LIGHT METALS

APRIL
1945

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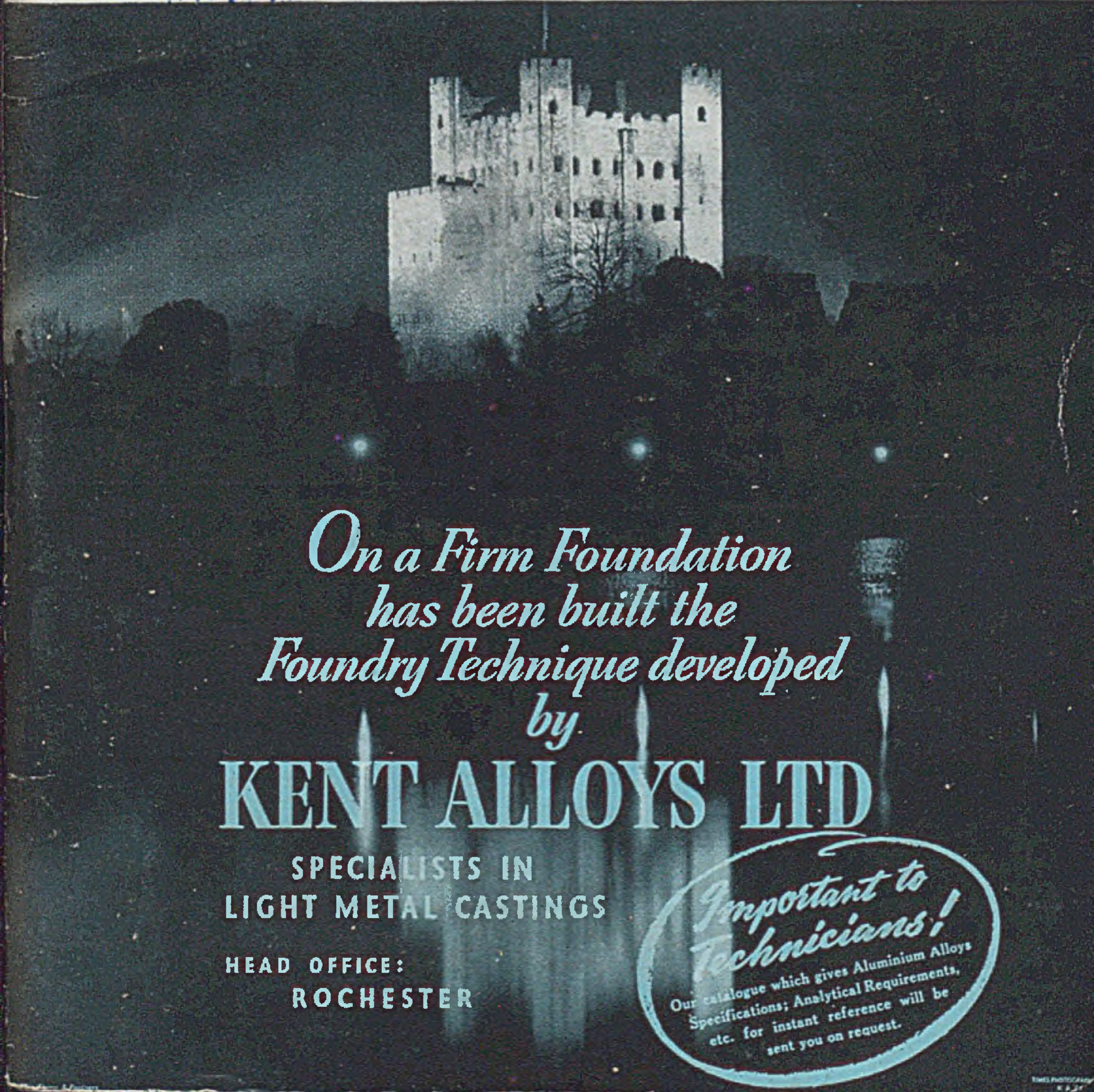

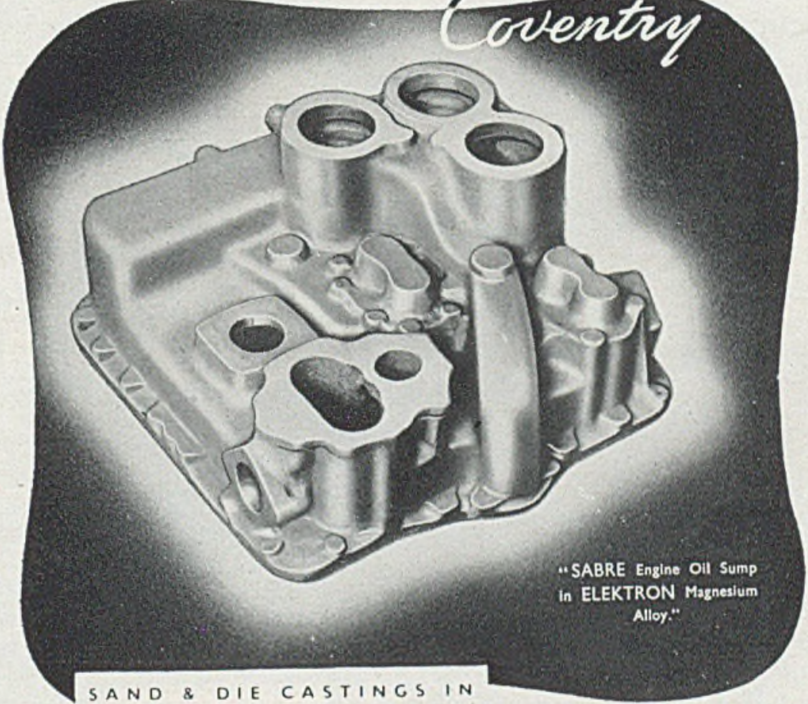

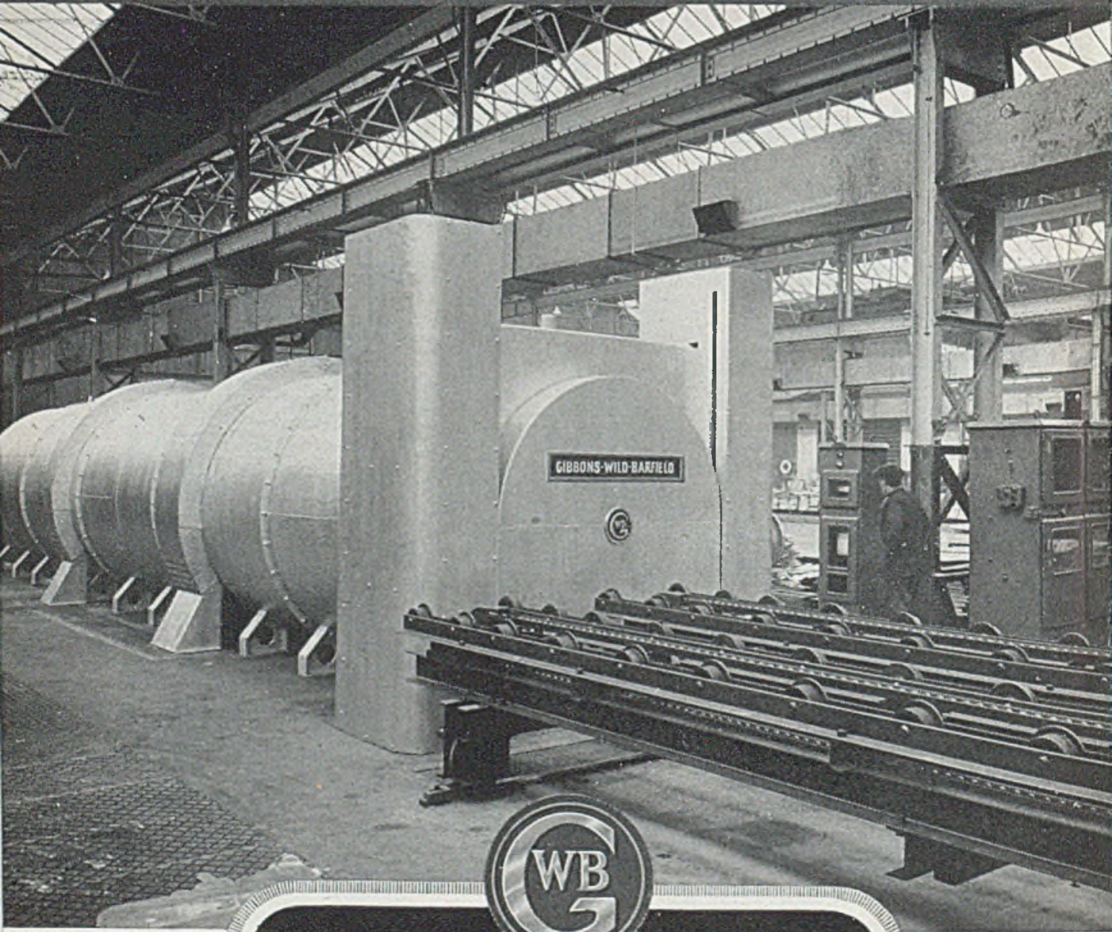
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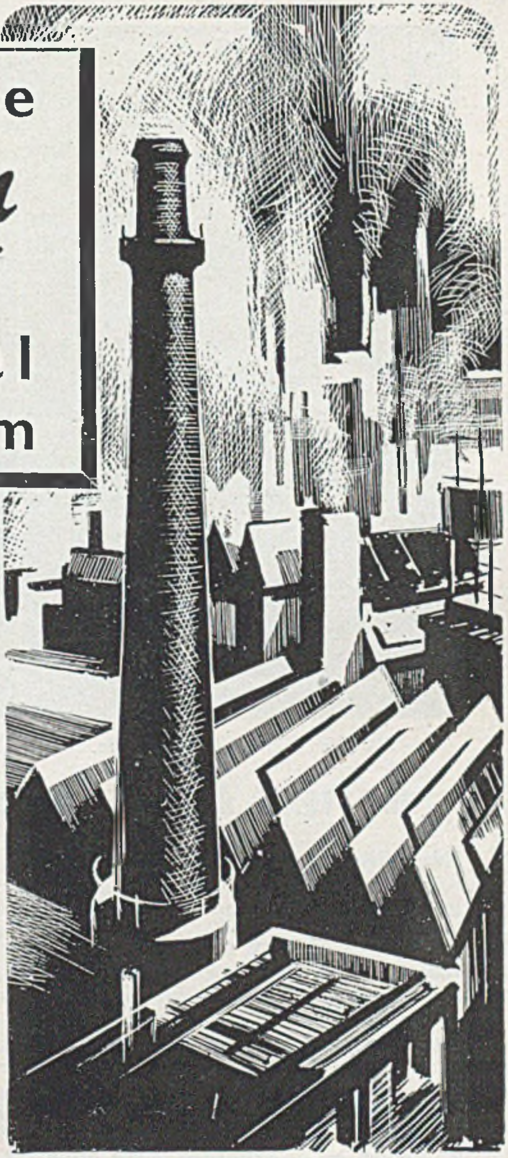

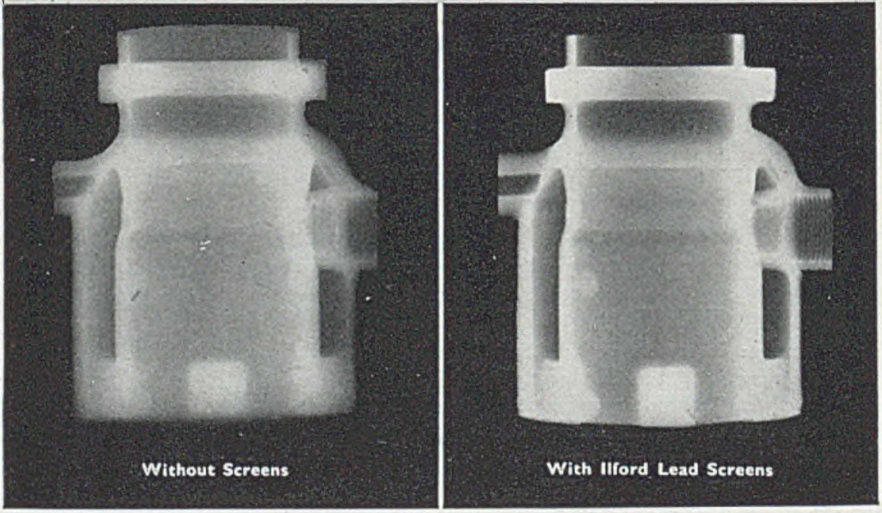

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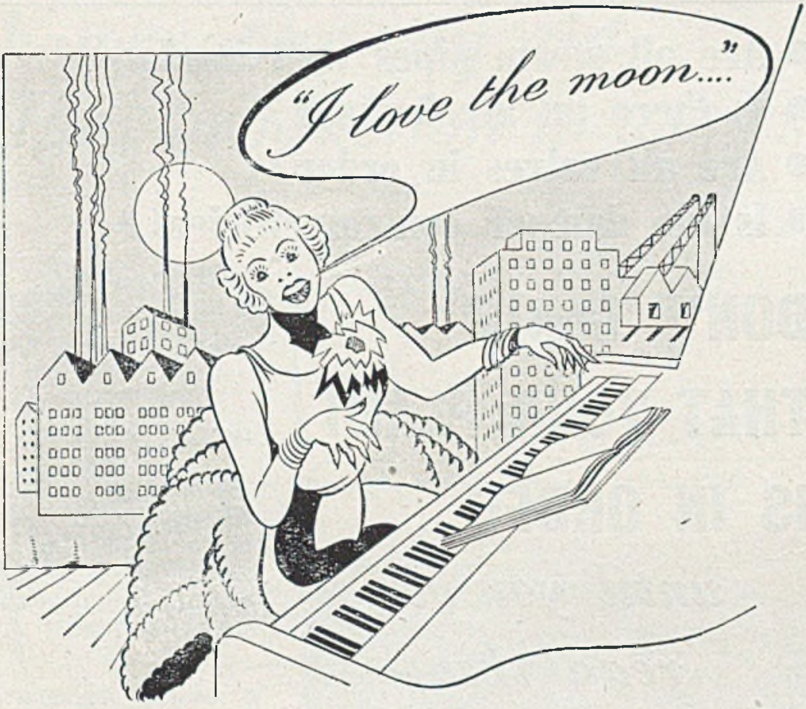

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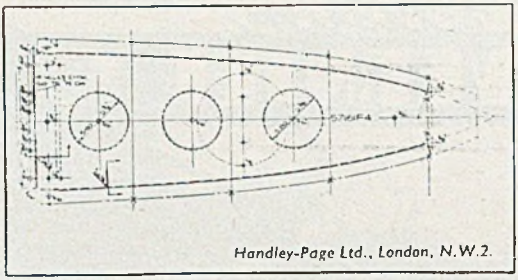
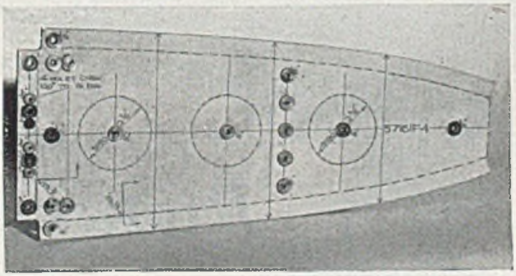


(1) *Original drawing as prepared by draughtsman.*



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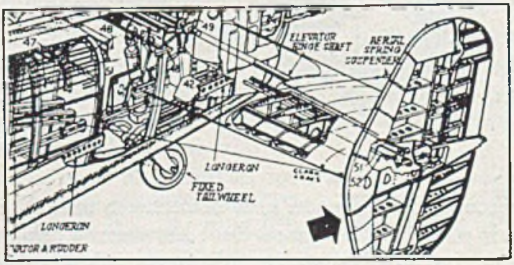

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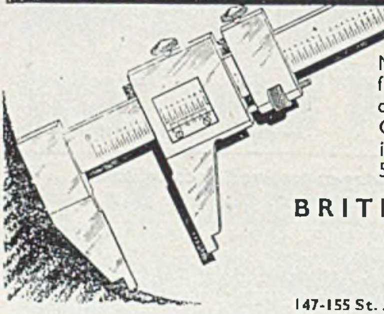

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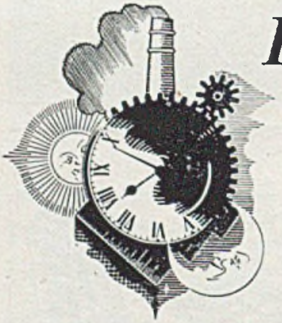

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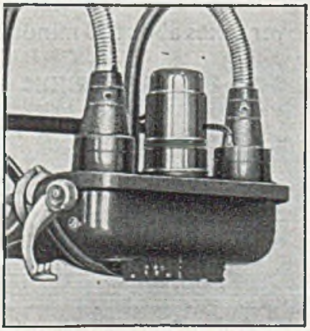

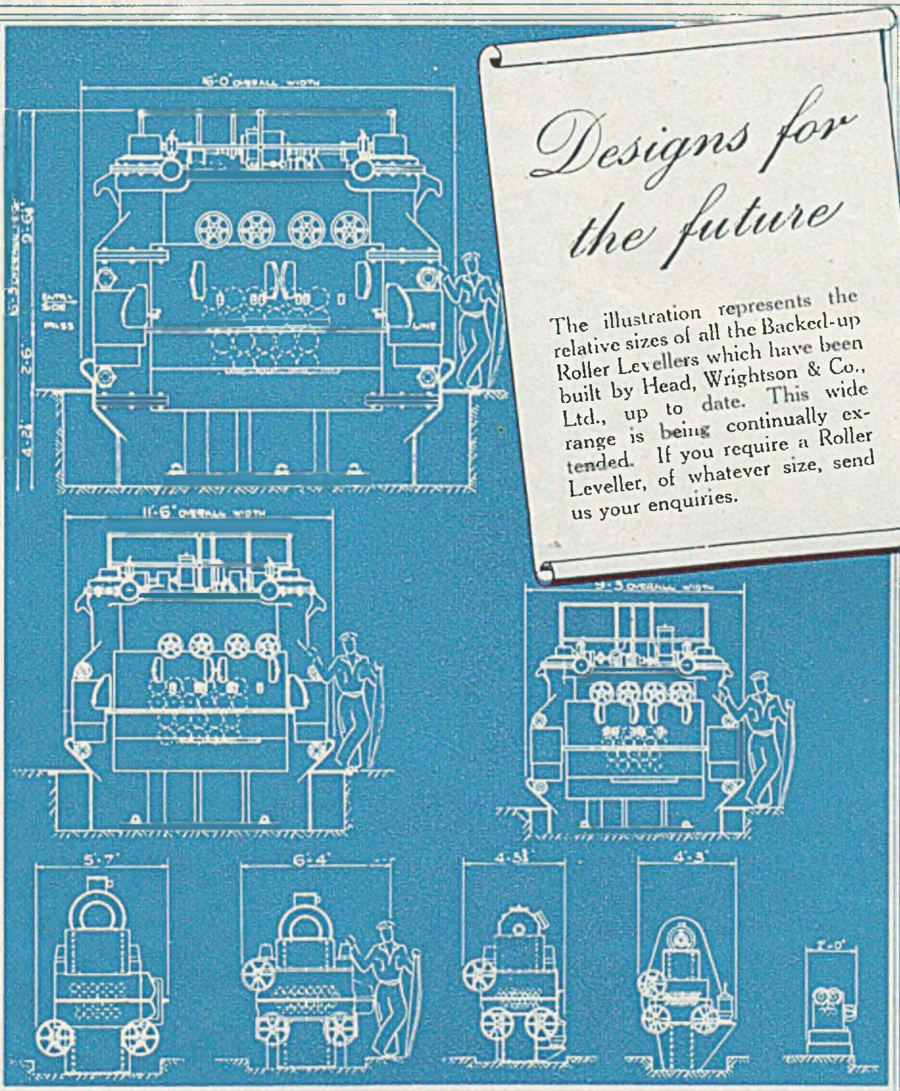
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PASS LINE
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4'-2"
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VOL. VIII. No. 87 APRIL, 1945

LIGHT METALS

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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

So Long Since We Met!

AS a prelude, it is hoped, to full co-operation between the interested parties in the near future, aluminium and the civil consumer are, after five years intensive preoccupation with the war effort, to be accorded a ceremonial reintroduction. This is to take place in May at Messrs Selfridge, Ltd., who, with the joint assistance of the principal producers, fabricators and founders in the country, will open to the public an exhibition (to be located there for one month) designed to illustrate the role of light metal in its transition from war to peace.

Responsible for the organization of the exhibition is a committee composed of representatives of Messrs. Selfridge, the principal aluminium producers, fabricators and founders, the Wrought Light Alloys Development Association, and the technical Press. The committee has been assisted in its work by the willing co-operation of many manufacturers and individuals outside the aluminium industry proper.

It is not proposed at this juncture to attempt to describe in detail the full range of work to be shown; of greater importance is the fact that, in this presentation of the aluminium story, continuity is to be, throughout, the guiding principle. This conception will be adhered to in every aspect, whether the development of civil aircraft components from their war-time counterparts is being demonstrated, or whether the life history of the metal is being told as in the mural motifs, by means of which visitors will be presented, at a glance, with a synopsis of the background to the metal as the lay public encounters it.

Somewhat naturally, those phases of the exhibition devoted to the peace-time uses of aluminium will occupy greater floorspace than the war-time applications; the former are, essentially, of a more bulky and expansive nature, the latter being entirely utilitarian, and calculated, principally, on the basis of maximum weight reduction and maximum ease of production and assembly consistent with Service requirements.

Light metals in the home will be illustrated mainly in group exhibits. Aluminium in house construction, representing as it may well do an important application for the metal, will be shown not only in the form of a complete assembly, but also further emphasized by the inclusion of especially prominent features, such as doors and window frames of special design. Here, too, the murals will assist in the continuity as they, too, will be eloquent of the decorative value of the metal. Individual items in the house, such as the kitchen and the bathroom, will be exhibited to show not only the trend in modern designs, but also the way in which light metals can assist in the realization of combined functional and artistic ends.

