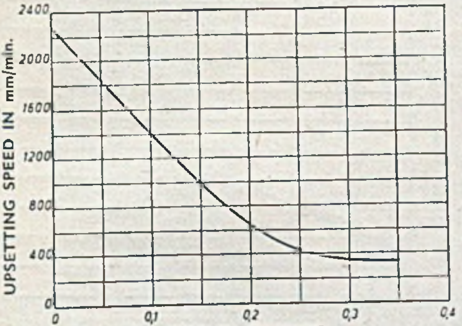

Fig. 6.—Curve for speed of deformation during upsetting to form flat headed rivet, for 6 mm. wire in Duralumin LN.93. Testing carried out 3 hours after quenching, wire upset from 9 mm. high to 2.5 mm. high. Test carried out on squeeze riveter normally adjusted.

In the case of this second series it is clear that the diminution in height of the rivet head at any given stage of upsetting becomes constantly less than that for which the press was adjusted. This might be expected as resistance to deformation increases and calls forth a corresponding increase in the back reaction of the press. In order that a more rapid and constant degree of upsetting could be obtained, the adjustment of the press was calibrated to give consistent heading stages of 0.2 mm. From the results obtained the arithmetic mean between the values for the smallest height of rivet head free of cracks and the height at which fissures begin to appear was deduced.

A further series of tests was then conducted, commencing with the 6 mm. wire already upset to give a head of 9 mm. diam. and further upsetting in stages of 0.4-0.8 mm. until fissuring appeared. Again a mean value was extracted. In the particular investigation concerned here, values for heading in stages of 0.2 mm. were rendered useless by the accidental kinking of the wire. Finally, heading heights were determined for single-stage upsetting until fissuring appeared. The data obtained are summarized in Fig. 1.

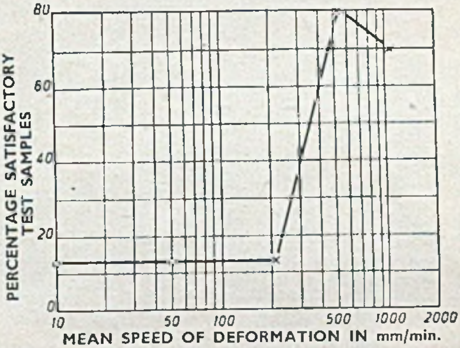

Fig. 7.—Effect of speed of deformation on the apparent heading capacity of 6 mm. wire in Duralumin LN.93, upset to give flat headed rivet, three hours after quenching from 505°C. Upset from height of 9 mm. to 2.5 mm., shear strength of material 23.3 Kg./mm.^{2}; o—headed in universal testing machine; x—headed in squeeze riveter.

It will be noticed that for a press adjustment of 8 mm. upsetting, a rivet head 2.4 mm. high was obtained. It will be observed that capacity for heading increases with increase of press stroke; in addition, heading capacity, as determined for a single effective stroke of 3.9 mm. and for the same degree of upsetting by stages, is greater than heading capacity determined under the same two sets of conditions commencing from 6 mm. wire already upset to give a head 9 mm. diameter.

The optimum value for heading capacity is yielded by a single stroke upset operation. The results of these investigations showed that, in general, the results of determination of heading capacity are only comparable when upsetting has been carried out under conditions of equal effective stroke. In other words, only by upsetting in a single stroke can the true heading capacity of the material in the rivet-heading press be evaluated and be independent of all external interfering factors.

Description of New Apparatus

It has already been shown that true capacity for heading cannot be determined by stepwise deformation. For this reason, heading capacity is re-defined by the authors as the smallest height of head which may be given to a test piece in a single stroke without the appearance of fissuring, and for the attainment of a given head diameter. This point is termed "limit of headability." In contrast to previous testing methods this system gives an immediate evaluation of the heading capacity of the material. It is to be understood that the final diameter selected for the head must be so chosen as to correspond to the desired height of head. Results are based on the height rather than the diameter of the rivet head as the former is more easily controllable than the latter.

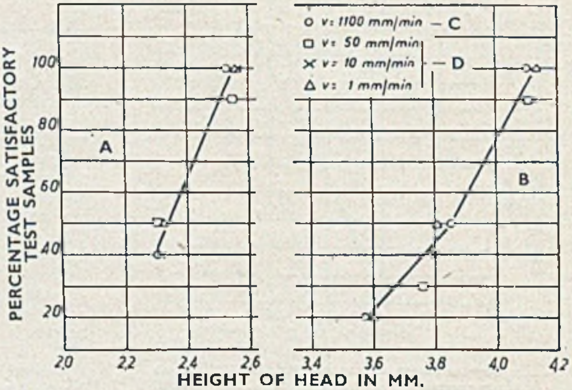

Fig. 9.—Effect of speed of deformation on the apparent heading capacity of fully aged rivet wire in Duralumin 681H, 5 mm. diameter (left); a Duralumin LN.93, 6 mm. diameter (right).

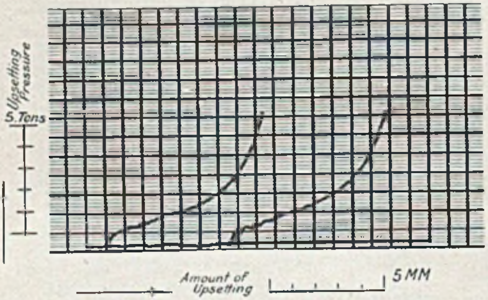

Fig. 8.—Autographic recording of upsetting process carried out in universal testing machine. Graph refers to 6 mm. diameter wire in Duralumin LN.93. Upset to give flat-headed rivets 3 hours after quenching from 505°C. Material upset from 9 mm. to 2.5 mm. at a speed of 10 mm./min.

Single stage upsetting to any required height of head is achieved by the use of rings placed between the heading die and the punch, as shown in Fig. 2. The material to be investigated should be examined beforehand to determine the degree of spring-back it is likely to exhibit. This spring-back, however, is quite small and, in the case of a 6 mm. wire in Duralumin 681H required to give a head height of 3.3 mm., amounts to only about 0.1 mm.; this may be corrected, however, by removing a corresponding amount from the rings placed on the die face.

The course of a typical test is illustrated in Table 2. The test commences with a wire diameter 6 mm, upset to give a head 3 mm. diameter. If the material successfully withstands this operation the head is now upset to 2.4 mm. high. Should this be unsatisfactory, that is, should fissuring appear, then a new test is carried out to obtain a head 2.7 mm. high. According as whether or not this test is successful, the limit of headability for the material will be either 2.7 or 3 mm.

From Table 2 it will be seen that with quite a small number of test pieces and operating in steps of 0.3 mm., a range of head heights from 1.5-4.5 mm. may be covered. For a wire of 6 mm. diam., upsetting in amounts of 0.3 mm. gives a satisfactory enough practical indication of the heading capacity of the material, 12-20 test pieces being sufficient for the purpose. In the same way, operating on wires of 2-3 mm. diam., single stage upsets of 0.1 mm. would be chosen. For wires 3.5-5 mm. diam., upsetting would be increased by 0.2 mm. for each succeeding test piece. Similarly, for 6 or 7 mm. wires, increments of 0.3 mm. would be used,

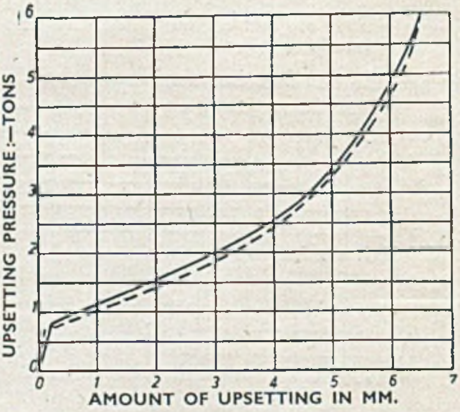

Fig. 10.—Pressure stroke diagram for heading of 6 mm. diameter wire in Duralumin LN.93. Material upset to a flat-headed rivet 3 hours after quenching from 505° C.; 9 mm. of wire allowed for formation of rivet head 2.5 mm. high: continuous line—squeeze riveter broken line—universal testing machine.

whilst for wires of 8 and 9 mm. diam. increments of 0.4 mm. would be chosen.