It is possible, too, that the trained eye may see in the application of these easily worked materials, a vital clue to that speeding up of reconstruction and re-creation now being insisted on both by the general public and authoritative bodies, not only in this country but also abroad. In short, it may be anticipated that the exhibition will go far to stimulate the interest of buyers of British goods in overseas markets.

A further phase of the aspect of continuity might here be pointed out: the ready availability of aluminium and its light alloys in standard sheet and extruded forms offers a direct and sound solution to more than one problem in quantity production; honest design and workmanship are both equally assisted. The use made of aluminium tube and sections, sheet and castings will be seen to extend from the most complex item of war-time equipment to the purely decorative feature in the drawing-room.

Nor is this all; the continuity and permanence of imaginative work based principally on metals demands, like successful human effort, sound team-work. In the exhibition, light metals will be seen playing their part, side by side not only with other metals but, in addition, with non-metals, particularly the newer plastics. No more convincing proof could be asked of aluminium, on this the centenary of its first definite isolation, than that it has attained full equality with its elders in the ranks of structural materials.

Contents

SPECIAL ARTICLES

REGULAR FEATURES

"LIGHT METALS" is published in London, England, on the fourth Wednesday of the preceding month.

Aluminium and Magnesium Alloys in LIGHT ENGINEERING

Presenting the First Part of a Detailed Survey of the Applications of Light Metals for a Wide Variety of Smaller Structures where Low Deadweight is of Primary Importance

THE applications of light alloys in heavy engineering were surveyed in a previous article. The apparent incongruity of light alloys and heavy engineering was remarked upon, and then with the aid of numerous instances from engineering practice, remarkable serviceability of the partnership in many applications was demonstrated. In light engineering, aluminium and magnesium alloys would appear obviously to be more in their own element and, after such an excellent record in heavy engineering, one might expect great things of the light metals in those branches of the engineering industry in which material is dealt with on a less massive scale. In actual fact, the result is not disappointing, for many applications of the light and ultra-light alloys, some of them highly original whilst, at the same time, quite practical, demonstrate the remarkable versatility of these metals and the benefits which accrue from using the right material in the right place.*

In order that the contents of this review can be seen in their proper perspective and to link together what might otherwise

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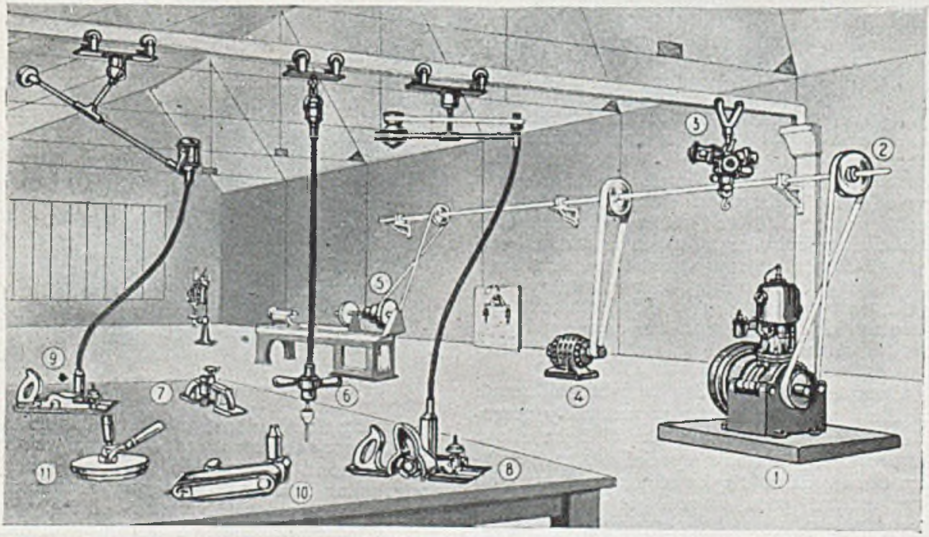
* Certain illustrations referred to in this section of the account will appear in the concluding section.



SCHEMATIC view of machine shop showing possible points for the application of light alloys: 1.—Petrol engine constructed substantially of light alloys and weighing, for units of 1-3 h.p., not more than 10-25 kilos. 2.—Pulley. 3.—Hoist, illustrated in greater detail on a subsequent page in this account. 4.—Dynamo with end caps, casing, etc., in light alloys. 5.—Stepped pulley: the remaining tools shown in this illustration are provided with flexible drives running in flexible aluminium tube. 6.—Hand drill provided with suitable reduction gear. 7.—Small hand shaper. 8.—Simplex type rebating plane. 9.—Unic type plane. 10.—Hand-sanding machine. 11.—Surface grinder. (Reproduced from "Revue de l'Aluminium."

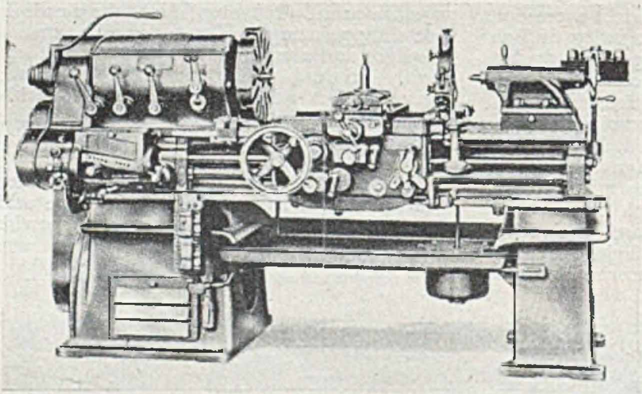
appear to be a series of disjointed descriptions of machine tools and other appliances, it will not be redundant to commence with a summary of some recorded examples.

A most obvious application, and one in which both aluminium and magnesium, either as commercially pure metal or as alloys, have already figured, is in the case work of portable or hand tools. The function of the light metal here is a secondary one, but, nevertheless, the saving in weight is important and a valuable contribution towards the reduction of fatigue and the elimination of errors and mishaps consequent upon the fatigue of the operator. Portable grinders, pneumatic and electric drills, polishers, engraving machines, large braces and hand-lapping tools are all instances of this type of application. Welding torches, spray guns, jigs and gauges have been provided with light-metal components for the same reason. An additional advantage of aluminium for the fabrication of jigs and gauges is that it can be anodized and dyed to a jet black colour of remarkably low reflectivity which largely eliminates the eye strain which results from the constant handling of a bright steel object under artificial or natural lighting.

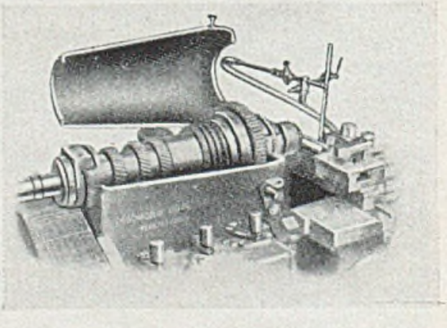
Considerations of low weight, adequate rigidity and freedom from unsightly corrosion have indicated the use of light alloys in a drawing board of special design, in aircraft and other types of instruments and instrument panels, and in a portable weighing machine for determining the loaded weight of aircraft. Aluminium hammers have been used for special purposes, for example, for beating magnesium-alloy sheets. Thin coatings of aluminium applied by spray are used as a protection for soldering iron bits and for coating hacksaw blades; in the latter case, the layer of soft metal functions as a lubricant.

Being non-magnetic, aluminium has been employed in permanent magnet assemblies used in certain applications in engineering, whilst, in combination with iron and nickel or with iron, nickel and cobalt, alloys with particularly well-developed properties of permanent magnetism are produced which have already found application, for example, in the construction of magnetic chucks.

In machinery for the working of both wood and metals, light metals fulfil functions of primary as well as secondary importance. In the larger machines, such as radial drills, lathes and rams, light alloys have been employed for a number of the larger components with the object of reducing the inertia of reciprocating parts, of cutting down vibrational stresses and, in certain special cases, of reducing dead weight. For diamond-impregnated grinding wheels and similar tools, age-hardening aluminium alloys have proved very satisfactory as matrix materials in which the diamond dust is embedded, superior, in fact, to copper or plastics for the purpose.



SHOWN at the left is a Prentice 14-in. lathe embodying numerous aluminium alloy elements and designed specially for use on U.S. naval craft. The standard iron and steel model weighs 3,600 lb., whilst this pattern scales at 3,000 lb. Shown below is part of a precision lathe with covers of aluminium manufactured by Schaublain-Villeneuve, Bévilard.



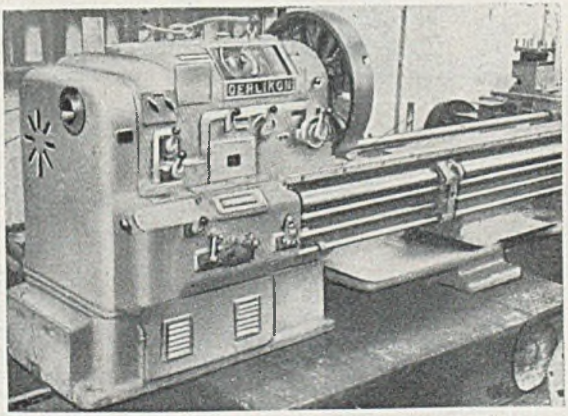
Light Alloys in Machine Tools

With this summary in mind, these various types of application may now be dealt with in more detail, paying particular attention to the reason for the choice of light metal and the manner in which it is used to achieve the desired result. Directing attention first to the use of these materials in machine tools, it is obvious that their suitability must depend on certain specific characteristics of light alloys, such as their low specific gravity, relative softness, good heat conductivity, property of age hardening and ease of machining, since they cannot compete with tool steels in hardness and ultimate tensile strength.

In modern machine tools, the qualities chiefly demanded are rigidity and the absence of vibration, both of which are essential for accurate working. Both of these qualities can be promoted by the accumulation of masses of metal and, in point of fact, this is the manner in which the problem has been most generally tackled in the past. It is frequently the case that the practical man's opinion of a machine rises in proportion to its weight and cost. But this is fundamentally unsound, as smoother running can be achieved by reducing vibrational stresses in rotating parts and lowering the inertia of reciprocating parts by the substitution of well-designed light-alloy components for heavy metal parts, whilst the attainment of rigidity has been shown to be more a question of design than mass.

The value of light weight in rotating and reciprocating machine tool parts is considerable, allowing the use of higher speeds and increasing through-put without increase in motive power or vibration. Thus, light metals find application in the construction of large reciprocating or rotary tables which have to be rapidly started, stopped and reversed, for shaper rams, heads of shears, saddle assemblies of radial drills, face plates and parts of automatics, printing and capping machinery, mechanism operated by cams, the Geneva stop motion or by specially controlled motor drive, and so on. A typical high-speed ram in aluminium alloy, in operation on a shaping machine, weighed only one-third of its counterpart in steel, and was operated over a range of 14 to 200 strokes per minute, the higher speed of operation being considerably faster than the maximum which could be employed previously with the steel ram.

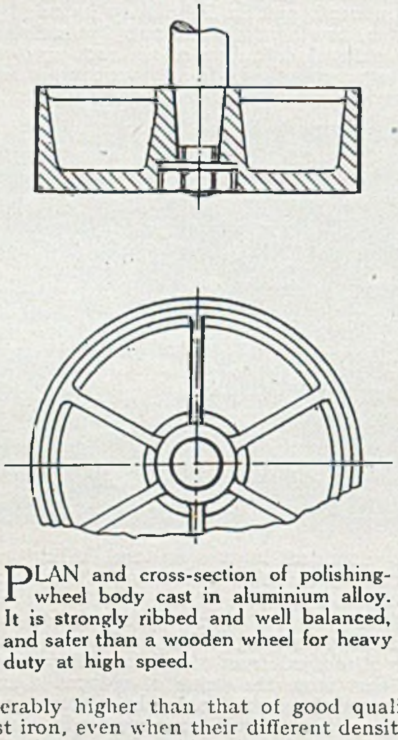
In certain cases, greater rigidity and accuracy of operation are secured by the use of light alloys where reduction in weight involves a decrease in vibrational stresses and less deflection in supporting members. Typical of such instances is the driving head of a radial drill made by the Cincinnati Bickford Tool Co. in which 500 lb. of cast iron were replaced by casting in Al-Cu-Zn-Fe alloy totalling only 130 lb. in weight. The components cast in light alloy included 11 covers, two brackets and two flywheels and the reduced deflection of the arm was said to be very marked. In another case, greater accuracy resulting from lowered distortion was obtained in a spur and helical-gear grinding machine constructed by the National Tool Co., of Cleveland, Ohio, by replacing the cast-iron work head slide by a light-alloy casting. The work-head casing was fabricated from aluminium-alloy sheet.



MODERN lathe with covers of aluminium by Oerlikon. The use of the metal here is designed to achieve maximum rigidity without undue increase in weight, and at the same time to assist in the maintenance of a clean, corrosion-free machine.

Apart from the value of reduced distortion and lowered inertia in rotating and reciprocating parts, numerous advantages accrue from the reduction of dead-weight in large machine tools, although most practical men will need to be educated to this point of view, which is radically opposed to the opinions they have developed from experience with all-steel machines. In the first place, heavy expenses may be incurred in handling massive machine parts in the shop, where assembly may often demand the services of an overhead crane travelling from machine to machine during the course of erection; a corresponding component in light alloy may often be handled by a simple pulley block. Other components requiring several men for their manipulation can, with no sacrifice of rigidity, be so reduced in weight as to be capable of manipulation by one pair of hands. In the fabrication of machine-tool components, the use of light alloys in place of cast iron and steel means that higher cutting and machining speeds may be employed. Shipping and transport costs and even duty, if based on weight, can be cut and the machine, when laid down, demands foundations less massive and costly than in cases where cast iron is used in bulk.

For the purchaser of the machine, advantages are to be derived from the easier handling of the machine during the installation operation and dismantling for repair or scrap. The price of high-grade light alloys is considerably higher than that of good quality cast iron, even when their different densities are taken into consideration. Against this can be set the lower cost of machining light alloys, economies in handling and in transport costs and the higher scrap value of the light metal when the machine is finally discarded. Nevertheless, the cost of a machine tool incorporating light alloys is, at the moment, at all events, somewhat higher than that of a machine built entirely in the customary heavy materials, but not high enough to crush interest in those who pause to consider the advantages of lightweight construction and, incidentally, of freedom from rusting.



PLAN and cross-section of polishing-wheel body cast in aluminium alloy. It is strongly ribbed and well balanced, and safer than a wooden wheel for heavy duty at high speed.

Illustrated is a modern lathe made at the Machine Tool Works, Oerlikon, in which the covers were made of aluminium, chiefly for lightness and resistance to corrosion. Also illustrated is the Prentice 14-in. lathe, in which a total of 600 lb. has been saved. This lathe was designed especially for use on board U.S. naval craft, submarines, destroyers, etc., and incorporates numerous aluminium alloy components. Heat-treated aluminium alloy castings were used for headstock motor leg, tailstock leg, covers and hand wheels. The net weight of the machine constructed in heavy metals was approximately 3,600 lb., so that the substitution of aluminium for cast iron and steel resulted in a total weight saving of some 20 per cent. This figure is reasonable when it is borne in mind that nearly half the weight of the apparatus is concentrated in rotating parts, gears, spindles and ball bearings, etc., which must, in any case, be made of steel.

A precision lathe with aluminium covers has been built by the concern of Ch. Schaublain-Villeneuve, Bévilard. Even more interesting is the precision lathe shown, in which the main portion of the lathe was redesigned as a sand casting in magnesium alloy with a rigidity equal to that obtained by normal construction in cast iron and welded steel. Careful observation revealed that, with maximum cut, the performance was equal to that of the heavy-metal machine. Owing to the relatively low hardness of the magnesium alloy, the rails on the bed of the lathe were strengthened with heavy-metal strips. This is, in fact, usual practice with aluminium as well as with magnesium alloys, and parts which are subjected to heavy wear, such as slides and bedways, must be protected by steel strips, as is customary in all high-grade tools. On the other hand, the good bearing qualities of certain light alloys are such that spindle bearings may be housed directly in the light metal body or in pressed-in bronze bushes. Cast magnesium alloys can be used effectively in cases where exceptional lightness is called for in machine tools owing, for example, to their being set up in travelling workshops or in the upper stories of buildings.

Heat-treated Cu-Al alloy arbor supports weighing 25 lb. each were adopted by the Cincinnati Milling Machine Co. for use on one of their milling machines. These replaced cast-iron components weighing 50 lb. each. A further considerable saving in weight was achieved by adopting light alloy construction for the cover of the motor compartment. On some large grinding wheels, covers weighing 75 lb. each were fabricated in light alloy in replacement of cast iron covers weighing 300 lb. each. Sand cast inspection doors on these grinders weighed 4 lb. each.

The Aluminum News Letter for November, 1937, notes a high-speed tapping machine in which the following parts were fabricated in light alloy: work trays, top head, oil splash guard, lamp guard and reflector, belt guard, foot pedal and door. Earlier in the same year there was described[2] a turret lathe with turret and tool holders in aluminium. The turret, which was of ribbed construction, weighed 373 lb. in light alloy compared with 950 lb. in ferrous metal. The tool holders weighed 100 lb. compared with 200 lb. in steel, so that the total weight saved was in excess of 50 per cent.

An aluminium frame was used for the " File-All " continuous filing machine made by the George Alexander Machinery Co., Ltd., of Birmingham.

Although more notch sensitive than the ferrous alloys, both aluminium- and magnesium-alloy components can be used satisfactorily under conditions of severe fatigue stress provided that the design be suitable and that notches produced accidentally during fabrication are eliminated from the finished component. As an example of the satisfactory operation of light-alloy components under such conditions may be instanced a lever for a Lorenz-geared wheel slotting machine which gave satisfactory service when sand cast in magnesium alloy. This component moved continuously backwards and forwards and was required to brake large inertia forces. A hollow section was chosen for this lever, since it was subjected to both bending and torsional stress. The necessary holes for supporting the cores were well rounded on the inside to eliminate notches from the inner surface of the casting.

Design of Light Metal Components

When considering the use of light metal components in machine tools, it is obviously not sufficient to replace a cast-iron or a cast- or wrought-steel component by an exactly similar part in light alloy. Allowance must be made for the difference in the mechanical properties of the two classes of material and, in particular, for the lower modulus of elasticity of the light and ultra light alloys. A previous article in this journal[3] recommends the following formula to evaluate the rigidity or stiffness R of a machine body and its resistance to vibrations:—

$$R = n^2.W = \text{prop.}\,\frac{W}{\delta}$$

where n = vibrations per second of the body

W = weight or mass of the unit

δ = prop./E.I. bending deflection (ins.)

The bending vibrations of machines may be determined by means of special instruments, some of which, incidentally, incorporate light-alloy structural units as essential parts of the design, and it is, therefore, relatively easy to demonstrate whether plant constructed of light alloys has the same regidity or stiffness as a similar assembly built of cast iron or steel.

If a component in cast iron be replaced by one of high-grade aluminium alloy of the same size and wall thickness, the weight (W) is reduced in the ratio 1:2.7, deflection being increased in the ratio $9.7 : 15 = 1 : 1.55$, owing to the lower modulus of elasticity of the light alloy. Thus, equal dimensions imply that the rigidity of the aluminium body is reduced in the ratio—

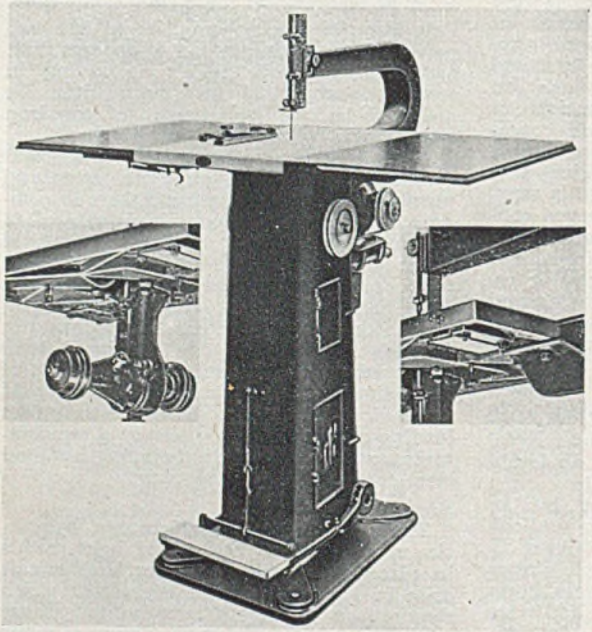
$$\frac{1}{2.7 \times 1.55} = \frac{1}{4.2}$$

and, to obtain in the light alloy rigidity equal to that obtained with cast iron, the cross section of the aluminium alloy unit must be increased in the ratio $\sqrt[2]{4.2} = 2.05$. Bringing the specific gravities of the two materials into consideration, it appears that, for units of equal rigidity, a saving in weight of about 32 per cent. may be achieved by the replacement of cast-iron components by those in aluminium.

A much earlier paper[4] recommended that in designing machine elements, structural members in tension, short members in compression, beams, and containers subject to internal pressure, all under conditions of static loading, the design stress for both tension and compression should be taken as ¼ of the U.T.S. or ½ of the yield strength, whichever was the greater. For repeated or alternating stresses, the design stress employed should not exceed 80 per cent. of the fatigue limit. Increased factors should be employed for members subject to impact loading or to operation at elevated temperatures, as is customary in designing iron and steel components or structures.

Screw Threads

The most noticeable differences in practice resulting from the use of light metals in place of ferrous or copper base metals arise in the construction of beams, which require an increased depth to secure adequate rigidity, and in the design of screw threads. Most aluminium alloys are soft in comparison with tool steels or even brass and there is a considerable tendency for aluminium threads to bind. In consequence, it is general engineering practice to avoid the use of aluminium bolts and nuts wherever possible and for studs and tapped holes in light alloys to employ the coarse or U.S. standard screw thread. The depth of the tapping is made rather greater than is customary in tapping holes in heavy alloys, about twice the diameter being regarded as good engineering practice for tapping holes in aluminium alloys. It is obvious that some judgment must be used in the selection of the proper depth of a tapped thread, as this is also conditioned by the frequency with which the screw is to be removed, frequent removal soon damaging the light-alloy thread. Wear may be minimized by suitable lubrication and by increasing the length of the thread engaged. Steel studs or bolts used directly in contact with light alloys are, however, not without grave disadvantages since electrolytic action between the two metals is liable to result in rapid deterioration by corrosion. Galvanized screws are an improvement in this respect, and bitumastic coatings also assist, but, for reliable behaviour under corrosive conditions, it is essential to employ bolts, nuts and studs of an alloy similar in composition to the metal they contact.