The height of the first head chosen in the test is selected such that it is always smaller by one stage than the specified rivet head within the group. In Table 2 are given values showing by what amount the material may be upset beyond the required degree as laid down in the specifications. If the specified head height cannot be reached, these values then, of course, will be negative.

Accompanying this account will be found numerous curves demonstrating the practical application of the new method. As a rider to the work carried out by the authors it appeared desirable to determine whether the time intervals during which heading was possible, as indicated in the graphs, were, in fact, valid in engineering practice where either the rivet press or the pneumatic hammer are commonly employed for heading. The press tool used in practice commonly performs the heading operation in one stage, thus corresponding to conditions followed in the experiments. In the case of the pneumatic hammer it appears that the time interval during which heading is possible is somewhat extended. Thus, for example, rivets in Duralumin LN93 6 mm. diam. and with 15 mm. shafts could be headed for a period of six hours after solution treatment, under the experimental conditions described, whereas with a 3.3 kg. pneumatic hammer operating at 2,700 blows per min., the same rivets could be headed with perfect satisfaction after storing at 20 degrees C. for a period of 15 hours. It would thus seem that the velocity of deformation and the way in which the material is worked have some bearing on the problem.

Five mm. diam. wires in Duralumin LN93, not fully age-hardened, were then investigated. The material was quenched from 505 degrees C. and after storing for six hours at 20 degrees C. was subjected to heading at a speed of 1,300 mm. per minute in a heading press, a further series of tests being carried out in a universal testing machine at heading speeds of 1-50 mm. per min. The effect of variation of speed of deformation was quite clearly noticeable. With a mean speed of upsetting in the heading press of 1,300 per min., the degree of heading was carried by 2.7 mm. beyond that laid down in the specification, in spite of the fact that the material had been stored for two hours longer than the maximum period specified. Using a universal testing machine with lower upsetting speeds, however, it was found impossible, with certain test pieces even to reach the specified degree of upsetting, as fissuring appeared before this point could be attained.

The results presented here are noteworthy in that they do not correspond entirely with the normal behaviour of the metal. It is known that in deformation processes in general the resistance of deformation apparently increases with increasing speed of deformation. From this it might be deduced that, at higher working speeds, the capacity for deformation to a material should suffer apparent deterioration. On

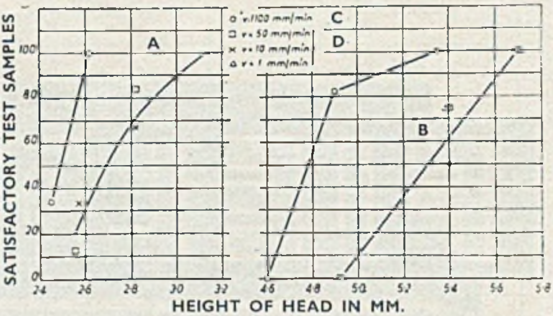

Fig. 12.—Effect of speed of deformation on the apparent heading capacity of a 6 mm. diameter rivet wire in an aluminium-zinc-magnesium alloy material tested 2 hours (A) and also 10 days (B) after solution treatment and quenching in water from 440°C.