FRETSAW machine by Inderbitzing and Co., France. This machine, designed for cutting paper, card, plastics, hard rubber and soft metals, will handle material up to 100 mm. thick. Table, controls, transmission, guides, etc., are all in light alloy.

A number of articles which have appeared in the Technical Press in recent years have shown that aluminium-alloy threads are not so inferior to their steel counterparts as had been generally supposed; at the least, sufficient information has now been published to bring the behaviour of aluminium screw threads on to a predictable basis. Thus, research into the tensile strength and resistance to repeated axial impact blows of light-alloy screws threaded with both metric and Whitworth screw threads showed that better results were obtained with the Whitworth threads under conditions of both static and dynamic loading.[5] The material chosen for the tests was Anticorodal in the fully heat treated condition.

A further test was devoted to the determination of the minimum ratio of screw thread height of nut to screw shank diameter, again under conditions of both static and dynamic loading, nuts of pure aluminium and of Avional being employed. The results obtained for the minimum ratios are given in the table above.

Minimum Ratios
Screw Thread Height of Nut Screw Shank Diameter*

Condition of loading	Material of nut	Metric thread	Whitworth thread
Static ..	Avional (heat-treated)	0.7	0.7
	Aluminium	1.6	1.7
Dynamic ..	Avional (heat-treated)	0.5	0.4
	Aluminium	1.7	1.7

* Anticorodal screws used in each case.

The fatigue strength and reaction to repeated tightening of light-alloy screws has been exhaustively investigated by Bollenrath, Cornelius and Siedenburg, and reported in a lengthy paper, a résumé of which has been published in this journal.[6] Screws cut from two aluminium-base alloys were investigated, one being a wrought alloy containing 4 per cent. Cu and 1 per cent. Mg, and the other a free-cutting alloy of the same group with the addition of 2.1 per cent. Pb. The Brinell hardness of the first alloy was 124 to 140 and that of the second was 104 to 121. From these materials in bar form were machined standard screws of diameters 6, 8, 10 and 14 mm. with corresponding pitches of 1, 1.25, 1.5 and 1.75 mm. For comparison purposes, a 10 mm. diameter screw of 1.5 mm. pitch was employed. These were used with nuts of the free-cutting alloy and compared with steel bolts used with steel nuts. The investigation also

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MAGNESIUM BASE ALLOYS

MAGNESIUM CASTINGS & PRODUCTS LTD • SLOUGH covered the influence of chromium plating and of anodizing the aluminium screws and nuts. It is interesting to note that the tensile strength of the screw and nut assembly in steel was only some 28 per cent. greater than that of the assembly in the first aluminium alloy and that the steel assembly actually showed a slightly lower proof strength. The beneficial influence of greasing light alloy screw threads to reduce the risk of seizure was well brought out in this research, greased screws only showing slight signs of seizing after tightening and loosening 10 times.

Anodizing was found to confer no advantageous mechanical properties on the screws and to be definitely harmful in that the tendency to seize was relatively high both for greased and ungreased screws; fracture occurred in several tests at loads equivalent to $\frac{1}{3}$ to $\frac{1}{2}$ of the strength of the thread. It is assumed that the tendency to seize is due to the exfoliation of the particles of the anodized coating; the comparative roughness of the thread flanks would favour this hypothesis, which was further borne out by the fact that seizing was more apparent with tight than with loose fits. It was considered possible that dimensional differences might be partly responsible for the behaviour. Similarly, in the case of chromium plating, the tendency to seize remained practically the same as in the case of bright screws whilst, when tightening, exfoliation of the deposited chromium considerably increased the danger of seizing. The use of rolled screws of special sine-curve form might be well worth investigating from the standpoint of better mechanical properties and decreased tendency to seizing.

Light-alloy Pulleys and Polishing Wheels

The main reason for the use of light alloys in components embodying discs rotating at high speeds, such as high-speed pulleys, polishing wheels, milling cutters, buffs and grinding and lapping wheels is to reduce the centrifugal stresses which arise as the result of the inevitably slightly imperfect balance of these assemblies. Low specific gravity simplifies balancing and assists in the reduction of vibrational stresses. Plywood has been used in this connection but, for high-speed operation in the neighbourhood of 7,200-11,000 ft. per min., its use is obviously coupled with some danger. In consequence, cast-aluminium or magnesium-alloy bodies have been used and, more recently, strong wrought light-alloy pressing with steel inserts for the hub and certain stressed points have been adopted.

A filing ring, available in diameters from 6 ins. to 10 ins., was so designed as to fit over a split aluminium body expanded by means of a conical bush pressed into the hub, so that the ring was held on by friction.

Diamond-impregnated lapping wheels contain an annulus of phenolic resin impregnated with diamond dust which is attached to an aluminium body by means of dovetails integral with the resin moulding and fitting into corresponding slots in the metal base. Actually, the use of light alloy in this connection was dictated not so much by its low specific gravity, as the resin possesses an even lower density, but rather by reason of the higher strength and greater heat conductivity of the metal. Furthermore, whereas the dimensional stability of the light metal is never likely to be called into question, large plastic mouldings frequently cause trouble in this direction. It is said that instances have been recorded where impregnated wheels of this type, produced entirely from plastics, have distorted sufficiently to render precise operation difficult.

Difficulties were also experienced in obtaining perfect balance with impregnated wheels operated at high speed and moulded in plastics, whilst excessive tightening of the clamping screws again frequently damaged the resin body, a serious matter in wheels costing £10 to £20 each. Moreover, the incorporation of a light-alloy supporting body enhances the appearance of the tool, the metal in this case being diamond turned as a rule and thus possessing a finish of manifestly high quality.

Actually, this is by no means the whole story of the employment of light metals in diamond-impregnated tools, as certain aluminium-base alloys have been employed with considerable success as the matrix in which the diamond dust can be directly embedded. More will be said about this type of application later.

The use of light alloys, however, is not confined to the high-speed components alone, and their application in the construction of relatively slowly revolving pulleys of larger diameters was one of the first applications of light alloys in the mechanical engineering field. It was in 1911 that the American Tool Works Co., of Cincinnati, adopted aluminium driving pulleys on their larger-size planers. The advantages were many. On the 36-in. and larger heavy-pattern machines the driving pulley weighed 105 lb. in cast iron, but only 35 lb. in light alloy. An immediate result of this was a 70 per cent. reduction in momentum which not only decreased the strain on the planer belts, thereby greatly increasing their life, but also enabled their travel to be increased by 2 ins. as the after-run after each stroke was reduced by a similar amount.

Great interest was aroused by this innovation, and a number of American concerns followed the example set by the American Tool Works Co. The Butler Machine Tool Co., of Halifax, made a special study of aluminium-alloy pulleys and, in 1927, this concern installed a large open-sided planing machine in which the reversing pulleys were constructed in aluminium alloy with cast-iron centres. Substitution of these composite pulleys for similar all-cast-iron components reduced the reversal inertia to one-third of its previous value and gave a smoother and considerably less noisy reverse.

Light Metal Hammers

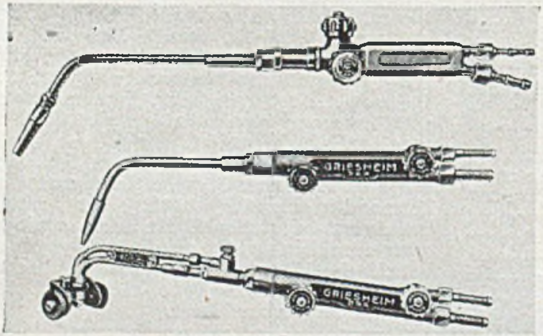
The inherent softness of light metals has been used to produce soft-faced hammers for special purposes. An aluminium-base alloy developed by one Continental hammer manufacturer proved to be more satisfactory than the copper which it displaced as, for the same average consumption of energy, the compression of the light alloy was less than that of the copper with, consequently, less deformation of the working face and a longer life for the hammer. An even softer aluminium-base alloy was developed to give characteristics similar to those of lead hammers as used for working on brass and light-metal sheet. This same alloy has successfully been employed for protecting work whilst being held in the vice, and has proved quite as successful as lead- or copper-faced jaws. The light-metal hammers referred to above were of the inserted type, working faces being from ⅜-in. to 4-in. diameter, the overall length of the head being between 3 ins. and 8⅜ ins., with corresponding weights between 3½ oz. and 17½ lb. Such hammers are very suitable for the bending of magnesium alloys as they cause no scratching of the surface.

Diamond Polishing Wheels

An application of greater moment, however, is based on the use of age-hardening alloys to produce a medium presenting characteristics of softness at the time of fabrication and hardness when the latter quality is required without the application of the high temperatures needed for the heat treatment of steel. In this way, light metals have been employed as matrix materials for abrasive grains of various types of which perhaps the most important is diamond dust as used in the fabrication of grinding and lapping wheels.

Matrix materials for this purpose must satisfy a number of stringent requirements. In the first place, they must be capable of receiving the diamond dust or other abrasive material and of retaining the embedded grains under conditions in which the tendency to tear them from the matrix material is very great. The material must possess considerable strength, as centrifugal forces at the high speed of operation employed are considerable, and accidents due to splitting of the wheel are serious, involving considerable danger to personnel. Low specific gravity is an advantage in this connection, but the necessity for good heat conductivity rules out the use of fabric-reinforced plastics, except for the lightest duty work, although plastics would otherwise appear to offer considerable possibilities. It is, therefore, preferable to employ a metal for the matrix and, except in the smallest sizes of wheels and arbors, the abrasive-loaded matrix is often confined to a zone extending from the periphery of the wheel to only a small distance below it. This is secured automatically when the diamond is pressed mechanically into the peripheral surface of the wheel but, in cases where the starting point is a powder mixture, such as aluminium powder or a mixture of metal powder and synthetic resin, the abrasive-laden band may be formed as a separate component which is attached to the hub of the wheel by expanding the latter mechanically with wedges, by the use of suitable keys and slots or, occasionally, by the use of solders or adhesives. But, whatever method is employed, it is necessary to take into consideration the coefficients of thermal expansion of all the materials to prevent loosening, cracking and disintegration under the combined influence of heat and centrifugal stress.

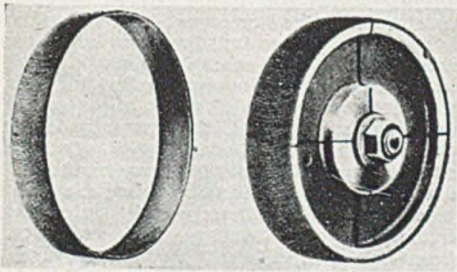
A possible post-war development is the production of wheels of this type by cold-pressing aluminium-alloy powders blended with diamond dust, and possibly with the



ILLUSTRATED here is a group of cutting or welding torches, the bodies of which consist of aluminium-alloy forgings; similar equipment has been produced utilizing chill-cast magnesium-alloy bodies.

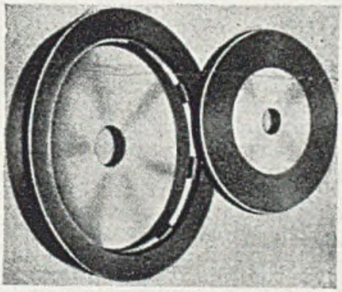
addition of corrosion-promoting materials to remove the light metal slowly under pressure and thus to eliminate glazing due to the smearing of the matrix. For the moment, however, impregnated wheels are produced by embedding the abrasive grains into a metal surface. This is none too easy a process. Copper as a matrix material might appear to present definite possibilities, but it holds the embedded abrasive grains far too insecurely to give any reasonable life, and the problem seems to revolve around the choice of a suitable age- or heat-hardening alloy since hardening appears to tighten the hold of the metal on the abrasive, whilst the preliminary softness of the metal simplifies the introduction of the grains into it. Steel is really excessively hard and it cannot be used with diamond dust as the high temperatures needed for hardening would almost certainly destroy the diamond.

Age-hardening aluminium-base alloys of the duralumin type, on the other hand, possess a satisfactory hardness, being soft enough in the annealed condition to simplify the introduction of the abrasive material by mechanical pressing, if required, and of sufficient hardness in the hardened condition to possess satisfactory life. The abrasive grains are securely embedded in the hardened alloys, and materials of this type have already been used satisfactorily for the production of diamond impregnating, grinding, polishing and lapping wheels and arbors. After such wheels have been prepared with the diamond dust, they are solution treated and finally precipitation hardened at 500 degrees C., a temperature at which the diamond does not oxidize, even in the finely divided form. Anodizing is said to improve the wheels.

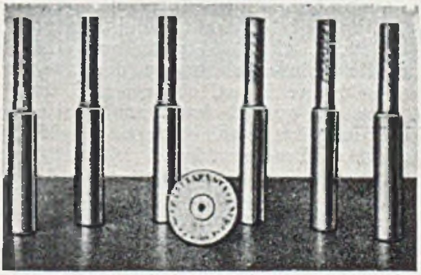


Diamond-impregnated wheels for glass working, consisting of diamond dust embedded in a duralumin base, are available in diameters of 1½ to 2 ins. Grinding arbors similarly impregnated in duralumin are also available down to the smallest sizes.

A number of methods have been proposed for the manufacture of these abrasive wheels and arbors. Thus, the Norton Co. have proposed to use a powder mixture consisting of 40 per cent. by volume of aluminium and 60 per cent. by volume silicon as a bonding medium for diamond particles,[7] the wheels being pressed and sintered in such a way that alloying between the aluminium and the silicon takes place to only a limited extent. Alternatively, the abrasive particles may be mixed with molten aluminium-copper or aluminium-zinc alloys which have approximately the same specific gravity when molten as the abrasive particles, and the mixture allowed to solidify. Suitable compositions of alloy are aluminium 62 per cent. and copper 38 per cent. or aluminium 58 per cent. and zinc 42 per cent.

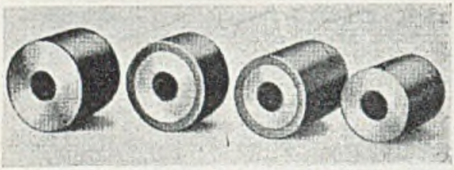


SHOWN above are diamond lapping wheels consisting of a diamond-impregnated plastic annulus attached by dovetailing to a machined and polished true-running aluminium hub or disc. At the left is a filing ring available in diameters of 6-10 ins. It is shown dismounted and also mounted on a split aluminium-alloy disc on which it is tightened by means of a conical bush. Below is a group of grinding arbors and a wheel, consisting in every case of a diamond-impregnated duralumin base suitably mounted on a non-impregnated body to economize in diamond dust.



U.S. patent 2,072,051 suggests the use of copper-base alloys for holding the abrasive, one such alloy consisting of 85 per cent. copper and 15 per cent. aluminium. Such an alloy has a melting point in the region of 1,000 degrees C. and is relatively tough.

The active part of the wheel in this case consists of an annulus mounted on a massive aluminium hub, to which it is fixed by means of silver solder. Two other ideas make use of a combination of metal and synthetic resin. Thus, in U.S. patent 2,150,086, assigned to the Norton Co., the proposed matrix consists of aluminium powder bonded with synthetic resin, the grinding face of the wheel consisting of diamond dust bonded also with a synthetic resin. In manufacture, the composite is moulded in one operation. The composition of the disc is such that it contains not more than 25 per cent. by volume of synthetic resin, and hence, owing to its high metallic content, retains excellent heat conductivity. Because of the lightness of a moulding of this type, any vibration in use due to unbalanced loading is reduced to a minimum, thus making for accurate grinding. It is pointed out in the patent that the use of aluminium in this connection results in a decreased cost since the bulk density of the aluminium is low. In practice, 70 parts by volume of 100 mesh aluminium powder are blended with 14.8 parts by volume of phenolic resin moulding powder, the compact being pressed at 160 degrees C. for 5 to 25 mins. A special characteristic of wheels made according to this principle is said to be that the bodies expand and contract during heating and cooling without separation of the rim from the wheel or disc centre, and that cracking does not occur in these circumstances. Such wheels are claimed to be especially suitable for internal grinding.



SMALL diamond-impregnated synthetic resin lapping wheels mounted on aluminium alloy hubs.

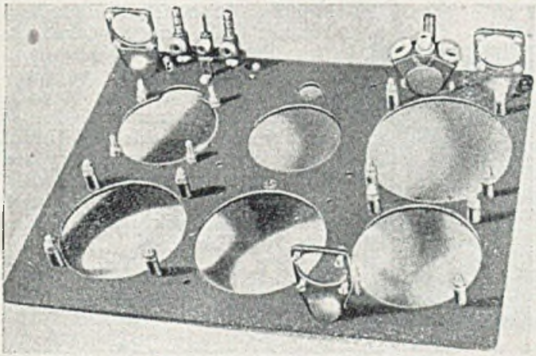
U.S. patent 2,092,591 uses synthetic resin as the essential matrix material in the form of a thin disc faced by thin aluminium sheets, presumably to increase the strength of the disc and to assist in the dissipation of heat from the mass. Thus, in an example, two thin aluminium discs 5 ins. in diameter and 0.013-in. thick were bonded together by means of a synthetic resin adhesive, with which was mixed an abrasive such as aluminium oxide, silicon carbide, diamond or boron carbide. For economy, this might have been confined to the outer zone. The adhesive used was a phenolic resin or other suitable plastic, reinforced, if necessary, by means of cloth, metal foil or metal powder. The wheel was manufactured by pressing at 2 tons per sq. in. for 20 mins. at a temperature of 140 degrees C. Thick wheels may be produced by compounding a number of such metal-faced discs to give the thickness required. An essential requirement for reliable performance is that the expansion of the resin core, the abrasive-filled resin matrix layer and of the aluminium sheets should all be much the same, a requirement which it has been found quite possible to satisfy by suitable choice of standard aluminium alloys, synthetic resins and filling materials.

Gauges and Jigs

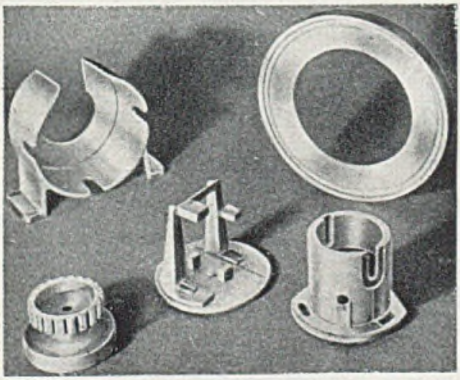
Light alloys are finding increasing application in the construction of gauges and jigs of various kinds. In many cases, the main reason is to reduce the weight of instruments which are handled repeatedly and whose weight would tend to become excessive if constructed in iron or copper-base materials. Large snap gauges for diameters of 8 ins. and over, for example, may prove unpleasant in routine use owing to their weight, as the result of which the operator becomes fatigued and the tendency is for personal errors to be accentuated. In such applications, the use of aluminium and magnesium alloys can be highly advantageous; the instruments weigh less in light than in heavy alloys and they suffer less from corrosion, whilst they are stronger, more resistant to abrasion and largely immune from the evil of distortion and sensitivity to changes in humidity which are inevitably associated with the use of organic materials such as wood and plastics. They possess the disadvantage, however, of sensitivity to temperature changes on account of the relatively high coefficient of thermal expansion of the light alloys, and they must not be held in the hands for long (1 min. has been recommended as the maximum for gauges) as the small mass of metal is conducive to rapid temperature rise due to heat transfer from the hands. This applies particularly to the ultra-light alloys. If, however, light alloys be employed only for the handles of the gauges, this drawback is generally eliminated, leaving the gauges possessed of the advantage of some reduction in weight and of a more sensitive " feel " or " touch " due to the higher heat conductivity and lower heat capacity of the light-alloy handle. Block gauges have been made in this way with handles of magnesium alloy and with measuring faces of steel.

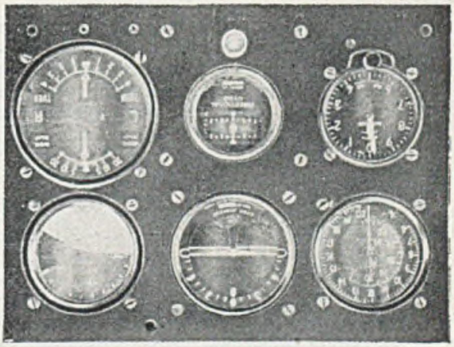
The low weight of light-alloy gauges makes it necessary to issue a note of warning to the operator who may otherwise be liable to cause damage to the instrument.

Thus, returning to snap gauges again, it is usually recommended that, in use, the gauge should fall over the workpiece by its own weight. If, now, the weight of the gauge be reduced by 60 per cent. or more, there appears to be a very real danger of the operator applying some extra force to help the tool on its way. Not only does this produce an inaccuracy in itself but, also, in the case of a gauge consisting largely of magnesium alloy, the low modulus of elasticity of this group of metals as contrasted with steel might result in the gauge becoming damaged. For the handling of precision instruments of this kind and in these special materials, particular recommendations must be put forward as regards the avoidance of unduly rough usage.



ABOVE is a blind-flying panel in duralumin for aircraft with instruments removed. A number of aluminium alloy components may be seen; these are designed for coupling up instruments to venturis, pumps and pressure heads. Below are light-alloy cast components embodied into aircraft instruments of various types. The parts here are concerned mainly with compasses. At the right is a blind-flying panel complete with instruments, all of which embody considerable quantities of light alloys.

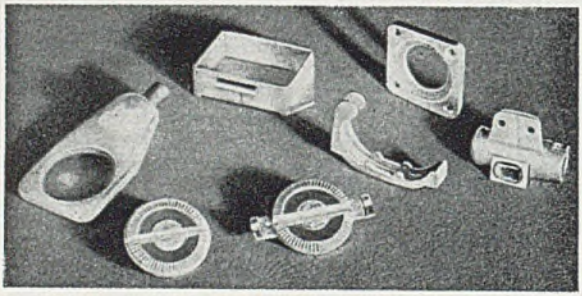




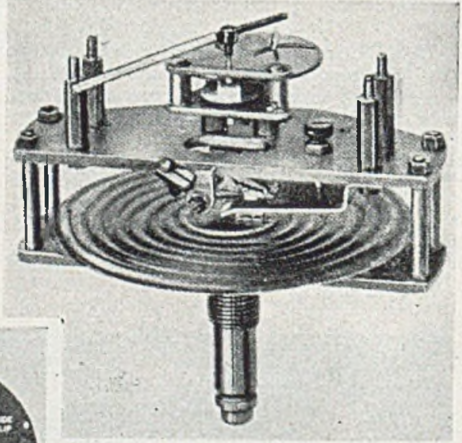
Of especial interest are the matt black finishes of exceptionally low reflectivity which can be produced on aluminium surfaces by processes of anodizing and dyeing. Such processes have been applied to aeroplane propellers for purposes of night flying and similar finishes are being used on aluminium jigs and gauges for close work where it is desired to avoid the eye-strain that may occur where the operator is continually watching fine material such as filament wire.

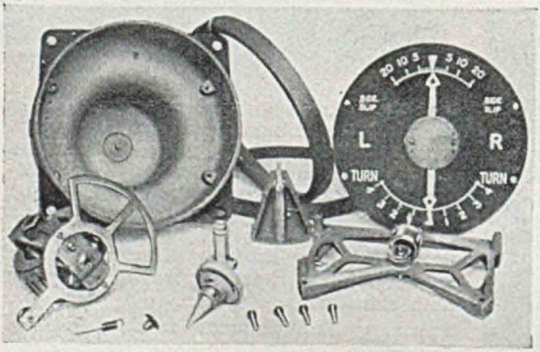
In the case of jigs, much greater application has been made of the light alloys than for the construction of gauges because the advantages detailed above hold to a greater extent for jigs, since the latter are usually heavier structures, whilst the disadvantages are less marked. An additional factor favouring the adoption of light metal is the ease with which the light alloys may be fabricated. It is reported that there was a comparatively extensive use of light-alloy jigs in the U.S. as early as 1911, and certain it is that their use has grown to such an extent that they are now taken for granted in the majority of progressive workshops on both sides of the Atlantic.

Among the pioneers in the use of aluminium jigs must be cited the Computing Scale Co., of Dayton, Ohio, which was employing aluminium jigs for drilling parts of weighing machines before the 1914-1918 war. Mostly, the jigs were produced by casting and it was found that the making of a light-alloy jig represented a considerable saving in time over what had been previously required in making jigs of cast iron. This was due in part to the superior quality of the light-alloy castings, which contained less sand and fewer blow holes, and partly to the superior machining qualities of the metal; in addition, less dulling of the tools was experienced. All holes were lined with hardened bushes and the jigs were provided with hardened steel feet to stand on. Location was by dowel pins and, on account of the reduction in weight due to the use of light alloys, this was achieved more easily and accurately, resulting in a saving in the operator's time and in a substantial reduction in the number of broken drills. As an indication of the weight reduction achieved, it is stated that, whereas a certain jig in cast iron weighed 30 lb., its counterpart in aluminium alloy weighed only 12 lb. Performance was excellent, and, after 10 years, no undue warping or deterioration was observed.



ABOVE is pictured a group of cast light alloy components for compasses, automatic pilots and sights used in aircraft. At the right is shown a capsule incorporated in the Smith air-speed indicator, together with associated components. Below, shown in the dis-assembled condition, is the Reid and Sigrist turn indicator. The small triangular box in the centre is a typical pressure die-cast component.





Tools for the Working of Wood

The " Revue d l'Aluminium " has published a detailed survey of the uses of aluminium and its alloys in wood working which it will be appropriate to summarize here. As in other branches of industry, timber and joinery workshops, whether engaged on new constructional work, on maintenance or on repairs, usually contain a quantity of heavy machinery for which the usual materials of construction are cast iron for the framework, supports and pedestals, steel for the mechanism and bronze for the bearings. Bulk of weight has tended to become associated with rigidity and accuracy, an entirely erroneous conception as has been proved by certain French manufacturers, and, incidentally, by manufacturers in America and elsewhere, in using plant incorporating light alloys in various degrees. Progress in the aluminization of wood-working tools was very live in France just before the war, the goal which designers set themselves being the complete displacement of all unnecessary weight. This did not imply the thoughtless condemnation of all heavy metals but rather the use of the right material in the right place, and it involved an understanding of the advantages and of the limitations of light metals.

This evolution was fostered particularly in France and notably by the Etablissements René Volet, a concern which is noted in

France and in many other countries, for the production of machine tools for the joinery trade, and the Etablissements R.G.A. The latter concern exhibited a number of light-alloy electrically driven woodworking tools at one of the Paris fairs.

The general trend of this evolution was the adoption of aluminium alloys for the bodywork, casing and handles of portable and semi-portable tools, such as drilling, paring and grinding machines, and similar alloys for certain rotating and reciprocating parts of fixed plant. The ultra-light alloys do not appear to have entered into consideration.

Illustrated are a number of applications in which aluminium alloys have actually been employed to advantage in France. The tools and other appliances are as follow:—

1. An internal-combustion engine of a type frequently employed to supply the motive power in a joinery works, made with framework and casing entirely in aluminium. By this means it was found possible to produce medium horse-power motors of exceptionally low weight. Machines of this type are sometimes required where plant is in operation on an upper floor, the loading of which must be kept within low limits, in travelling workshops and on board ship.

2. A light-alloy pulley, low in both deadweight and inertia, reducing vibration and conserving power.

3. Overhead tackle in aluminium alloy. The bodywork of this tackle was cast in Alpax (10-13 per cent. Si) alloy by the Belgian firm, les Usines de Montfiore. A great advantage of lightness in overhead equipment of this type is that it reduces the load on the suspension system which can, accordingly, be made of lighter and cheaper construction—an economy which may exceed the extra cost of the aluminium tackle.

4. Dynamo, with pedestal and casing of aluminium alloy for the same reasons which led to the adoption of light alloys in the internal-combustion engine referred to above.

5. Cone pulleys which, because of their low weight and inertia, reduce vibration and permit more rapid starting and stopping. The following tools were designed by the Etablissements R.G.A. and exhibited at one of the Paris fairs: They were each independently driven by means of an electric motor suspended on overhead runways. The drive was taken to the tool by means of a flexible driving cable, the outer covering of which, incidentally, was of aluminium. In each tool, the greatest possible substitution of light alloy for heavy metal was made to reduce deadweight and to make the equipment as portable and as easy to handle as possible:—

6. Electric drill.
7. Chiselling and countersinking machine.
8. An electric plane.
9. An electric smoothing plane.
10. Polisher.
11. Portable grinder.

Although no details are given, it would appear that the whole of these tools, with the exception of the actual mechanism and cutters, were made in light alloy. Even where hard wood might have been employed as in the handles, aluminium alloy was used for greater strength and longer life. Two types of hand-saw with aluminium handles are illustrated.

In a small tool grinder for bench mounting, which is illustrated, every part, except the abrasive wheel, its axle and the small pinion, was made of aluminium alloy. The large pinion was cast and subsequently machined. It was found to be perfectly satisfactory in use in spite of the softness of the light alloy.

The fret-saw illustrated is a good example of the application of light alloys in non-portable machines. Here there was no point in the use of light alloys in the main framework and pedestal except in those exceptional circumstances which have been instanced above, where deadweight might have to be kept to a minimum. There is, however, considerable point in using light alloys in several of the machine's components. The large work-table was removable and adjustable and it was, therefore, made in light alloy to enable one operator to handle it comfortably. The reciprocating arm carrying the saw blade was made of an aluminium-alloy casting, the advantage of which was a low inertia and consequent increased speed of operation with a given power supply, and a reduced vibration. For similar reasons, light alloys were employed for a number of pulleys fitted in this machine, all connecting rods, guides and slides and the foot-operated control pedal. This machine was capable of handling wood, paper, cardboard, celluloid, horn, ebonite, leather and rubber up to a thickness of 10 cm.

Altogether, it would appear that cabinet-makers and similar workers in France have been served by a progressive group of plant and machinery constructors who appear to have been developing light alloy-containing plant along sound scientific lines.

Portable Metal-working Tools

The advantages of light weight in portable tools are too obvious to need much explanation, and it is the light alloys probably more than any other material which have made possible the production of truly portable tools. A few examples will show the way in which light alloys have been developed for this purpose. Illustrated is a drilling winch of rather large size forming part of the portable equipment of a workman engaged on heavy constructional work. Aluminium alloy was the material of construction chosen by the makers (Messrs. Buhler Bros., Uzwil) in order to reduce the weight of the tool to such an extent that it could be carried by the workman with reasonable ease. All parts of this tool were of aluminium alloy except the lower pivot, which was, naturally, of hardened steel.

The use of aluminium for the motor housing assisted in reducing the weight of a high-speed profile grinder to only 85 lb. This grinder, said to be the first portable machine of its type, was put on the American market by the Boyer-Schultze Corp. early in 1939 to fulfil many requirements in modern tool and die shops. It was built with a reciprocating spindle operating at 20,000 r.p.m. through a table capable of tilting through 5 degrees, this high spindle speed being chosen to enable more rapid working to templates and scribed lines, mating of dies and punches and grinding die clearances. The motor speed was 3,450 r.p.m. and the aluminium housing was not only light in weight but, in addition, it effected a substantial reduction in vibration and noise compared with a steel housing, whilst it markedly assisted in keeping the motor cool by more rapidly dissipating the heat generated.

Illustrated is a handy pneumatic drill which weighs only 24 oz., thanks to its incorporation of aluminium alloys. This "Broomwade" drill has an aluminium-alloy casing. Light alloy is also employed for a cage carrying a robust but minute epicyclic gearing by means of which the speed of the multivane motor, running at 15,000 r.p.m., is reduced to 2,700 r.p.m. for the drill spindle. Although the ball-bearing units are of stainless steel, whilst gears, rotor and shaft are made of nickel-chromium steel, the employment of aluminium alloys has made possible a considerable reduction in weight. Whilst light weight is always welcome in reducing fatigue on the part of the operator and in increasing the speed of operation, it is doubly welcome in tools of this type which are intended for precision working, where fatigue and clumsiness alike may soon lead to error.

Very similar is the "Hand-ee" electric tool which is claimed to be capable of use as a hand-drilling machine, grinder, cutting, carving, polishing and engraving tool. It is 6 ins. long, weighs 12 oz., and is equipped with an aluminium-alloy motor and gear housing enclosed in a plastic case.

Also illustrated is a high-speed drill, the casing and grip of which are made of cast magnesium alloy, and an electric drill of rather different type made by Siemens-Schuckert (G.B.), Ltd., in which ultra-light alloy castings form the main components of the tool.

Illustrated is a group of pressure-die-cast magnesium-alloy static components and moving parts of portable pneumatic or electric hand tools, all of which help to reduce the weight of the finished tool to a convenient level.

Spray guns with a die-cast or pressure-die-cast light or ultra-light alloy body have long been on the market. They are light to handle and no coloured corrosion products are formed by atmospheric corrosion or by reaction with the paint or lacquer to contaminate the coating, neither are the drying properties of the latter affected by the light metal.

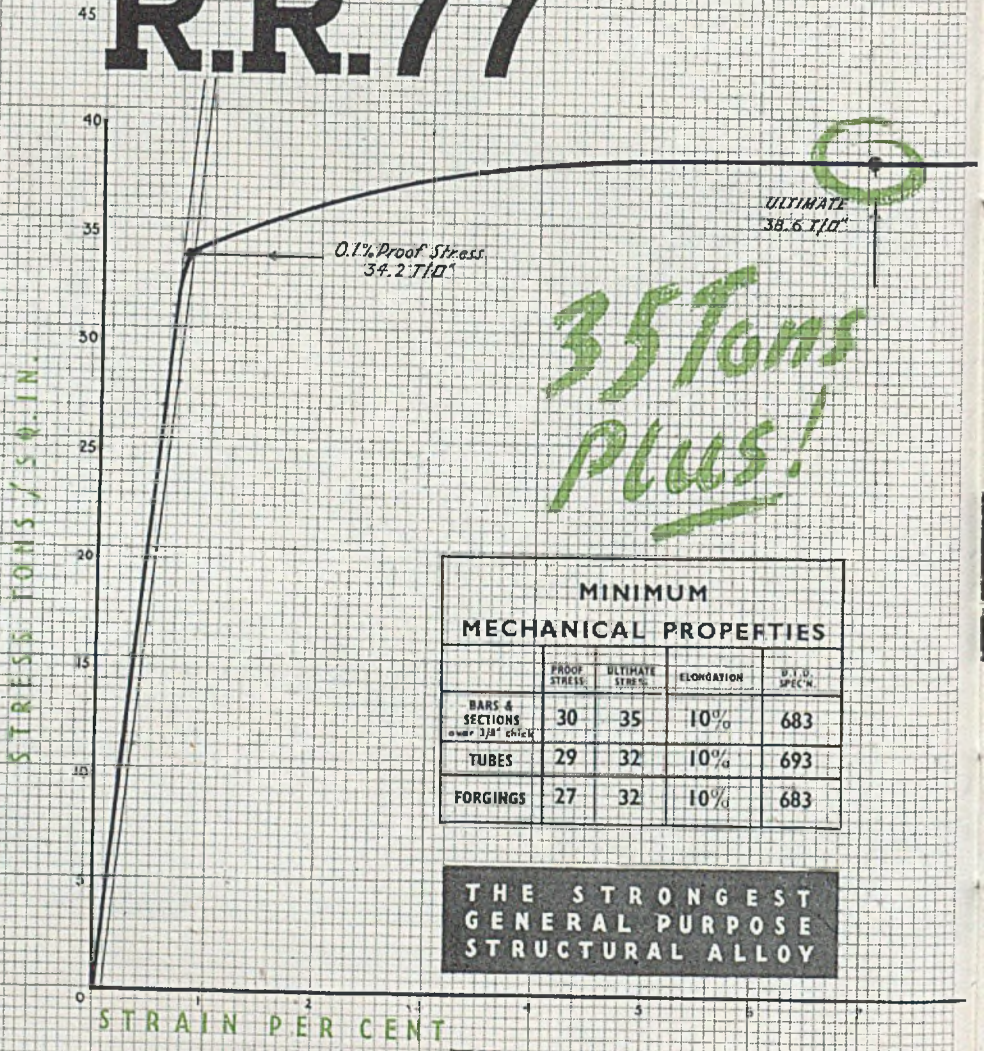
Welding and cutting torches have been provided with handles of a corrosion-resistant light alloy in place of the more massive brass assemblies at one time used. Here, the replacement of brass by aluminium can effect a decrease in deadweight of 30 to 40 per cent. The grip is of seamless construction and, therefore, cannot leak, whilst its shape is carefully adapted to the hand, thus still further reducing the opportunity for fatigue when the tool is in continuous use. The illustration of the Griesheim products demonstrates how a standard design of torch has been evolved in order to facilitate interchangeability of several types of welding and cutting nozzle. The convenient positioning of the valve for the acetylene supply should be noted. A range of welding torches with aluminium bodies manufactured by the Continental-Licht-und Apparatebau-Gesellschaft, Dubendorf, is also illustrated.

Most of the development work on light-metal welding torches appears to have been carried out on the Continent. Construction has not been limited to cast aluminium; welding torch bodies have been forged in Anticorodal, whilst die-cast magnesium-base alloys have been successfully employed for the same purpose.

In U.S.A. the "Aluminium News Letter" of March, 1937, noted the introduction to the American market of a light-weight, aluminium-bodied welding torch weighing only 17 oz. Details, however, do not appear to have been given.

A hand-lapping tool used for the stoning of sintered carbide-tipped tools as employed in automatic screws and other machines, has been provided with a small light-metal handle, suitably formed to provide a good grip. The active part of the tool consists of a phenolic-resin-moulding impregnated with diamond dust. The use of light metal in the assembly in this case enabled the mass of the abrasive-bearing unit to be reduced.

(To be continued.)



MINIMUM MECHANICAL PROPERTIES

	PROOF STRESS	ULTIMATE STRESS	ELONGATION	D.T.D. SPEC'N.
BARS & SECTIONS over 3/8" thick	30	35	10%	683
TUBES	29	32	10%	693
FORGINGS	27	32	10%	683

NEWS—General, Technical and Commercial

ISSUED in France in 1942, during the period of German occupation, this 50-centime piece in aluminium-base alloy is one of a number of coins struck at the time in light metal. Its actual diameter is 0.7 in. (see also "Light Metals," 1941/4/94: 248).

Metals in Housing

ON Thursday, March 8, at a meeting of the London Local Section of the Institute of Metals, G. H. Friese-Greene read a provocative paper on the subject of "Metals in Housing." Emphasis was laid upon the need for the correct correlation of all available structural materials, metallic and non-metallic, and considerable interest was stimulated in the subsequent discussion as to the precise definition of the expression "personality of a metal," which was introduced by the speaker.

Mr. Friese-Greene drew attention to many weaknesses in the current outlook on design and production of metal components for houses; in particular, he deplored the uncontrolled use of excessively thin-gauge sheet. Comments on prototype houses exhibited by M.A.P. and M.O.W. on the Tate Gallery site were received with interest. The parts to be played by aluminium and magnesium in buildings of the future were briefly analysed and the architect's attitude to new materials summarized.

Society of Instrument Technology

MEETING of the Society of Instrument Technology will be held at the London School of Tropical Medicine, Keppel Street, London, W.C.1, on Saturday, April 21, 1945. The morning session will commence at 11 o'clock and the afternoon session at 2.30 p.m.

The president, Sir G. P. Thomson, M.A., F.R.S., will be in the chair, and three papers will be read and discussed. Any non-members of the Society who wish to attend should apply to the Hon. Secretary, Mr. L. B. Lambert, 55, Tudor Gardens, London, W.3.

Air-strip Landing Mats

FLEXIBLE steel landing mats for quick surfacing of air strips and air fields in combat areas were developed early in the war by the U.S. Corps of Engineers in co-operation with certain large manufacturers of steel mats for civilian industrial and other purposes. There proved, however, to be many areas where such surfacing mats were needed quickly and had to be flown in on air transports. The steel articles were too heavy for this service, so aluminium mats were developed; these are described by the U.S. War Department as similar in design to the steel pierced-plank type. Each mat is about 10 ft. long by 15 ft. wide, with strength comparable to the steel. But the weight for each 10-ft. by 15-ft. panel is 31.8 lb., compared with 63.9 lb. for the steel.

Mats are fabricated from aluminium sheets that are 3/16 in. thick. Two 3/4-in. parallel ribs are formed in the long section of the panel to add rigidity. Three rows of two 1/16-in. holes are punched on 4-in. centres with their flanges tubulated to add additional strength and reduce weight. Individual panels are connected by interlocking bayonets and perforations along the edges of the plank.

Mats are bundled for shipment in six sub-bundles of five planks each, which form a master bundle of 29 10-ft. planks and two 5-ft. planks. The master bundle for air shipment, together with the clips, weighs about 1,000 lb., compared with 2,000 lb. for steel mats bundled in the same way. In actual use, the War Department says that aluminium mats have been laid at about 250 sq. ft. per man-hour, compared with 150 sq. ft. per man-hour for the steel mat. The weight advantage of the aluminium mats in actual transport by air is demonstrated in the following comparison by the War Department. The weight of a runway of 150 ft. by 5,000 ft. is 975 tons for the aluminium mats and 1,928 tons for the steel. This means 163 air transport loads for aluminium and 322 similar loads for steel. The aluminium has been flown frequently in Africa and the South Pacific and China.

Light-alloy Freight Car

ALTHOUGH the U.S. is emerging from the war with a capacity for aluminium production that is three times pre-war, prospects are opening up steadily for real tonnage consumption. Aluminium railroad passenger coaches are an old story now, but the aluminium freight car is less common, even in the U.S. Just recently, the first experimental boxcar of this type was completed. Companies contributing to its fabrication to designs of the Great Northern Railway included Youngstown Steel Door Co., Standard Railway Equipment Mfg. Co., Morton Mfg. Co. and American Steel Foundry Co.

Purpose of the car is to use it in high-speed express service attached to passenger trains of the streamline variety. Aluminium in the car is *Alcoa* and weighs 3,722 lb. Use of aluminium saves 4,057 lb. in weight, according to the Aluminum Co. of America. Aluminium use includes outside sheathing, roof, corrugated ends, doors, floor protective doorway plates, " W " corner posts, running boards, brake step and many minor parts. Aluminium alloy rivets were used in fabricating the roof, ends, side sheets and doors.

Another item of railway equipment into which aluminium has been introduced in the U.S. is the railroad inspection car. Fairmont Railway Motors, Inc., Fairmont, Minn., has brought out an inspection car, motor-driven, a large number of parts of which are of aluminium. It reduces weight by almost 100 lb. and makes it easier to remove the inspection cars from the rails when necessary.

Aluminium Alloys for Castings

" WHILST we would agree with Mr. Carrington ('Light Metals,' March, 1945, p. 103-110) in the need for an aluminium casting alloy having a high degree of ductility with medium-high tensile strength, we do, however, consider his reference to the elongation of D.T.D.298 alloy to be an understatement. To quote: 'with D.T.D.298 11 per cent. is often obtained.' We have examined the mechanical test results obtained in recent routine production in this foundry and find that the average elongation shown by separately cast test-bars is 16.4 per cent. the lowest being 14 per cent., and the maximum 21 per cent.

" In the case of D.T.D.300, although a minimum value for elongation of 7 per cent. is specified, results considerably in excess of this are obtained in normal production; for example, analysis of our routine production reveals an average elongation of 14.7 per cent. with a minimum value of 11 per cent. and a maximum value of 21 per cent.

" Reference is made later in the same paper to the use of aluminium alloy dies for die casting. To quote: 'and as they have the same thermal expansion as the casting, the danger of cracking is practically eliminated.' This is claimed ' to be one of the biggest steps forward in the industry for some time.' The former statement is, of course, fallacious. From consideration of die casting practice it is obvious that the thermal expansion of the die material is almost a negligible factor in determining the constraint to the contraction of the casting in the die, providing the thermal conductivity of the die material is of a relatively high order; this, of course, is true in the case of an aluminium alloy die."—For Kent Alloys, Ltd., F. N. Smith, Chief Metallurgist.