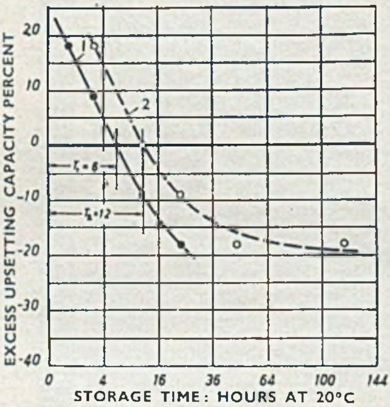

Fig. 11.—Capacity for heading beyond specified limits in relationship to degree of age-hardening, for 2 wires in Duralumin LN.93 6 mm. diameter.

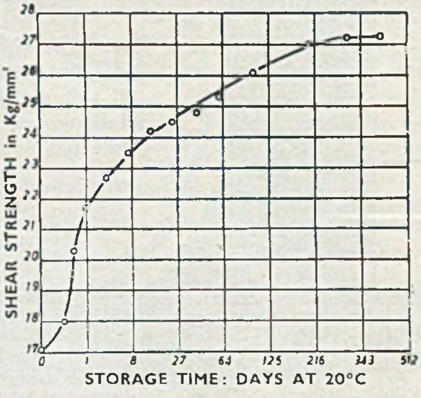

Fig. 13.—Variation of shear strength with age-hardening for an aluminium-zinc-magnesium alloy solution treated and quenched from 440°C. in water.

the other hand, as clearly shown in Fig. 2, the high deformation speed obtained with a riveting press indicates better heading qualities for the material investigated than those deduced from the results obtained on the universal testing machine at lower speeds.

Effect of Method of Working

It was thought that the apparent differences in heading capacity as revealed by tests with the riveting press and the universal machine was the result, not so much of the difference in speed of deformation, as of various interfering factors associated with the two machines; thus riveting presses of the type used for this work are known not to be entirely rigid, whilst the universal testing machine can be considered as perfectly rigid throughout its whole range of permissible loading. Furthermore, the true upsetting speed with the riveting press varies throughout the stroke, whilst with the universal testing machine it is practically constant throughout the stroke.

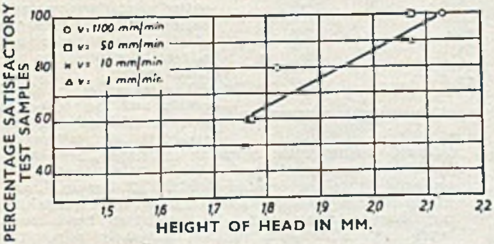

Fig. 14 (above).—Effect of speed of deformation on the apparent heading capacity of 5 mm. diameter rivet wire in duranalium MG.5 material tested in fully annealed state with shear strength of 19.3 Kg/mm.^{2}.

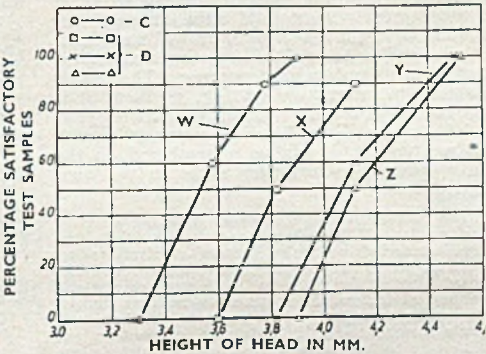

Fig. 15 (right).—Effect of speed of deformation on the apparent heading capacity of 6 mm. diameter rivet wire in duranalium MG.9, fully annealed with shear strength 23.7 Kg/mm.^{2}: C, squeeze riveter; D, universal testing machine.