Contributions to " Light Metals "

TO facilitate the editing of copy, and to guard against the occurrence of needless errors, we would ask those forwarding papers for proposed inclusion in our editorial pages to be so good as to observe the following points:—

(1) As far as possible, all copy should be typed with double spacing on one side of the page only.

(2) All illustrations should be numbered consecutively thus:—" Fig. 1, Fig. 2. . . ." This applies both to line drawings and half-tones, between which we do not distinguish for this purpose.

(3) Tables should be numbered consecutively thus:—" Table 1, Table 2 . . ."

(4) References should, as far as possible, be given in the form " year/volume/page," thus:—" 'Light Metals,' 1941/4/29." Only in the case of those journals where each issue is separately paginated is the issue number and/or month of issue necessary. In the case of Russian and Japanese journals it is advisable, however, to detail references as completely as possible, as irregularities have frequently been found.

We would point out that readers wishing to examine the originals referred to in the bibliographies, etc., in this journal should, before taking further steps, inquire at the appropriate departments at the Patent Office and the Science Library (both in London), where, in most cases, they will be found, and from which institutions photostat copies may, if necessary, be obtained.

Staff and Managerial Changes

WE have been informed by the Dowson and Mason Gas Plant Co., Ltd., Alma Works, Levenshulme, Manchester, that L. G. A. Leonard, late assistant general manager of British Furnaces, Ltd., of Chesterfield, has been appointed general manager of Dowson and Mason Gas Plant Co., Ltd., as from March 1, 1945, in succession to James Paton, who is retiring, but will, however, retain his seat on the board of directors.

Specialloid, Ltd., North Finchley, London, announce that it has taken new premises for the establishment of a central London office and warehouse at 140-142, Great Portland Street, W.1. This depot will cover sales and service to the Home Counties and London. A. W. Roebuck, Ltd., has been appointed main concessionaire of Specialloid pistons for the London area.

Under the title of New Metals and Chemicals, Ltd., Broad Street Avenue, London, E.C.2, a new company has recently been formed to deal in the rarer metals and their alloys, compounds and ores. The company is interested in a number of new industrial applications for these materials, and has modern research facilities in London, North of England and in Scotland.

The directors of Edgar Allen and Co., Ltd., announce that they have elected William H. Higginbotham as chairman of the board of directors of the company in succession to the late C. K. Everitt, who died recently. W. H. Higginbotham has been associated with the company since 1930 and became a director in 1933.

Birmingham Electric Furnaces, Ltd., of Tyburn Road, Erdington, Birmingham, inform us that the company has decided to change its name to Birlec, Ltd. The trade mark "Birlec" has been established for many years, and the company feels that it is already more widely known by this shortened title. The policy, management and personnel of the company (which is a subsidiary of the Mond Nickel Co.) will not be in any way affected by the change. Birlec, Ltd., has pioneered innumerable types of industrial electric heat treatment and electric furnaces in this country.

From Williams and Womersley, Ltd., Wakefield, we have received a copy of a catalogue dealing with machines for the production of metal sections. These have been developed largely for the aircraft industry and for the manufacture of metal airframes, but are likely to find increasing use in the cold forming of mild steel and light-alloy strip. Some of the machines embody features not hitherto incorporated in any plant of this type. This series of machines make up a complete range suitable for dealing with material from the commercial strip to the finished rolled section.

Founding of Magnesium Alloys

The Principles of Ultra-light Alloy Casting are Summarized and the Need for Assessing Each Individual Case on Its Own Merits is Stressed. (Continued from "Light Metals" 1945/8/124)

MOULDING cannot be taught in a single article; neither can die design nor die sinking. The methods of moulding and die sinking are largely the same, regardless of the metal in which the casting is to be produced. This is not to say that individual metals and alloys having their own peculiarities, due to ease of oxidation and lack of fluidity, for example, do not require modifications to the broad methods to allow for these differences.

In this article, therefore, it is proposed to deal with the details relating to the specific material, magnesium alloy, in mould planning, whether of sand or die. Even with this limitation of scope, the subject is not easy, for what is suggested here as being a necessity for successful magnesium-alloy casting will, no doubt, be contradicted, in practice, in the first foundry the reader enters. The most that can be done is to provide reasonable guidance; experience will show whether every precaution need be taken in every job.

It may be suggested that the golden rule for beginners is "Play for safety and observe all the precautions!" Experience will show where individual safeguards may be ignored.

The requirements for moulds and dies must be based upon the chemical and physical properties of molten magnesium-alloy that have been discussed in previous articles. It will be remembered that the most undesirable aspect of the molten metal is the ease with which it oxidizes, for, as distinct from aluminium alloys, the oxide film is not protective and, therefore, the formation of oxide is progressive. The prevention of oxide formation by various methods is the basis of a large part of the peculiar molten-magnesium technology. We are not concerned here with the prevention of oxide on the molten metal supply; attention must be focused on the prevention of the oxide, formed during pouring and running, from entering the mould. Three methods are used to effect this, and they may be described as chemical, physical and mechanical.

Chemical methods are used during pouring and, of course, during actual running because of contact with the inhibited sand. The metal stream in its passage from the pot to the mould is protected by means of sulphur dust shaken from a bag. In some foundries a more complex powder containing fluorides and boric acid is used. The use of the dusting powder, as it is commonly called, is said to provide more permanent protection of the metal stream. Neither material completely prevents oxide, but actually assists in the formation of an oxide tube through which the molten metal flows. The type of film formed is of remarkable permanence, and does not continuously break down, as might be expected.

There is, then, effective control of oxidation during pouring by the method described, but, nevertheless, the tube of oxide, effective as it is, must obviously be prevented from entering the mould cavity. Any oxide produced within the running system must also be prevented from entering the mould, and, therefore, the method adopted takes care of what might be described as both externally and internally formed films.

The general rule is that the metal stream from the downright must not enter the mould directly. The entry from the runner is taken off at an angle against the direction of the metal flow, and this simple method is usually sufficient to give a physical separation of the oxide from the metal. In those cases where the casting is of thin section and, therefore, the presence of even small oxide discontinuities is serious, extreme means of prevention of oxide inclusion must be taken. A method often adopted is that of the well-known whirl gate, frequently applied in non-ferrous foundry work. On the face of it, it appears senseless to apply such a method, which aims at producing a quick rotating motion, to such an easily oxidizable material as magnesium-alloy, but, as is often the case, a successful result arises from what appears to be unsound theoretically. The methods described above are, of course, only applicable to sand casting, but the knowledge of them is useful in considering design of die running systems.

The other method of oxide separation is one we have termed mechanical, and this is applicable to dies as well as sand moulds. A filtering medium such as steel wool, or perforated sheet, is placed in the running channel guide close to the gate and, again, although it would appear that producing a multiplicity of metal streams would only lead to further oxide production, in practice these methods are often extremely successful.

The mechanism of protective tube formation on the poured metal has been described, and now the other details of avoiding formation of oxide within the running system must be considered in further detail. In most foundries downrights of rectangular cross section are used both in sand and die, to avoid the production of vortex. On consideration, it will be seen that this is not illogical, even although a whirl gate, which aims at producing a whirl, has been described. In the case of sand casting a further precaution can be taken; the use of a stepped running cup can be applied so that the downrights it feeds are always maintained full of metal. The same conditions must be obtained in die runners by design of the runner acting with the maintenance of the proper pouring speed.

Another method applicable to sand and die alike is the slit gate which extends the complete length of a mould cavity of fairly regular cross section, for example, as in a cylindrical mould. In this method the hottest metal continuously flows on top of the metal already present in the cavity and, as the slit gate extends farther to join up with the risers, at the conclusion of the pouring the hottest metal flows into the risers, giving the temperature gradient from bottom to top of the casting which is so essential to produce sound castings. The slit gate can be recommended whenever it can be applied; some expenditure of ingenuity is worth while in attempting to apply the method even where its application is not obvious.

Although the mechanical method of filtration has been described, it is, in fact, difficult to see why it should be necessary if other precautions be taken. It may be noticed that filtration is required more often on castings of such type that a long metal fall in the downright is unavoidable.

In order to achieve peaceful, non-turbulent filling of the mould, bottom pouring is often recommended, but even this apparently very sensible recommendation is ignored in practice. The chief consideration, whatever method of gating is adopted, is that oxide-free metal shall enter the mould quietly.

(To be continued.)

PRESSURE DIE CASTING

Some Observations on the Effect Exerted by Air Trapped in the Die Cavity on the Physical Properties of Certain Die-casting Alloys and on Their Heat Treatability. The Author Describes Particularly the Design of a Special Die Constructed to Investigate the Effects

By
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M.Inst. Met. Formerly Chief Metallurgist,
Western Die Casting Company.

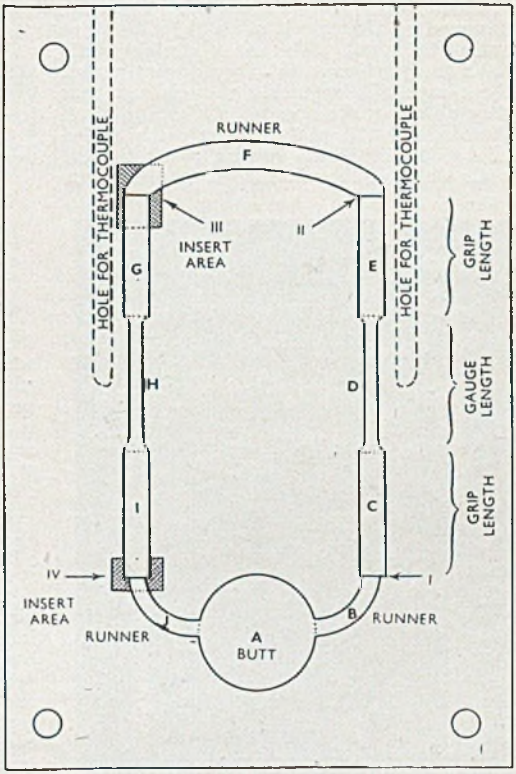


Fig. 1.—Specifications for special test bar die used throughout the experiment.

THIS paper presents the results of an experimental investigation designed and executed to determine specifically the effect which trapped air (necessarily confined within the die cavity of the steel die moulds used in the manufacture of pressure die castings) has upon the solidification of the molten metal which is forced into the die cavity under high pressure ($>$ 20,000 p.s.i.), and also the effect of such trapped air upon the metal's strength and ductility properties in the final cast state.

It needs to be mentioned at this point, before proceeding to give the results of the experiment, that since the very inception of the technique of pressure die casting, those companies engaged in the manufacture of pressure die castings have recognized the fact that trapped air gives rise to porosity in certain circumstances. This porosity is indirectly responsible for: (1) the almost universal opinion of engineers that pressure die castings are inferior to sand and gravity die castings as regards uniformity of tensile and fatigue strength properties; (2) the inability of manufacturers to heat treat pressure die castings successfully; and (3) high rejection rates in cases where the pressure die castings must be absolutely radiographically sound.

Manufacturers have attempted, by the employment of various techniques, to manufacture porosity-free pressure die castings for over 30 years. The three most common

ACKNOWLEDGMENTS

The author is indebted to Professor Ralph Hultgren, of the University of California, Berkeley, California, for his criticism of the manuscript; to the management of the Western Die Casting Company, in particular Mr. C. C. Voglesong, President; to L. Crawford for preparation of all photomicrographs; to A. J. Hales for testing all the samples; and to Agnes Erickson for preparing the manuscript.

techniques employed currently are: (1) the employment of heavy and abundant straight vents. Vents are passages which are cut into the steel die faces of the die blocks to facilitate rapid escape of the air which is confined inside the die cavity. They are designed so that air is allowed to flow out and metal is not. The use of straight vents has two drawbacks: (a) they do not permit the escape of air quickly enough and thus they do not make possible the escape of all the air, and (b) they are too easily sealed off by molten metal flowing along the die walls ahead of the main metal masses before the interior of the cavity fills with metal where there is yet air. (2) A second technique which is employed in an effort to produce porosity-free pressure die castings is to employ wells or overflows. These are separate cavities cut into the face of the steel die blocks adjacent to the main die cavity. Molten metal is permitted to wash through a flat connecting channel running between the main die cavity and the well-cavity itself. The idea of this device is sound. Wells do act as reservoirs for the compressed air, i.e., the metal forces the air into these extra cavities. In many instances the wells serve as efficient air traps, however these extra cavities take up space on the die surface, thus increasing the need for greater locking pressure and, further, time is needed to machine these cavities into the die face. Castings made from a die which contains overflows have as part of their shape these overflows as added appendages which raise the cost of machining as these appendages must be removed before the castings are usable. (3) The third technique advocated for producing pore-free castings is to force the molten metal into the die cavity by means of a pressure great enough to compress and disperse the trapped air within the metal. Manufacturers of high-pressure die-casting machines advertise that high pressures will produce pore-free castings—not gas-free castings.

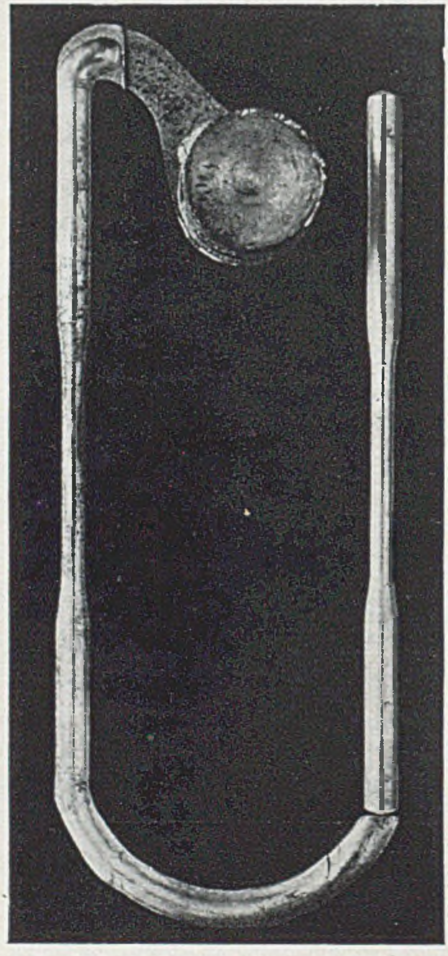


Fig. 2.—Double bar cast in the special die shown in Fig. 1. Note the arrangement of the two parallel test bars in relationship to the gate. The metal flows from the butt to test bar, from it through the runner, afterwards passing through and around an arc and entering the second test bar. The casting shown here is in a condition as removed from the die-casting machine.

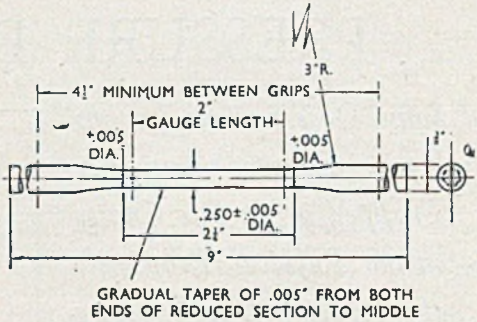


Fig. 3.—From A.S.T.M. Specification E.3/42 covering quarter-inch test bars, dimensions laid down in this specification are adhered to in the test bars produced in the die shown in Fig. 1.

Pressure die castings which are made by each of the individual processes described, exhibit, when heat treated for 10 minutes at a temperature just below the solidus temperature of the alloy, certain defects. Those particular castings which are made by employing only high pressure show, upon their removal from the furnace, defects which render them completely unfit for use. Those castings which were made by the use of only extensive, well-placed, overflows will be the least altered as regards smoothness

GATE SIZES	
Type A	Type B
Circular	
0.100 inch in diameter	0.375 inch in diameter

Fig. 4.—Gate sizes Types A and B for "large gate" and "small gate" as set out in Fig. 5 below.

of surface and dimensional tolerances. Consequently the most suitable method for gas removal is this latter method.

The author has made pressure die castings employing a die which had no overflows or vents and die cast by a machine which developed 45,000 p.s.i. pressure. These pressure die castings were radiographically sound upon first inspection, but after a short-time heat treatment they all developed undesirable surface blisters.

High pressures are essential in the manufacture of any alloy pressure die castings where it is essential that the metal must be forced very quickly into the die before *any* crystallization occurs. This is particularly important when the die cavity is large. High pressures alone do not, on the contrary, make possible heat treatable pressure die castings. This is especially true if the high pressures be employed without the simultaneous use of overflows and vents. Certain alloys and certain types of castings absolutely do require the use of high pressure in conjunction with vents and overflows in order to ensure heat treatableness.

Purpose of the Investigation

Earlier work by the author demonstrated that when air was replaced in the die cavity by certain other gases and the metal was then allowed to fill the cavity in the ordinary fashion, the physical properties of the castings so made were quite different from the properties exhibited by the same metal when simply cast in air as is universally done. Some of the gases which the author used to replace air tended to improve the physical properties of certain alloys, whilst other gases definitely caused the same alloy to lose its desirable properties. Magnesium alloys were improved by sulphur dioxide and carbon dioxide, whilst helium brought about severe damage to the properties of strength and ductility of the same alloys.

The precise cause for the effect of gases on the properties of certain alloys when so die cast has not been explained satisfactorily. The author has postulated that besides such things as the gas ability to ionize or disassociate, to form compounds with the metal, or to dissolve directly in the metal, other facts are important when considering pressure die casting, viz., the extent to which the gas is mechanically mixed with the molten metal prior to solidification and the pressure under which this is carried out.

The fact that other gases besides air do have a pronounced effect upon the physical properties of metals die cast under pressure in their presence indicated that even air

SHOT TYPES

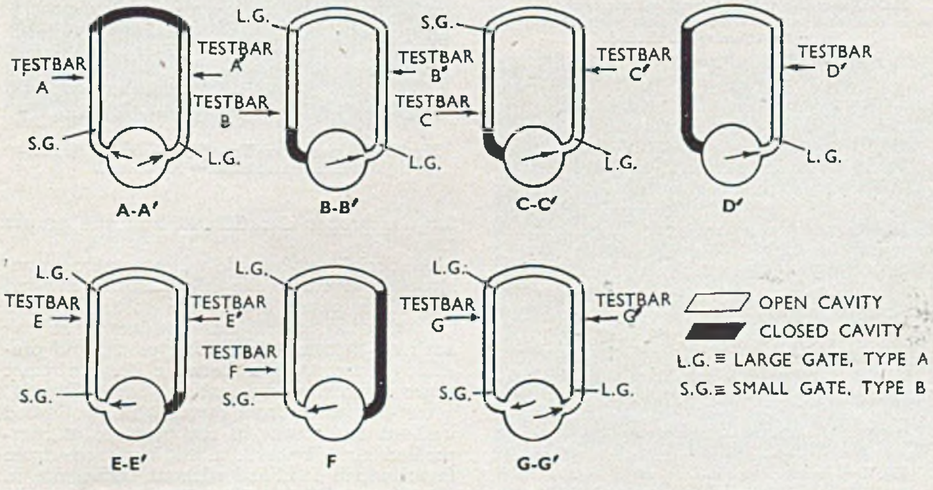


Fig. 5.—Diagrammatic illustration showing production of cast test bars of several different types by alteration of the gate size at points 3 and 4, as shown in Fig. 1.

Fig. 6 (Above).—Modified eutectic silicon-aluminium alloy referred to in this account as alloy No. 47, showing microstructure as received (see Table I). (Equivalent magnification in reproduction = 300 diams.).

Fig. 7.—Unmodified eutectic silicon-aluminium alloy No. 13X, similar in composition to alloy No. 47, showing normal unmodified microstructure in condition as received (equivalent magnification in reproduction = 300 diams.).

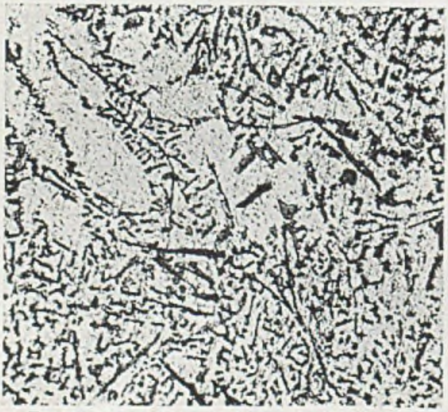


Fig. 8.—Microstructure in ingot form (equivalent magnification in reproduction = 300 diams.) of metal reclaimed from works and referred to in this account as alloy No. 13R. (For composition, see Table I.)

itself is responsible for the particular properties normally exhibited by the commercial pressure die castings.

The most obvious experimental method to study just how ordinary air influences the solidification of molten metals in contact with it under pressure was, of course, to inject the molten metal into an evacuated die cavity. This was done, but with little success because of the inability of the author's equipment to maintain a vacuum for the proper duration and at the proper time.

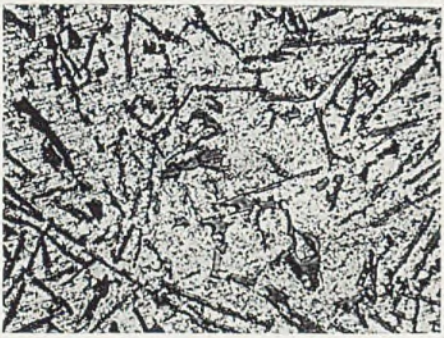


Fig. 9.—Microstructure Type A (equivalent magnification in reproduction = 300 diams.).

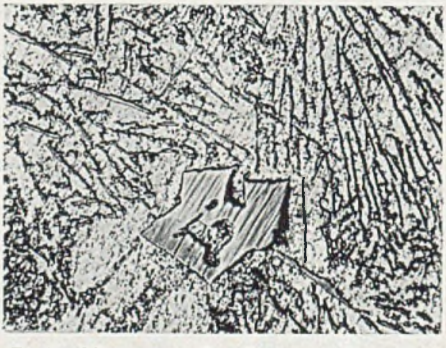


Fig. 10.—Microstructure Type B (equivalent magnification in reproduction = 300 diams.).

A special test-bar die was, therefore, constructed to study the effect of the trapped air. This paper details the results of this investigation which was conducted at the author's pressure-die-casting plant, and presents a comparison between four distinct types of pressure-die-cast test-bars. Type 1, a test-bar made from metal which solidified without turbulence in the presence of compressed air. Type 2, a test-bar made from metal which solidified without turbulence in the absence of air. Type 3, a test-bar made from metal which solidified after much turbulence in the presence of air. Type 4, a test-bar made from metal which solidified after much turbulence in the absence of air.

This comparison was made by simultaneously pressure die casting two test-bars within the same die. The stream of the incoming molten metal was so directed that it entered at one end of the test-bar cavity, passed through it into one end of the second test-bar cavity and continued flowing until it filled the second test-bar die cavity. It was hoped that, as the metal flowed through the first test-bar cavity, it would force the air ahead of it into the second cavity. The air thus compressed into the second test-bar cavity would remain there to mix with the molten metal entering behind it. Thus one test-bar would be made according to the requirements of types 2 and 4 castings, and one according to those of types 1 and 3.

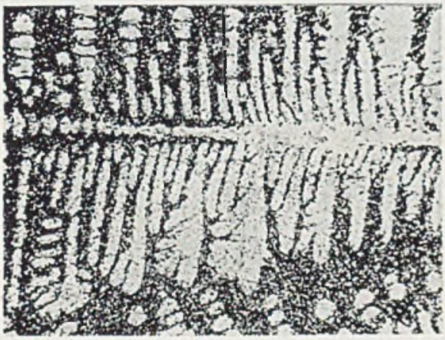


Fig. 11.—Microstructure Type C (equivalent magnification in reproduction = 300 diams.).

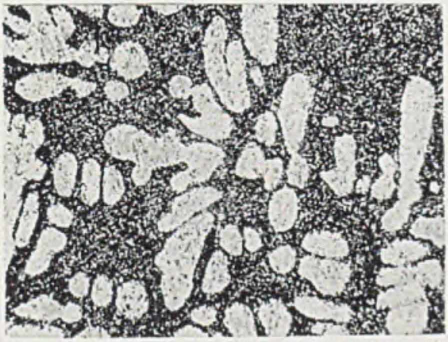


Fig. 12.—Microstructure Type D (equivalent magnification in reproduction = 300 diams.).

Equipment and Procedures

A. *Test-bar Die and Its Design*

The special test-bar die used throughout this experiment was constructed to the specifications illustrated in Fig. 1. An

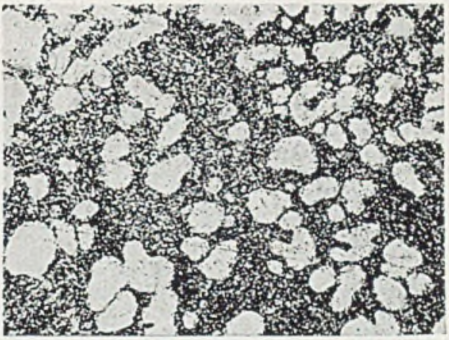


Fig. 13.—Microstructure Type E (equivalent magnification in reproduction = 300 diams.).

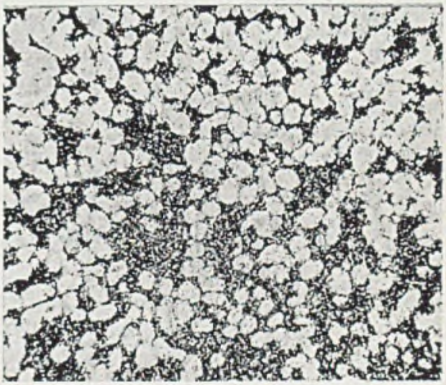


Fig. 14.—Microstructure Type F (equivalent magnification in reproduction = 300 diams.).

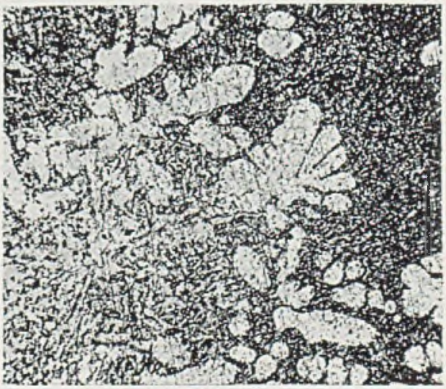


Fig. 15.—Microstructure Type G (equivalent magnification in reproduction = 300 diams.).

Fig. 16 (below).—Microstructure Type H (equivalent magnification in reproduction = 300 diams.). Fig. 17 (right).—Microstructure Type I (equivalent magnification in reproduction = 300 diams.).

illustration of one type of casting produced by this die is shown in Fig. 2. Test-bars produced by this die are in dimensional accordance with the A.S.T.M. Specification E8-42 which covers ¼-in. test-bars (Fig. 3)

The double-test-bar die cavity in a single die afforded a comparison of the influence of certain specific factors without there being a question as to whether certain other factors such as melting technique, duration of metal retention, pouring technique, well temperature, etc., might be responsible for the differences noted in the properties of the two bars. The design employed definitely limits the possible number of factors responsible for the variations observed in the two types of test-bars.

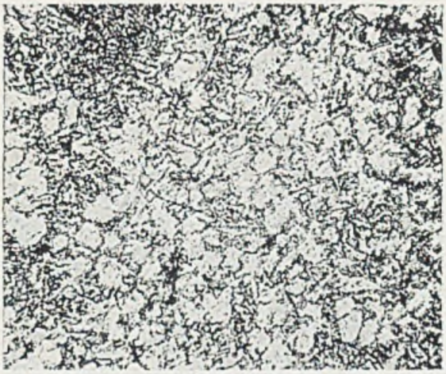
Fig. 18 (above).—Microstructure Type J (equivalent magnification in reproduction = 300 diams.). Fig. 19 (right).—Microstructure Type K (equivalent magnification in reproduction = 300 diams.).

Variable Gate Sizes.—The inserts for the point No. III, Fig. 1, were of two sizes (see Fig. 4). The gate size and shape employed for each is mentioned under the discussions for each separate phase of this experiment. The gate size at the point IV, Fig. 1, was always 0.03 in. by 0.375 in.

B. *Foundry Technique*

1. *Metal Employed.*—Test-bars made in this investigation were cast from several alloys. All of the alloys employed are listed in Table I which gives their respective chemical compositions. Of all the compositions examined, only two were used in obtaining the basic data discussed here; these were: aluminium alloy No. 47 and aluminium alloy No. 13X; both were purchased from the Aluminum Company of America.

The aluminium alloy No. 47 had almost the same composition as the Alloy 13X, being the eutectic silicon-aluminium alloy modified before sale by the Aluminum Company of America, and not used widely for the manufacture of pressure die castings (see Fig. 6 for the microstructure of this alloy as received).



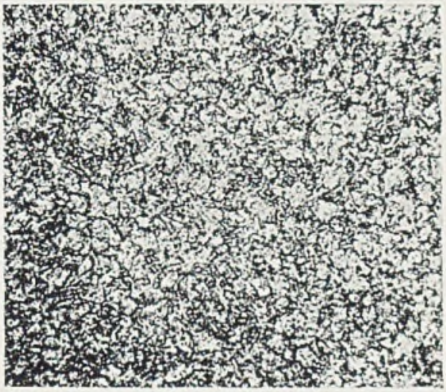


Fig. 20 (left).—Microstructure Type L (equivalent magnification in reproduction = 300 diams.).
Fig. 21 (below).—Microstructure Type M (equivalent magnification in reproduction = 300 diams.).

The aluminium alloy No. 13X is the standard pressure-die-casting alloy used universally to manufacture commercial pressure die castings; this is the normal unmodified eutectic composition (see Fig. 7 for the structure of this as received).

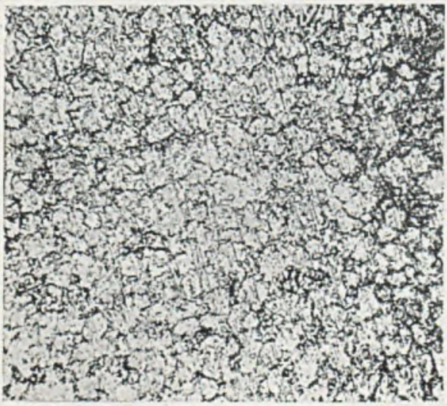
All of the metal used was carefully selected from several possible heats of virgin material and only those particular heats (as received from the Aluminum Company of America) which, when sand cast, produced pinhole-free test-blocks, were employed in this investigation. This was done in an effort to obtain non-gassy metal.

The aluminium alloy No. 13R was a product of the author's plants' metal reclaiming department and was prepared from clean sprues and runners of pressure die castings originally made with virgin aluminium alloy No. 13X (see Fig. 8 for its microstructure in ingot form).

The aluminium alloy 13S was purchased from a reliable refining and smelting company, and was represented to the author as selling as a high quality secondary eutectic silicon-aluminium alloy.

The alloy 13S′ was purchased purposely to try a very inferior secondary eutectic silicon-aluminium composition. Aluminium alloys 218 and 356 were virgin metals.

2. *Melting Technique.*—The metal used for all phases of this investigation was delivered to the holding furnace of the pressure-die-casting machine where it was preheated on the edge of the furnace up to a temperature of 400 degrees F. and maintained at this degree of heat for one-half hour prior to actually melting. It was then placed in a preheated, previously cleaned, silicon-carbide crucible-type holding furnace, where the metal was melted and its



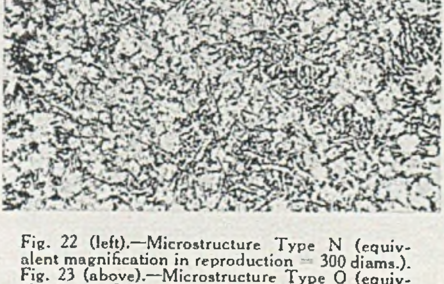
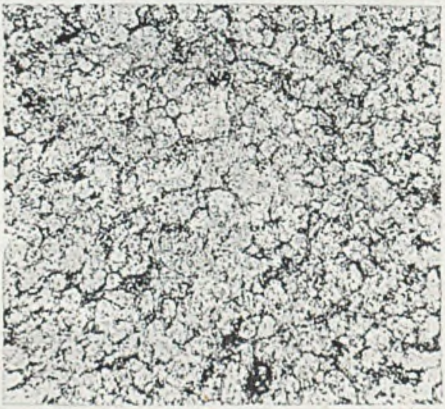


Fig. 22 (left).—Microstructure Type N (equivalent magnification in reproduction = 300 diams.).
Fig. 23 (above).—Microstructure Type O (equivalent magnification in reproduction = 300 diams.).

surface was protected from contact with furnace gases.

The metal was completely melted and its temperature was brought up to the desired point. It was then maintained another 7 mins. at this temperature prior to casting. No melting flux or covering flux was employed. The metal was not agitated or stirred during its retention, and, just before use, its surface was skimmed off with a clean ladle.

The temperature of the metal in the holding furnace was governed by an automatic Foxboro potentiometer which controlled the burners of the furnace. A portable Foxboro potentiometer was used to check periodically the automatic potentiometer. Three separate temperature readings were made prior to casting each series of test-bars and further readings were made throughout the entire procedure.



The particular holding furnace used was especially well insulated, and very similar to all stationary gas-fired aluminium melting furnaces. The automatic fire control maintained the molten metal at the desired temperature ± 5 degrees F.

All metal added to the melt during the casting procedure was preheated and was added in the form of ¼ lb. pieces cut from the standard 5-lb. ingots. All ingot additions were purposely made small in an effort to keep the temperature of the molten metal uniform—a condition found impossible to maintain if the entire 5-lb. ingot itself was introduced cold into the melt. The bath was never stirred, even after the addition of a new ingot, in an effort to avoid all possible turbulence.

C. *Pressure-die-casting Procedure*

1. *The Pressure-die-casting Machine.*—The pressure-die-casting machine used for this experiment is according to an original design of the author's company. It is a cold-chamber, or cold-shot, type plant capable of applying 50,000 lb. p.s.i. pressure on the molten metal once in the die cavity. It has a 1⅛-in. injection piston and develops a stroke speed of from 0.001 sec. to any slower rate desired. This was accomplished by a special valve-speed-control mechanism.

Fig. 24 (left).—Microstructure Type P (equivalent magnification in reproduction = 300 diams.).
Fig. 25 (above).—Microstructure Type 13S metal, edge of bar; gauge length C' test bar (equivalent magnification in reproduction = 300 diams.).
Fig. 26 (below).—Microstructure Type 13S metal, centre of bar; gauge length C test bar (equivalent magnification in reproduction = 300 diams.).

2. *Pressure Applied.*—The pressure applied to the molten metal during and just after injection was controlled by valves on the die-casting machine, and the applied pressure was read directly from a gauge previously calibrated to assure complete accuracy.

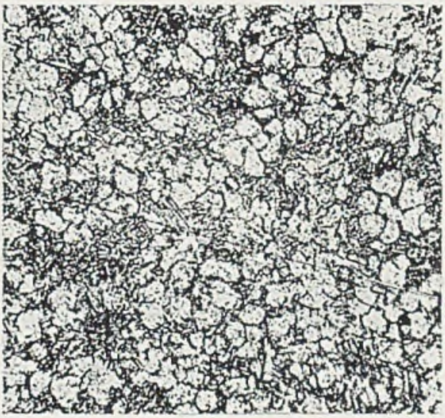


Fig. 27.—Microstructure Type 13S metal, centre of bar; gauge length C test bar (equivalent magnification in reproduction = 300 diams.).

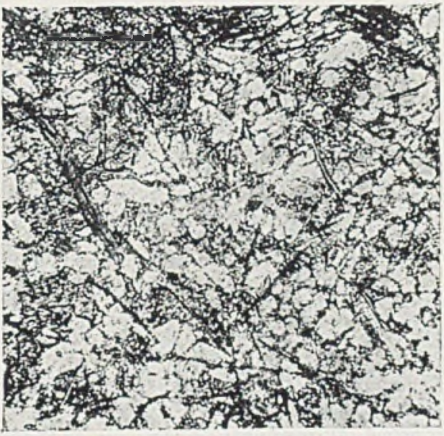


Fig. 29.—Microstructure Type 13S' metal, centre of bar; gauge length C' test bar (equivalent magnification in reproduction = 300 diams.).

The pressure gauge read directly in p.s.i. applied to the molten metal in the die. The pressure was held constant throughout each phase of the experiment at 25,000 p.s.i.

3. *Speed of Plunger Piston.*—The speed of the plunger piston was held constant at one inch per 0.12 sec., and travelled a distance of 8 ins. during each shot. The speed was calibrated and kept uniform from shot to shot by means of photo-electric cells and a General Electric timer control clock.

4. *Speed of Pouring.*—The speed of pouring the metal into the injection well was always very fast. Slow pours were avoided, since they always tend to give rise in the injection well to cold shuts which, when forced into the die cavity, produced a defective casting.

5. *Temperature of Injection Well.*—The temperature of the injection well was maintained throughout all the phases of the investigation at 400 degrees F. ± 20 degrees F. and its temperature checked periodically by means of a built-in thermocouple.

6. *Temperature of Die.*—The temperature of the die was maintained throughout all phases of the experiment at 400 degrees F. ± 10 degrees F. A nitrogen-filled thermometer inserted in a hole K in the die block (see Fig. 1) made possible accurate determination and control of the temperature of the die blocks.

Fig. 28.—Microstructure Type 13S' metal, centre of bar; grip section C' test bar (equivalent magnification in reproduction = 300 diams.).

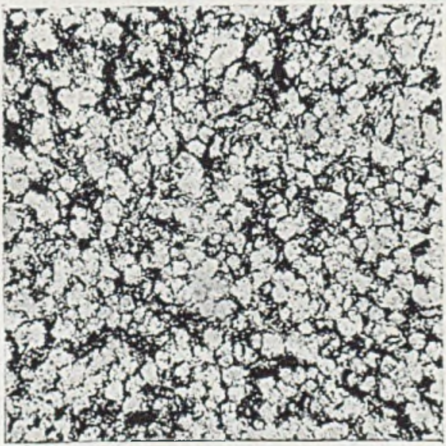


Fig. 30.—Microstructure Type 13S' metal, centre of bar; gauge length C test bar (equivalent magnification in reproduction = 300 diams.).

General Outline of the Experiment

A. *Types of Possible Test-bar Pressure Die Castings*

The test-bar die (see Fig. 1) employed to make the test-bars was capable of producing several types of castings each made in a different way, by simply altering the gate size employed at the points III and IV. This alteration was accomplished by merely replacing the inserts at these points. Each alteration makes possible a different type of casting. These various types of castings are illustrated diagrammatically in Fig. 5 and described here.

Type A′ Test-bar.—Metal enters at point I, large gate (see Fig. 1), and is forced to stop at point II due to the presence of an insert which is placed in the cavity F to obstruct its further flow. Such an internal arrangement in the die produced one test-bar made quite similarly to those made commercially in general practice where there is no escape for the air present in the die cavity as the molten metal fills it. No vents or wells were employed. The only major difference between this type of casting and the commercial type is the *lack of* a definite small gate.

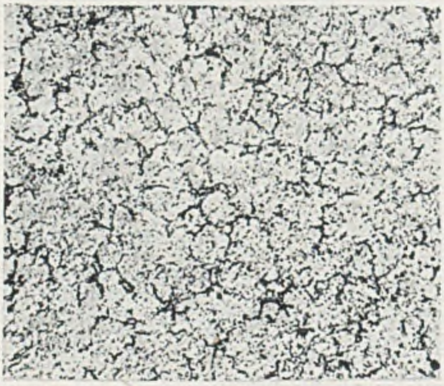


Fig. 31.—Microstructure Type 218 metal, centre of bar; gauge length C′ test bar (equivalent magnification in reproduction = 300 diams.).

Type A Test-bar.—Metal enters at point IV, small gate (see Fig. 1), and is forced to stop at point III due to the presence of an insert in the cavity F, which obstructs its further flow. The type A test-bar thus made is similar to the standard commercial pressure die casting where all of the air is trapped as it is made with a small gate. Type A and type A′ are cast simultaneously.

Type B and B′ Test-bars.—Metal enters at point I, large gate (see Fig. 1), and flows through the cavity CDE and around through the cavity F into GHI without being in any way hindered in its travel. This type of shot, termed the B-B′ type, produces a casting consisting of two separate test-bars, B and B′. The first test-bar, B′, made in cavity CDE, is cast after the main air mass, which fills the cavity CDE before the metal enters, has been compressed into the second test-bar cavity GHI.

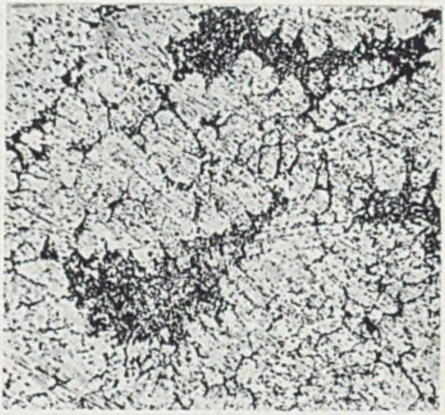


Fig. 32.—Microstructure Type 218 metal, centre of bar; gauge length C test bar (equivalent magnification in reproduction = 300 diams.).

The metal which finally fills the cavity CDE solidifies with much less chance of coming in contact with air than does the metal which finally makes the second test-bar, B, in the cavity GHI, for it, on the other hand, is in direct contact with the confined air during its solidification.

Type C and C′ Test-bars.—Metal enters at point I, large gate (see Fig. 1), and flows through the cavity CDE and around through the cavity F until it reaches the

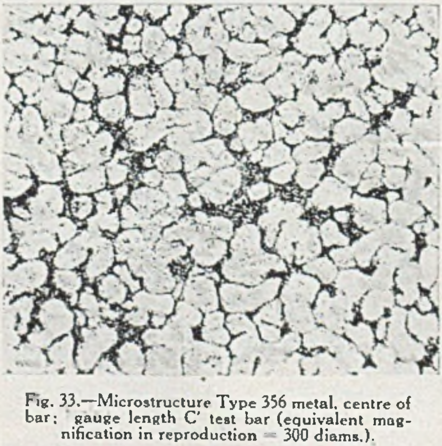


Fig. 33.—Microstructure Type 356 metal, centre of bar; gauge length C′ test bar (equivalent magnification in reproduction = 300 diams.).

Table 1.—Chemical Analysis of Alloys Cast.

Alloy No.	Si	Fe	Cu	Zn	Mg	Mn	Ti	Ni	Na	Al
47	12.97	0.21	0.01	0.005	—	—	0.02	—	0.10	— Remainder —
13x	12.89	0.32	0.01	0.005	—	0.01	0.02	—	0.002	
13x held	12.88	0.33	0.01	0.001	—	—	0.02	—	0.002	
13R	12.02	0.64	0.01	0.06	0.02	0.01	0.02	—	0.05	
13S	12.25	0.81	0.21	0.11	0.09	0.04	0.09	—	<0.001	
13S'	12.11	0.99	0.31	0.37	0.21	0.07	0.01	—	<0.001	
218	0.06	0.16	0.05	0.05	8.25	—	—	—	—	
356	6.97	0.21	0.01	0.01	0.36	—	—	—	—	

insert at point III, where a small gate is situated. The metal then passes through this gate, at point III, into the cavity GHI, where a C test-bar is cast. The first test-bar, C′, is made in the same manner here as is the B′ test-bar. The C test-bar differs from the B test-bar in that it has a small gate instead of a large one. During the shot the air in the cavity CDE is pushed out and compressed into the cavity GHI by the incoming molten-metal stream. The C test-bar is made while air is in direct contact with the molten metal during its solidification.

Type D′ Test-bar.—Metal enters at point I, large gate (see Fig. 1), and flows through the cavity CDE, after passing through the cavity F, until it reaches point III, where it is stopped, due to the presence of an insert placed in the cavity GHI to prevent further flow. In this case the incoming metal compresses the air into the cavity F. The amount of metal flowing through the cavity CDE before solidification sets in is less than if point III were not blocked and the cavity GHI were opened to permit continued flow.