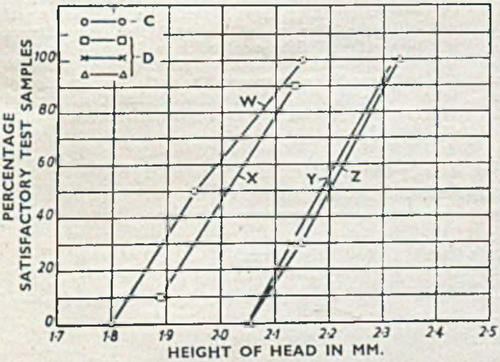

Fig. 16 (below).—Influence of speed of deformation on apparent heading capacity of 4 mm. diameter rivet wire in duranalium MG.7 fully annealed with shear strength 21.9 Kg/mm.^{2}: C, squeeze riveter; D, universal testing machine; W, upset at 11,000 mm./min.; X, at 50 mm./min.; Y, 10 mm./min.; Z, 1 mm./min.

To clarify the first point, the test pieces were headed in the universal testing machine is such a way that the sample of wire rested not directly on the bed of the press but on a spring mounting with characteristics under load similar to those shown by the riveting press. Nevertheless, the same results were obtained as previously. It is thus concluded that any elastic reaction jn the heading machine can be dismissed as a causitive agent for the varying results.

To determine the effect of variations in upsetting speed such as occurred with the riveting press, a further series of tests were carried out on this machine at lower speeds. Furthermore, to elucidate still further the results given in Fig. 2, these experiments were carried out on a 6 mm. wire in Duralumin LN93, the material being used three hours instead of six hours after quenching. For the lowest rate of upsetting a speed of 10 mm. per min. was chosen.

In Fig. 7 are presented the data obtained. The curve clearly shows the drop in upsetting speed as the process proceeds. Normal time of upsetting on this machine would be 0.35 sec., but by suitable adjustment of the air inlet it was controlled to give upsetting times of 0.73 and 1.87 secs. To give a head 9 mm. diam., with a height of 2.5 mm., a double stroke of the press amounting to 6.5 mm. was required, the speeds of deformation being then 1,100, 540 and 210 mm. per min. Further results are presented in Fig. 8. From the curve reproduced here, the effect of speed variation on deformation may clearly be seen. Test pieces headed in the riveting press at a mean speed of 210 mm. per min. differ in no way in their heading capacity from those headed in the universal testing machine at speeds of 50-10 mm. per min.; thus it follows that apparent differences in heading capacity, as shown by results on the two machines, depend solely on variations in the speed of upsetting during the single stroke and on no inherent physical cause.

Fully Age-hardening Alloys

It has already been shown that, in the case of alloys in the non-fully hardened state, speed of deformation exerts an influence of some significance. In view of this, it was determined to investigate the effect of this factor on a fully age-hardened alloy. For the purpose, Duralumin 681H was chosen; this material has almost unlimited heating capacity. At the same time, 6 mm. diam. rivet wire in Duralumin LN93 quenched from 505 degrees C., aged at 50 degrees C. for three days and stored for three months at 20 degrees C. was also investigated.

Test pieces of both materials were headed in the rivet press with normal adjustments corresponding to mean upsetting speeds of 1,100 mm. per min. and in the universal testing machine at speed of 1, 10 and 50 mm. per min. The results obtained are summarized in Fig. 5. Here, it is to be remarked that no significant effect of speed of deformation upon heading capacity occurs. This was not so, it will be remembered, in the case of these age-hardening alloys in the non-fully hardened state.

Table 1.—Specified Head Heights and Diameters with Respect to Wire Diameter.

Nominal wire or rivet dia. mm.	Minimum hd. dia. mm.	Maximum hd. height mm.
2	3.4	1.0
2.6	4.4	1.3
3	5.1	1.6
3.5	5.9	1.8
4	6.4	2.2
5	8.0	2.7
6	9.6	3.3
7	11.2	3.8
8	12.8	4.3
9	14.4	5.0

Addendum: Defective Rivets

The results of the above investigations into the factors connected with the process of rivet-heading are useful in so far as they fall within the limits imposed upon the process by mechanical and metallurgical factors. It is generally realized that to work outside these limits is to court failure, but until recently comparatively little definite information was available as to how serious the effects of such failure might be. Tests in this connection at the Aluminium Research Laboratories[1] have given somewhat unexpected results.