Type E and E′ Test-bars.—Metal enters at point IV, small gate (Fig. 1), and passes through the cavity GHI and through point III, a large opening, into the cavity F, and finally into the cavity CDE, where it is stopped at point I from further flow. Two test-bars are produced, E and E′. The E test-bar is made in the absence of air and using a small gate; the E′ test-bar is made by molten metal, which has only passed through the small gate at IV and thence around through the cavities GHI and F into its final resting place, the cavity CDE, without further obstruction, where it solidifies with compressed air present.

Type F Test-bar.—Metal enters at point IV, small gate (see Fig. 1), and flows through the cavity GHI until it reaches point II, after passing through the cavity F, where it is stopped, due to the presence of an insert in the cavity CDE, which prevents further flow. In this type of shot the incoming metal compresses the air into the cavity F. The amount of metal passing through the cavity GHI before solidification takes place is less than if point II were not closed, i.e., if the cavity CDE were to be filled.

Type G and G′ Test-bars.—Metal enters point I, large gate (see Fig. 1), and point IV, small gate, simultaneously. The entire die cavity is permitted to fill from both gates at once. (Test shots showed that the metal flowed in through gate I so fast that the cavity CDEF was filled solid before the section IH was only partially filled.) The two test-bars made in this manner were the small gated one, G, and the large gated one, G′.

Table 2.

Alloy No. 47. Metal temperature 1,300°F. Pressure applied 25,000 p.s.i.

Type of shot	Type of test-bar	Gate size dia. in inches	Yield strength p.s.i.	Tensile strength p.s.i.	% Elongation in 2 inches	% Radiographically sound
A–A′	A	0.100	22,000*	35,000*	2.5*	70
A–A′	A′	0.375	23,000*	45,000*	3.6*	100
B–B′	B	0.375	26,000*	37,500*	4.0*	60
B–B′	B′	0.375	27,000*	50,500*	6.5*	100
C–C′	C	0.100	24,500*	36,000*	2.5*	50
C–C′	C′	0.375	26,500*	51,000*	5.5*	100
D′	D′	0.375	25,000*	47,000*	5.3*	100
E–E′	E	0.100	25,000*	45,000*	6.0*	80
E–E′	E′	0.375	21,000*	40,000*	3.5*	40
F	F	0.100	24,000*	43,000*	5.5*	60
G–G	G	0.100	20,000*	32,000*	2.0*	30
G–G′	G′	0.375	29,000*	49,500*	6.5*	100

*Ten tensile tests.

B. *Tests Performed on Test-bars*

1. *Radiograph Inspection.*—All test-bars cast, without exception, were submitted to X-ray inspection to determine the degree of internal porosity before any tests were performed. All radiographs were made with 200 kv G.E. equipment in the author's laboratory.

All the test-bars were graded according to the degree of porosity prevalent, and only those test-bars whose gauge lengths and tapering sections were *absolutely free* from even the slightest porosity were used to obtain the data presented in this investigation. All other test-bars were discarded, save a few, which were inspected metallographically.

Noted in Tables 2 to 6 are the ratios of good to bad test-bars out of 20 test-bars each, for each successive phase of the investigation.

2. *Tensile Test.**—Only those test-bars which showed absolutely no porosity or any other defect, shrinkage, crack, or inclusion were tested; and all test-bars manifesting any such defect after testing were discarded.

Table 3.

Alloy No. 13x. Type shot C-C' Pressure applied 25,000 p.s.i.

Type test bar	Metal temperature °F.	Gate size dia. in inches	Yield strength p.s.i.	Tensile strength p.s.i.	% Elongation in 2 inches	% Radiographically sound
C	1,250	0.100	22.000	37,000	3.5	50
C'	1,250	0.375	26,000	46,500	6.5	100
C	1,300	0.100	24,500	39,000	5.0	45
C'	1,300	0.375	26,000	50,000	7.0	100
C	1,350	0.100	21,000	39,500	4.5	45
C'	1,350	0.375	32,000	51,000	8.0	100
C	1,500	0.100	27,500	39,000	4.0	30
C'	1,500	0.375	34,000	53,000	9.5	100

Ten sound test-bars, and only ten, were selected to represent each single phase of this investigation. In a few instances ten test-bars having no porosity were not available due to the large number which had to be discarded after radiographic inspection.

3. *Metallographic Inspection.*—From the ten fractured test-bars representing each separate phase of the investigation, two test-bars were selected for metallographic inspection, one test-bar having the best combination of yield strength, ultimate tensile strength, and ductility, and the other that test-bar having the most inferior combination of properties. These two test-bars were sectioned one in the gauge length and one in each grip section. The sections were then mounted in Bakelite, polished, etched, examined, and the most typical portion of each cross-section photographed.†

4. *Spectrographic Check.*—Twin test-bars (those made during the same shot) which showed the most radical difference of physical properties were spectrographed. No significant difference was discovered.‡

5. *X-ray Diffraction Study.*§—Twin test-bars which showed the most radical difference of physical properties were subjected to X-ray diffraction study. No differences were noted.

6. *Heat Treatment.*—The main aluminium alloy 13X, used throughout this investigation, is not a heat-treatable alloy. No test-bars were heat treated for the purpose of improving their physical properties. Heat treating was merely done to determine the effect of various casting conditions on the formation of surface blisters, internal porosity, and dimensional distortion.

Only those test-bars having a porosity-free structure *throughout* both the gauge length and the grip sections were subjected to heat treatment. After heat treatment the test-bars were (1) subjected to tensile test, (2) radiographed, (3) checked visually and (4) checked dimensionally.

The heat-treating procedure was to heat up groups of the test-bars quickly to a temperature close to the solidus temperature and hold each of the groups there for a different length of time. After this the test-bars were either air-cooled or quenched in cold water.

In Table 6 are presented the results of some tensile tests on heat-treated test-bars made from the aluminium alloy No. 13X.

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* All tensile tests were conducted at the Hersey Inspection Bureau, Oakland, California, on a 50,000-lb. Olsen tensile testing machine certified by the U.S. Navy.

† All of the photographs were taken by Mr. L. Crawford, of the University of California, at Berkeley Metallurgical Laboratories.

‡ Any difference of more than .005 of 1 per cent. between the amount of a given element in one specimen and that of another would have been considered significant. Likewise the presence of an element in one specimen and not in another would have been considered significant.

§ X-ray diffraction pictures were made at the University of California Metallurgical Laboratories under the direction of Professor Ralph Hultgren.

Table 4.

Alloy 13x " held." Type shot C–C'. Pressure applied 25,000 p.s.i.

Test-bar type	Metal temperature, °F.	Gate size, dia. in inches	Yield strength, p.s.i.	Tensile strength, p.s.i.	% Elongation in 2 inches	% Radiographically sound
C'	1,150	0.375	27,000	44,000	3.5	100
C'	1,200	0.375	28,000	45,000	3.8	100
C'	1,250	0.375	31,000	45,000	3.6	100
C'	1,300	0.375	32,500	45,000	3.6	100
C'	1,350	0.375	33,500	46,000	4.2	100
C'*	1,350	0.375	34,000	46,000	4.4	100
C*	1,350	0.100	28,000	40,000	3.2	50

* Die temperature raised from 400°F. to 600°F. for these shots.

Phase I, Table 2, Alloy No. 47

Table 2 gives the results of Phase I, in which the premodified aluminium-silicon eutectic alloy was pressure die cast into the experimental die in the following various ways: Shot types A-A', B-B', C-C', D', E-E', and G-G'.

Shot Type A-A'.—The results of this type of shot showed that gate-size influences the ultimate tension properties of metal which has been forced to solidify under pressure in the presence of confined gases.

The physical properties of both the A and A' test-bars were inferior to test-bars cast similarly, i.e., with the same size gates only cast in the absence of air, namely E and C' test-bars respectively. This conspicuous difference in properties indicates that when a metal is forced into a sealed cavity containing air, the air itself *does* influence the properties of the metal in the cast state.

Also shown is that the size of the gate influences the magnitude of the internal porosity formed within the test-bars. The small gated A test-bars exhibited sufficient porosity in the gauge length to have them rejected at the rate of three out of ten, whilst the A' test-bars evidenced no rejectionable porosity in the same area; ten out of ten were satisfactory.

The microstructure of the A' test-bars examined was modified throughout. The A test-bars exhibited a semi-modified structure in the gauge length and grip section nearest the gate.

Shot Type B-B'.—The results of this type of shot showed that when the air is forced out of one cavity, CDE, into the other cavity, GHI, the test-bars B' made in cavity GHI, in the absence of air, are far superior to the test-bars B made in the air's presence. Test-bar B is comparable to test-bar A'; both were made with large gates, minimum turbulence, and from metal which solidified in the presence of confined air. The B test-bar's properties are inferior to those of the A' test-bars because of the greater volume of air present within the cavity GHI when it was cast (the air in cavity CDE plus cavity F plus cavity GHI).

The B' test-bars were 100 per cent. porosity free, whilst only 60 per cent. of the B test-bars had no porosity within the gauge length.

The microstructure of the B' test-bars examined was completely modified within their gauge length; the microstructure of the B test-bars was " almost " completely modified (see Fig. 15 for type microstructure found).

Shot Type C-C'.—The results of this type shot showed that the properties manifested by the B test-bars could be considerably decreased by causing the metal entering into

Table 5.

Shot type C–C'. Metal temperature 1,300°F. Pressure applied, 25,000 p.s.i.

Alloy	Test-bar type	Gate size, dia. in inches	Yield strength p.s.i.	Tensile strength p.s.i.	% Elongation in 2 inches	% Radiographically sound
13R	C'	0.375	26,500	44,000	5.0	100
13R	C	0.100	24,000	38,000	3.3	40
13S	C'	0.375	31,000	43,000	3.0	90
13S	C	0.100	26,500	36,000	2.8	40
13S'	C'	0.375	32,500	45,000	3.1	80
13S'	C	0.100	22,000	35,000	3.0	30
218	C'	0.375	25,000	43,000	15.0	100
218	C	0.100	19,500	33,000	7.1	80
356	C'	0.375	25,000	42,500	10.5	100
356	C	0.100	23,000	38,000	7.8	70
356	D'	0.375	25,000	34,000	4.0	100

the cavity GHI from cavity F to pass through a small gate. This additional condition changed the manner in which the cavity GHI filled from that of a uniform moving molten metal front flowing from G to I, to that of a small diameter cylindrical stream of molten metal which filled the cavity GHI from I back to G, producing the C test-bar. The added turbulence to which the molten metal was subjected in the presence of the confined air served pronouncedly to affect the properties of the metal in its final solid state.

Radiographic inspection showed 100 per cent. of the C′ test-bars to be sound; 50 per cent. of the C test-bars. All of the C′ test-bars examined had modified structures in their gauge lengths. All of the C test-bars had unmodified structures.

Table 6.

Alloy No. 13x. Metal temperature 1,300°F. Pressure applied 25,000 p.s.i. Type shot C-C′.

All test-bars radiographically 100% sound prior to heat treatment.

Test-bar type	Heat treated at 525°C.	Gate size dia. in inches	Yield strength p.s.i.	Tensile strength p.s.i.	% Elongation in 2 inches	% Radiographically sound after H.T.
C	0 mins.	0.100	21,000	41,000	4.0	—
C	5 mins.	0.100	17,500	32,000	13.0	0
C	10 mins.	0.100	15,000	26,000	16.5	0
C	60 mins.	0.100	12,500	19,000	21.0	0
C′	0 mins.	0.375	31,000	51,000	8.0	—
C′	5 mins.	0.375	19,500	34,500	15.0	100
C′	10 mins.	0.375	15,000	28,000	19.0	100
C′	60 mins.	0.375	11,500	21,000	23.0	100

Shot Type D′.—The results of this type of shot showed that when a large gate plus a large overflow (cavity F) were employed together and the air was forced into the overflow out of the gauge length, section D, the test-bar D′ manifested properties equal to the C′ test-bars previously described. All of the D′ test-bars cast were radiographically free of porosity and the two D′ test-bars examined micrographically had modified-type structures.

The results of the type shots B-B′, C-C′ and D′ raised the question as to whether the superior qualities of the B′, C′ and D′ test-bars resulted solely from the fact that the metal which composed them solidified in a pre-heated die cavity, i.e., due to a more pronounced temperature gradient between the die wall and the solidifying metal inside the cavity. By way of elaboration on the nature of the temperature gradient let the explanation suffice at this point.

All test-bars of the type B′, C′ and D′ were made by metal which entered the die cavity CDE after a certain volume of molten metal, namely, that which filled the cavity FGHI in the case of the B-B′ and C-C′-type shots and the cavity F in the case of the D′-type shot. This volume of metal flowed through the cavity CDE and, while so doing, it heated the die walls at the expense of losing heat itself (this pre-heating of the cavity CDE did not amount to a great deal, however). As the farthest part of the die filled up new hot metal entered the die. Directly this metal came to rest, there was a definite temperature gradient set up between the die wall and the centre of the test-bar die cavity just filled with metal. The question which arises from an examination of the results of the B-B′-type shot is: Are the properties of the B test-bars inferior to the B′-type test-bars because the temperature gradient in the section H was different from the temperature gradient in the section D by an amount great enough to effect a difference in the microstructure which in turn was responsible for the variation in physical properties? That the microstructure was different was an observed fact. Therefore the question is whether this difference in microstructure resulted from the fact that the metal, just before and during solidification, was mixed with air under pressure, or whether the difference in microstructure resulted from a difference in temperature gradients of the two. Two attempts to answer this question were made and will be described later.

Shot Type E-E′.—The results of this type of shot showed that the size of the gate through which the metal enters the die cavity originally influences the properties of the metal solidifying therein. The reduced gate size (from size B to size A) caused the metal to enter the first die cavity as a cylindrical stream (this was determined by the half-shot method) which flowed forward through the first test-bar cavity without forcing all of the air out of this cavity efficiently. It continued on around through cavity F and began filling up the second test-bar from the opposite end. The result was that the air in the second test-bar cavity was forced out into the F cavity. The second test-bar was therefore made by metal which had been subject to much turbulence and the first test-bar was made from metal which had been subjected to turbulence and yet which had not solidified in the presence of confined air.

Radiographs of all of the E-E′ type shots showed that the region of maximum porosity existed within the cavity F. Metallographic examination showed this to be a region of unmodified structure. Porosity was greater in the E′ test-bars than in the E test-bars by the ratio of 60 per cent. rejects for E′ test-bars, 20 per cent. for the E test-bars. Both the E and E′ test-bars had semi-modified structures within the gauge length; specifically the E test-bars had type H structures and the E′ test-bars had type I structures.

Shot Type F.—The results of this type shot showed that by placing an overflow at the end of a test-bar having a small gate size its properties could be improved. Thus the properties of the F test-bars with a small gate and an overflow (cavity F) were superior to A test-bars made with a small gate and no overflow present. Sixty per cent. of all of the F test-bars cast were radiographically sound within the gauge length.

Shot Type G-G′.—The results of this type shot showed that as the turbulence of the metal in the gauge length section was increased and as the confined air was forced into contact with solidifying metal within the gauge length region itself the physical properties of the test-bar so cast became very inferior. All of the G′ test-bars cast were radiographically sound and only 30 per cent. of the G test-bars passed inspection.

All of the G′ test-bars had a modified type (type E) structure within the gauge length, while the G test-bars examined had completely unmodified type (type P) structures.

Phase II, Table 3, Alloy No. 13X

Table 3 gives the results of Phase II, in which the unmodified aluminium-silicon eutectic alloy, 13X, was pressure die cast into the experimental die by means of shot type C-C′ only.

Table 7.

	Internal porosity	External blisters	Dimensional check
C′ Control ..	None	None	O.K.
C′ 5 mins. ..	None	None	O.K.
C′ 30 mins. ..	None	None	O.K.
C Control ..	None	None	O.K.
C 5 mins. ..	Very mild	Average of 11 blisters	Out of straight
C 30 mins. ..	Abundant	Average of 52 blisters	Completely off

To determine the effect of metal temperature upon the properties of the C and C′ test-bars a series of test-bars were pressure die cast over the range of temperature: 1,250 degrees F. to 1,500 degrees F.

The unmodified alloy was used to cast the test-bars for this phase so that the resultant microstructure manifested by the test-bars could be used to indicate something about the cooling rate of the metal.

The results (collectively for the entire phase) showed that as the casting temperature was increased, the properties of the C′ test-bars improved and the C test-bars were unaffected until the temperature reached 1,500 degrees F., at which temperature their ductility fell off and their yield strength increased. Also as the temperature increased the percentage of C test-bar rejections due to the presence of porosity increased.

All of the C test-bars examined had unmodified structures (Type P) within the gauge lengths and all of the C′ test-bars had modified structures (Types E and F) within the gauge length.

Phase III, Table 4, Alloy No. 13X

Table 4 gives the results of Phase III in which the unmodified aluminium-silicon eutectic alloy was retained in the holding pot for a period of four hours at a tempera-

Table 8.

Alloy No. 13	Micro-structure‡	Yield strength, p.s.i.*	Tensile strength, p.s.i.*	% Elongation*	Heat treatability**
		min.-max. range	min.-max. range	min.-max. range	
(Normal)					
No confined air and no turbulence	Type D	26,000-34,000	46,500-53,500	6.5-11.5	A
No confined air and turbulence ..	Type F	23,500-25,500	42,500-45,500	5.0- 6.0	B
Confined air and no turbulence ..	Type I	23,000-25,000	40,500-44,500	4.0- 6.0	D
Confined air and turbulence ..	Type P	22,000-27,500	37,000-39,000	3.5- 4.0	F
(Modified)					
No confined air and no turbulence	Type D	23,000-26,500	45,000-51,500	5.5-5.6	A
No confined air and turbulence ..	Type G	24,000-25,000	43,000-45,000	5.5-6.0	B
Confined air and no turbulence ..	Type J	23,000-26,000	37,500-45,000	2.5-3.6	D
Confined air and turbulence ..	Type L	22,000-24,500	35,000-36,000	2.5-3.6	F

‡ Determined from the examination of five separate test-bars and two sections from each.
* Determined from fifty tensile tests.
** A=Excellent. B=Good. D=Very poor. F=Not heat treatable at all.

ture of 1,250 degrees F. just prior to casting without agitating the melt. Only the C-C′ type shot was employed. Shots were made to represent five separate temperature levels, 1,140-1,150 degrees F., 1,190-1,200 degrees F., 1,240-1,250 degrees F., 1,290-1,300 degrees F., and 1,340-1,350 degrees F.

As the casting temperature was increased the yield strength rose slightly, as did the percentage elongation. All of the C′ test-bars were 100 per cent. radiographically sound; all of the C test-bars were 100 per cent. unsound. Only when the die temperature was raised to 600 degrees F. did the C test-bars turn out to be porosity free. When the die temperature was raised the yield point of the C′ test-bars rose and the percentage elongation decreased.

All of the C′ test-bars examined manifested modified structures (Type F) in the gauge length. All of the C test-bars, made at a die temperature of 600 degrees F., examined had completely unmodified structures (Types O and P).

Phase IV, Table 5, Alloys 13R, 13S, 13S′, 218 and 356

Table 5 gives the results of Phase IV in which several alloys were pressure die cast in the experimental die. The alloys employed were 13R, 13S, 13S′, 218 and 356. Their chemical composition is given in Table 1.

The " remelt " alloy, 13R, and the " secondary aluminium " alloys, 13S and 13S′, proved inferior as regards ultimate strength and ductility to the virgin alloy 13X. The yield strength of the two secondary alloys, 13S and 13S′, was higher than the remelt, 13R. The ductility of the remelt, 13R, was superior to that of 13S and 13S′, however the remelt's yield strength was lower. Not much difference is evidenced in the tensile strength of the three alloys, 13R, 13S and 13S′—all are inferior to virgin 13X.

It is interesting to notice that the C test-bars cast with the alloy 218 were *very* inferior to the C′ test-bars cast from the same alloy. The ductility of the C test-bars was considerably lower and the yield strength and the tensile strength also dropped off. This was again the case with C test-bars cast with the 356 alloy. The C′ type test-bar had low yield and high elongation. Metallographic examination of 13R alloy C test-bars showed an unmodified type (Type L) structure, while the C′ test-bars had semi-modified type (Type J) structures.

The 13S alloy C′ test-bars had a semi-modified type structure (see Figs. 25 and 26), and the C test-bars were semi-modified in structure (see Fig. 27). And the C′ test-bars had an abundance of primary silicon crystals while the C test-bars did not.

The 13S′ alloy C′ test-bars were of a modified type structure with abundant iron-aluminium needles (see Fig. 29). The 13S′ alloy C test-bars had a very poorly modified type structure (see Fig. 28).

No significant differences in the microstructure of the C′ and C test-bars cast from alloy No. 218 were observed (see Figs. 31 and 32).

No significant difference in the microstructure of the C′ and C test-bars cast from alloy No. 356 was observed. Both types of test-bars, C′ and C, evidenced modified eutectic and closely packed dendrites (see Fig. 33).

Phase V, Table 6

The results of the tensile tests performed on the various types of test-bars prepared as described below are given in Table 6.

All test-bars for Phase V were pressure die cast from the normal eutectic aluminium-silicon alloy No. 13X. The purpose of conducting this phase was to determine how heat treating the C′ and C test-bars affected their properties and appearance.

All test-bars were radiographed prior to heat treatment. Only those test-bars which were absolutely free of pores throughout their *entire* length were heat treated. Directly they were heat treated they were again radiographed, and the two radiographs " before " and " after " compared. Besides being inspected radiographically the heat-treated test-bars were further examined for dimensional distortion, external blister formation, and then finally subjected to a tensile test, the results of which are shown in Table 6. Results of the radiographic inspection are also given in Table 6, along with the results of the dimensional and surface inspection.

Summary. (See Table 8)

(1) This paper presents the results of an investigation to determine the effect of air trapped within steel die cavities used to make pressure die castings, upon the microstructure, tensile properties, and heat treatability of three common pressure-die-casting alloys.

(2) A special two-cavity test-bar die was constructed for the purpose of pressure die casting two standard A.S.T.M. $\frac{1}{4}$-in. test-bars during a single injection of the molten metal. The die was so constructed that the test-bars could be made using either a large or small gate. It was further designed that the incoming molten metal stream forced the confined air within one test-bar cavity into the other test-bar cavity, thus making possible a comparison of the properties of metal cast in the presence of air and the properties of metal cast in the absence of air.