Briefly, tensile and shear tests were made on joints with 17ST rivets with different heads cracked either during the manufacturing process, during driving, by driving the rivets in the heat-treated and aged condition, and cracks produced artificially by slitting with a saw. The degree of cracking in some of the rivets represented the very worst that is encountered in ordinary shop practice, and yet the tensile and shear strengths obtained with these rivets were entirely satisfactory, indicating that the strength of the rivets was not adversely affected by the head cracks.

The question of head cracks and their effect is also considered in an account[2] of laboratory tests on the strength, corrosion resistance, heat-treatment and ageing of rivets. It is stated that 24ST flat-head rivets heat-treated at 910-930 degrees F. and driven after more than about 15 mins. after quenching may develop shear cracks in the driven head. Such head cracks, however, do not adversely affect the static tensile strength, the static shear strength, or the shear fatigue strength of the driven rivets. Furthermore, the resistance to corrosion is not appreciably reduced. Therefore, cracked head rivets should seldom be replaced, particularly when the cracked heads are in an inconspicuous location in the finished structure. With smaller diameters of the driven head the tendency for head cracking is reduced, but this may also reduce the shear strength of the rivet and its resistance to being pulled through the hole in lap joints in thin sheet. In any lap joints in which the sheet thickness is not less than a quarter of the shank diameter a reasonable balance between cracking tendency and rivet strength seems to be achieved by making the diameter of the driven head about 1½ times the nominal shank diameter.

Some exploratory work in connection with the setting up of standards for the acceptance or rejection of driven rivets[3] has yielded some even more surprising results. Thus, it was found that the strength of rivets with heads cracked as the result of overdriving may be superior to that of normal rivets, because of the work-hardening of the metal produced by overdriving. Other tests showed that the cracks resulting from driving hard 17ST rivets did not extend far enough to reach the stressed part of the rivet and thus weaken it in fatigue. In fact, the work-hardening caused by driving the rivets in the hard condition improved the fatigue properties of most of the rivets. It is concluded that the accepted practice of replacing defective rivets is not necessary or practical.

Table 2.—Determination of Limit of Headability for Duralumin 681H wire (Fully Age-hardened) 6 mm. diam.

1 Head height (mm.) and quality	2 Head height (mm.) and quality	3 Head height (mm.) and quality	4 Head height (mm.) and quality	5 Limit of headability in mm.
3.0 G	2.4 G	1.8 G	1.5 G	1.5
3.0 G	2.4 G	1.8 G	1.5 P	1.8
3.0 G	2.4 G	1.8 P	2.1 G	2.1
3.0 G	2.4 G	1.8 P	2.1 P	2.4
3.0 G	2.4 P	2.7 G	—	2.7
3.0 G	2.4 P	2.7 P	—	3.0
3.0 P	3.6 G	3.3 G	—	3.3
3.0 P	3.6 G	3.3 P	—	3.6
3.0 P	3.6 P	4.2 G	3.9 G	3.9
3.0 P	3.6 P	4.2 G	3.9 P	4.2
3.0 P	3.6 P	4.2 P	4.5 G	4.5
3.0 P	3.6 P	4.2 P	4.5 P	4.5

G = Good. P = Poor.

References:—(1) Aluminium Research Laboratories publication, 1941, 9 pp. (2) "Aviation," 1943/42/139. (3) "Product Engineering," 1944/15/628.

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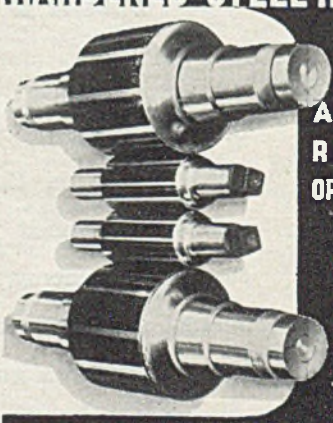

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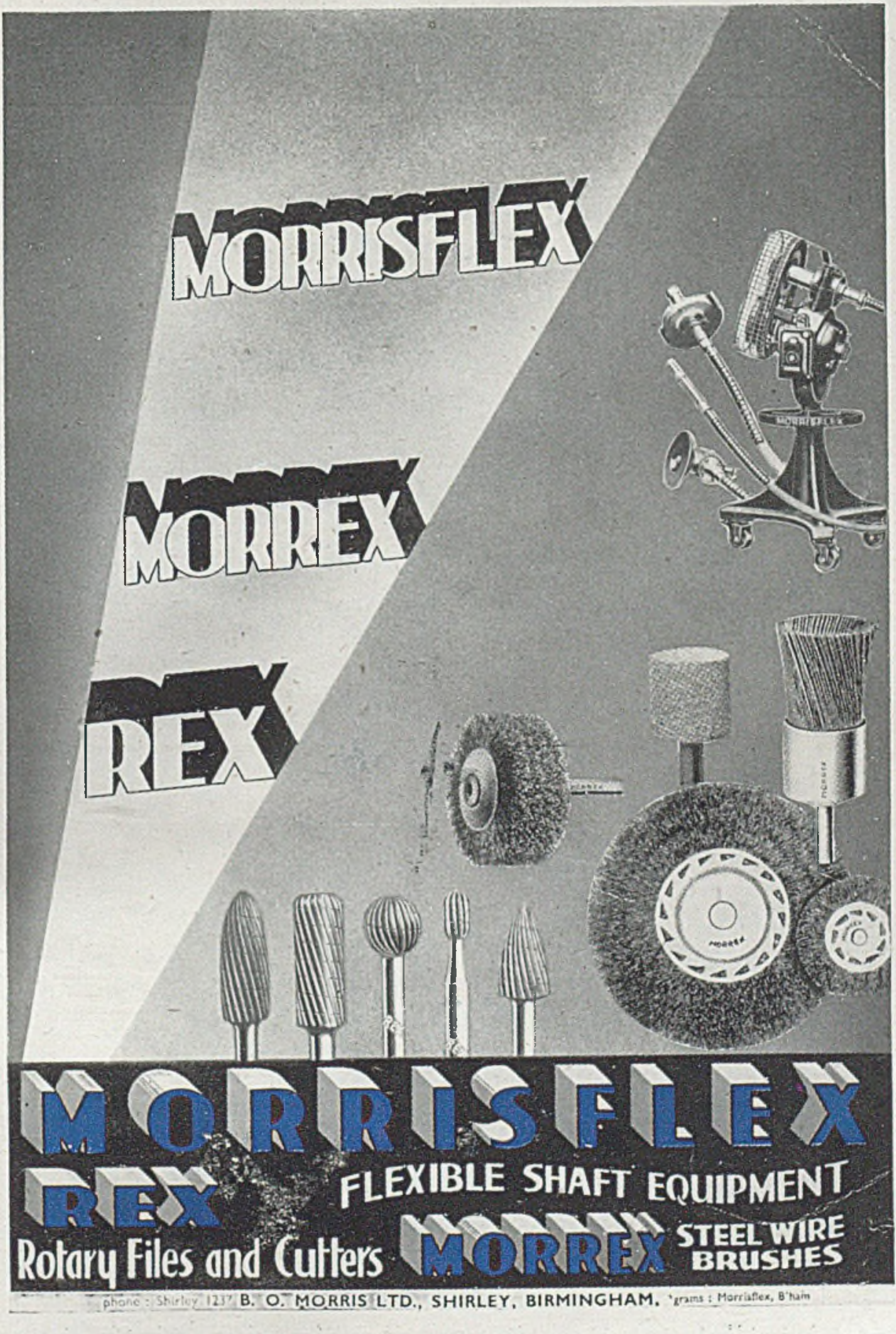
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