(3) The effect of confined air within the die cavity upon the tensile properties, the microstructure, and the heat treatability of certain aluminium alloys was studied.

(4) The effect of turbulence of the metal alone within the die cavity upon the tensile properties, the microstructure, and the heat treatability of certain aluminium alloys was studied.

Conclusions

(1) It is concluded that the presence of trapped air within the die cavity affects the metal, which is forced to solidify in its presence in such a way that heat treatment of the cast metal is not feasible. By pressure die casting aluminium alloys into steel dies from which the air has been forced, heat treatability of the metal so cast is assured.

(2) It was determined that confined air within the die cavity and turbulence of the metal, together or independently, affect adversely the microstructure of the aluminium alloys numbered 13, 218 and 356.

(3) It was confirmed that test-bars having modified type microstructures possess higher tensile properties than test-bars having the normal type microstructure.

(4) It was shown that both turbulence of the metal and confined air within the die cavity tend to promote internal porosity regardless of the alloy employed.

(5) It was shown that the presence of confined air within the die cavity tends to prevent the normal eutectic aluminium-silicon alloy from developing the modified type structure when it cools rapidly within the die.

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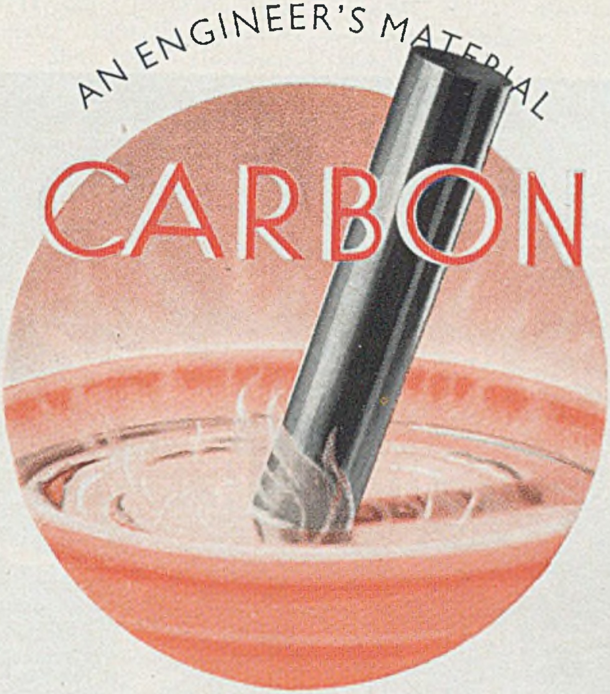

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Light Alloys in Rectifiers, Photocells and Condensers

Continuing from "Light Metals," 1945/87, Discussion on the Theory and Practice of Electrolytic Condensers

BEFORE leaving the subject of electrolytic condensers, some reference must be made to a broad survey covering the position in this country by Philip R. Coursey and S. N. Ray in the Journal of the Institution of Electrical Engineers, 1939, particularly because this gives further constructional and production details. This paper deals with the development of the electrolytic condenser as used extensively in modern radio receivers and amplifying apparatus. The evolution of modern designs is indicated from a brief historical survey, and the construction and electrical properties of the various types of electrolytic condenser now employed are described. The manner in which these properties influence the economic and useful employment of these condensers is indicated. The theories expounded to explain their action are critically examined. Manufacturing methods are dealt with as well as the considerations which influence the employment of these condensers in various practical applications. For ensuring uniformity in the assessment of properties, a standardized test method is advocated. An extensive bibliography is given, including patent references.

In so far as they add to the data already presented, the following notes are abstracted from this paper, retaining the sub-headings under which they appear in the original, namely:—

1. Introduction.
2. Historical Survey.
    (a) Eletrolytic condensers with solid (oxide) films.
    (b) Polarization condensers.
3. Theories of Operation.
    (a) Polarization cells.
    (b) Film theories.
    (c) Molecular structure of the film.
4. Development and Manufacture of the Aluminium Electrolytic Condenser.
    (a) Present-day types of electrolytic condensers.
    (b) Preforming of aluminium anodes.
    (c) Assembly and impregnation.
    (d) Ageing and testing.
5. Condenser Characteristics.
    (a) Capacitance.
    (b) Leakage.
    (c) Electrical losses.
    (d) Service life.
    (e) Dependence of condenser properties upon conditions of measurement and use.
6. Practical Applications.
    (a) In rectified a.c. circuits.
    (b) For direct connection to d.c. supplies.
    (c) For use in pure a.c. circuits.
    (d) " Regulating " condensers.

Particular attention will be given to items 4, 5 and 6.

1. Introduction

Coursey and Ray point out that besides aluminium and tantalum, other metals such as vanadium, niobium, bismuth and antimony can be used for the construction of electrolytic condensers, but although many different varieties of these condensers have been made, considerations of such practical factors as size, cost and constancy have caused aluminium to be used commercially almost universally.

The major portion of recent advances has been associated with the electrical forming, or preforming, of the aluminium electrode. They illustrate the forming process with a rather interesting form of curve. Thus, if a d.c. source of current be connected in series with a variable resistance and an aluminium electrode immersed in an electrolyte such as aqueous ammonium borate solution, the initial current is determined by the resistance in the circuit. Gradually, the aluminium becomes formed and the current decreases. By adjusting the variable resistance to maintain a constant current value, the potential drop across the cell will be found to vary with time in the manner depicted in Fig. 149. This shows that after a certain time, represented by the point A, the rate of increase in potential drop with time falls off, and this corresponds with a phenomenon of sparking over the aluminium anode. A further change occurs, as shown by the point B, beyond which the potential difference remains stationary with time. If a voltage higher than this value is applied the formed film breaks down, resistance falls and normal electrolysis occurs. This, briefly, shows the foundation and functioning of the electrolytic condenser. The two plates consist of the formed anode and the electrolyte in contact with the outer surface of the formed film. The cathode is necessary to provide electrical contact with the electrolyte, and the authors assert that from this point of view, the actual material of the cathode is unimportant provided that it is an electrical conductor.

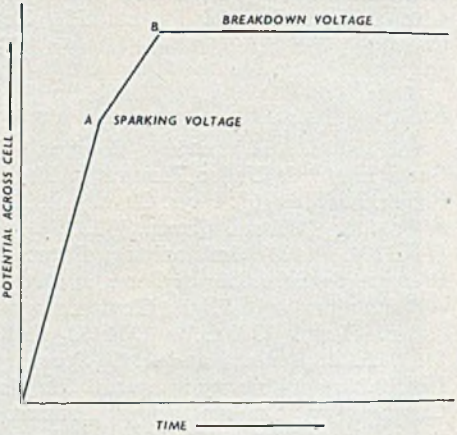


Fig. 149.—Electrical forming characteristic of aluminium cell at constant current (after Gunther-Schulze).

2. Historical Survey

Mention is made of Noden's colloid condenser, which is only of historical interest and not of direct practical importance. It is really a polarization condenser rather than a solid oxide film electrolytic. It consists of two foils of aluminium and magnesium—" the plates "—separated by an insulating porous material of which the interspaces are filled with a paste, made of sesqui-oxide of iron mixed with glycerine. Noden's condenser is described in "Comptes Rendus," 1926/182/1270. A point of interest is the use of magnesium in this application.

3. *Theories of Operation of Electrolytic Condensers*

Additional to the review already given on this aspect, it is noted that Coursey and Ray consider the solid-film theory to be inadequate, and that a theory put forward by Godsey (reference "Trans. of the Amer. I.E.E.," 1932/51/432) conveys a good physical idea of the process that goes on in an electrolytic condenser. Godsey considers that the normal film on aluminium or similar metal in an electrolytic condenser is of a greater thickness than the total effective film. The effective film maintains itself in repair by new growth wherever leakage currents flow. Water or other solvents from the electrolyte saturate the film and so increase the effective capacitance, water having a dielectric constant of about 80. A high dielectric constant keeps the film sufficiently thick to reduce the voltage gradients materially. Godsey attaches great importance to polarization capacitance which he thinks occurs in the outer layers of the film saturated with the electrolyte.

Coursey and Ray have found that the polarization effect, i.e., change of capacitance with the impressed alternating current, is small and can be accounted for if it is assumed that the dielectric has a hysteresis curve of the shape depicted in Fig. 150.

Lilienfeld and his co-workers (reference "Trans. Amer. Electrochem. Soc.," 1930/58/225 and 1932/61/531) from a study of the anodic layer conclude that the dielectric layer consists of a larger number of polar molecules. In a well-formed condenser these are properly oriented and the leakage current is low. Upon standing idle, the layer becomes disorganized, and the excessive leakage current on applying a voltage occurs while the reorganizing of the layer occurs. Consequently, there is only a very small change in capacitance owing to idling, and the law of chemical equivalents cannot be applied to the current used in the process of re-forming.

4. Development and Manufacture of Aluminium Electrolytic Condensers

(a) *Present-day Types of Electrolytic Condensers*

The main impetus to development has been provided by the requirements of radio receivers for condensers for smoothing rectified currents used in mains operated receivers. For this purpose condensers having a small size and of several microfarads capacity and for use on circuits of 400-500 volts max. are required. More inexpensive manufacture than the normal paper condensers is also an essential. A number of types of electrolytic condenser has been evolved, generally known as the wet or aqueous type, the semi-dry type and the dry or hard-dry type. The distinction between these is not too hard and fast and is determined by the nature of the electrolyte. However, in passing from the wet to the other two types there is a constructional change.

In all types there is the aluminium anode carrying the dielectric film, this determining the capacity of the condenser by its effective area. This area may be the natural area of the metal or it may be augmented by roughening, either mechanically or chemically. There is also the cathode which may be the container itself or a metal sheet or foil. In modern condensers for the wet type of construction which uses a thin electrolyte, the anode is generally in form to give maximum area, such as a fluted or grooved rod or stiff foil in the form of a spiral corrugated or pleated. This anode has to be sufficiently stiff to be self-supporting. Fig. 150 shows an anode in the form of a spiral, Fig. 152 depicts the perforated spiral, and Fig. 153 the grooved rod. Fig. 154 illustrates the folded or pleated strip, while Fig. 155 demonstrates an extruded aluminium rod having a star-shaped cross-section with corrugated fins. Using these types of anode, a separator layer of perforated rubber or of celluloid is generally used between the anode and the cathode; this is necessary to avoid contact between the two electrodes.

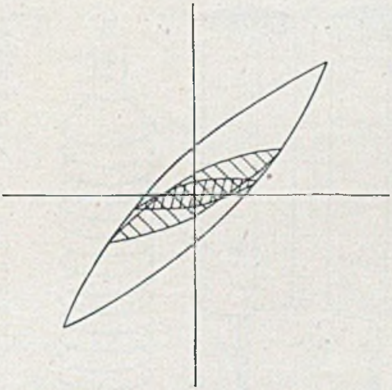


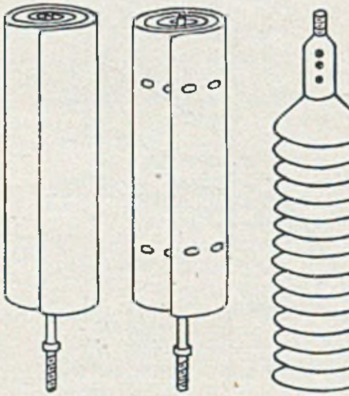
Fig. 150.—Hysteresis loop for dielectric film on aluminium anode (Coursey and Ray).

With the semi-dry and dry types of condenser, the anode is usually pure aluminium foil from thickness of 0.002 in. to 0.005 in. and the cathode can be similar material. The two are separated by means of an absorbent medium and wound into the form of a roll. The separator can be cotton gauze or paper, and this holds the electrolyte. It is possible, by virtue of the closeness of spacing that can be achieved, to produce condensers of lower power factor than with the wet types of the construction just described.

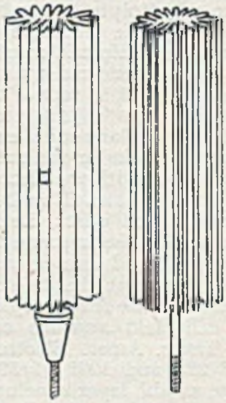
Different methods are employed for film formation, but in all cases, pre-formation of the dielectric before assembly, followed by a final formation and/or ageing after assembly, is carried out. Any etching or mechanical roughening used to increase the area of the anode naturally has to be performed before electrical forming.

(b) Pre-forming of the Aluminium Anodes

Two main alternative methods of pre-forming are employed. The first is a discontinuous process in which each anode or each group of anodes of the final finished shape is subjected to individual pre-forming in an electrolyte. The second is a continuous process wherein a length strip of aluminium foil is subjected to pre-forming in one or more stages. The first of these methods is almost invariably adopted for wet-type electrolytic condenser anodes of the types illustrated in the diagrams. These for forming purposes can be assembled in a rack and hung in the electrolytic bath to which the forming current can be applied until the desired voltage across the dielectric film is obtained. The control of the forming action can be achieved by means of a resistance in series with the supply circuit, or by controlling the supply voltage, for example, with a field control on a motor generator. By these means the applied potential can be raised gradually to the full value.



Figs. 151, 152, 153 (at the left).—Reading from the left are pictured here respectively the spiral anode, perforated spiral anode and grooved rod anode.



Figs. 154 and 155 (at the right).—Reading from the left are shown respectively an anode from strip folded to star-shaped section and an anode from extruded rod of star-shaped section and with corrugated fins.

A similar process is sometimes applied for forming strips of aluminium foil previously cut to the desired length for winding into the dry electrolytic condenser sections. It is more economic generally, however, to use a continuous pre-forming process for this type of anode.

In the continuous pre-forming process, one or more aluminium foil strips are passed over rollers through the electrolytic baths. The appropriate connections to pass the forming currents through the baths are made, the aluminium being the positive electrode in order to build the dielectric film upon it. This process can be carried out in a single stage, but more usually it is sub-divided into two or more sections so that the film may be built up more gradually. This gives a more stable type of film.

With regard to the electrolytes for pre-forming, whether the continuous or discontinuous process is used, they are generally solutions of sodium or ammonium borate. Sometimes, especially with multi-stage forming, an addition of some polyhydric alcohol such as glycerine is made. With multi-stage formation an alternative procedure includes the use of a low voltage formation in an acid solution of considerable conductivity, for example, chromic or sulphuric acid, this being used for the first stage in order to create a porous base film that has good adhesion to the metal foil and then the hard high voltage film is subsequently built up upon it.

(c) Assembly and Impregnation

With the wet-type condensers the subsequent manufacturing processes comprise mainly mechanical assembly of the anode posts into the outer container, the filling of the latter with the electrolyte and its closure, followed by ageing and testing. With the dry types of condenser, after pre-forming the continuous film, this has to be cut to length, the sections have to be rolled with the necessary combination of formed anode, separating material and unformed cathode foil. Following this the section is impregnated with its working electrolyte.

The electrolytes for semi-dry condensers consist of alkali glycero- or glyco-borates in solution of glycerine, ethylene glycol or other polyhydric alcohol, together with a small quantity of water. The dry condensers have a similar electrolyte which is thickened into a stiff paste, either by the addition of boric acid or of similar weak film-forming material, to such an extent that a mass of fine crystals is formed and permeates the electrolyte when it is cooled down to atmospheric temperature after manufacture, or by the addition of a gum which assists the formation of a gel with the solution. In some practices, the impregnation of the separator with the electrolyte before or during the winding of the section is carried out, and in others it is a separate impregnation operation applied to the rolled section. In all cases the object is to obtain as complete a filling as possible of the pores of the separator.

The subsequent treatment of the impregnated section varies with different manufacturers, as likewise do such details as the attachment of connecting wires and sealing. The container may be of metal or of waxed cardboard or other suitable material, in which the condenser is sealed by wrapping it in waxed or oiled paper, inserting it in the container and filling the latter with wax or bitumen.

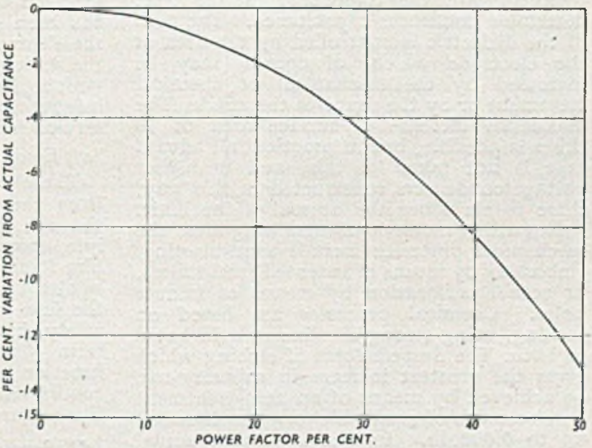


Fig. 156.—Effect of power factor of condenser upon its apparent capacitance as measured by the impedance method.

The drier types of condenser are more suitable for use with the cardboard type of container which are cheaper than the more robust aluminium or metal containers. The latter are essential for wet electrolytics and are really desirable for the semi-dry types.

From the point of view of performance, it is essential to seal the condenser as perfectly as possible against the ingress of moisture, just as it is with any other type of condenser. For this purpose one or more sections can be mounted in the same metal container and the negative foils can easily be commoned together. Other combinations of connection can be likewise catered for without difficulty.

(d) Ageing and Testing

Both wet and dry types of electrolytic condenser, after assembly, require an ageing process in order to repair any slight damage to the film that may have occurred to the foil during manufacture. For this purpose they are assembled on racks and the appropriate d.c. voltage is connected by joining them across bus-bars. The condensers can be maintained polarized in this manner for several hours, or until the leakage current, passing through them, falls to some predetermined value. A capacity measurement then follows.

For the needs of mass-production methods in the factory, electrical testing has to be as simple as possible. For capacity determination an impedance test is found most convenient. It consists in applying to the condenser a known fixed a.c. voltage, for example, about 20 volts, of known frequency, for example, 50 cycle supply mains. The a.c. milliamperes flowing through the condenser are then measured. For a limited range the milliammeter can be calibrated in microfarads of condenser capacitance. In making this test it is necessary to apply to the condenser a d.c. polarizing voltage of some convenient value below its maximum peak rating, such that the sum of this voltage and the peak value of the a.c. testing voltage is below the maximum voltage rating of the condenser. The circuit arrangement comprises an a.c. ammeter and voltmeter of appropriate ranges only.

The impedance method of measuring capacity is particularly useful for dry-type condensers, of which the power factor does not exceed 10 per cent. In this case the results of such measurements agree with the true capacity within 0.5 per cent. as is shown in Fig. 156. The alternative to the impedance test is an a.c. bridge method, but this becomes more of a laboratory test.

At all stages of manufacture of electrolytic condensers every care is taken to prevent contamination of any part of the condenser and particularly the electrolyte. Many impurities are very harmful to performance and anything that will introduce chlorine ions into the electrolyte must be scrupulously avoided.

5. Condenser Characteristics

These are considered under four main headings of capacitance, leakage, electrical losses and service life. In practical application of the condensers all these properties will not have equal importance in all cases. Different condenser construction may better suit specific applications.

(a) Capacitance

With various methods of producing the dielectric film on aluminium it has not been found that its dielectric constant has been altered thereby to any material extent. Therefore, the physical dimensions of the dielectric are the important factors that determine condenser capacitance. The area of the dielectric is controlled by the area of the electrode which, of course, may be increased by the mechanical or chemical treatment or by the shape of the anode. The maximum increase in surface area of 10 times is possible, but in practice full advantage is not taken of this, and in higher voltage condensers constructed in this way, three to six times the normal is the limit.

Regarding methods of increasing area, the mechanical processes include sand-blasting, embossing by means of indented steel rollers, or actual perforation by means of minute holes. Chemical processes are based on etching, using strong alkaline or acid baths or both. The deepest form of etching which gives the greatest increase in capacity can be achieved by means of an acid treatment on electrodes of small thickness, such as foil up to 0.006 in. In this treatment actual perforations may take place. Electrochemical processes are similar to the chemical ones, except that the action is accelerated by means of electrolysis, using the aluminium electrode to be treated as one pole of the cell and an inert electrode as the other. Under controlled conditions deeper etching may be obtained by this means and, further, generally less chemically active electrolytes can be employed for the etching which is an advantage. Actually, the process can be employed using solutions to which aluminium is relatively inert and still obtain a very deep etch electrolytically; for example, common salt alone or with the addition of a little hydrochloric acid is relatively inactive towards aluminium, but electrolytically, using such a solution, an area and capacity increase up to the maximum given above is achievable under quite stable manufacturing conditions.

The thickness of the dielectric film is the other factor controlling capacity. This is normally a direct function of the voltage under which the film is produced in the preforming process. It is not entirely a question of thickness of film, but adhesion and density and quality of the film, also enter. It is found that the most stable films, which are required for high-voltage circuits are generally those which are most coherent and solid and which actually have a smaller overall physical thickness than many of the lower-voltage films. The electrolyte used in forming the film, the temperature and time occupied in the treatment, also exert some influence upon the effective thickness and, therefore, upon capacity.

(b) Leakage

Leakage refers to the current that flows through the condenser under its d.c. polarizing voltage. It is dependent upon a number of factors, including the method of measurement and is not such a constant or definite quantity as capacity. It is a function of the type of film formation that has been employed in manufacture and of the electrolyte in the condenser. A study of the leakage current as a function of the various factors that affect it, give valuable information concerning the constitution and service performance of the condenser.

(c) Electrical Losses

The electrical losses or power factor arise from the flow of the capacitance current through the series resistance of the electrolyte, from the true dielectric losses in the film itself and from the d.c. leakage. This last item is generally only a small one. Usually the first two items are not considered separately, but are grouped together under the term " power factor." The losses are a function of temperature, voltage and other conditions of measurement, as well as of the construction of the condenser.

(d) Service Life

The useful effective life of an electrolytic condenser depends upon the maintenance of a reasonable proportion of its initial properties, particularly capacity and leakage. Generally, there is a tendency for the capacity to fall and the leakage and losses to rise after the lapse of a considerable time in use. The end of the useful life is determined by the capacity becoming too small to give effective operation, or by the d.c. leakage becoming excessive, or by the power factor becoming so great that over-heating results from the ripple current flowing through the condenser or by its filtering action becoming spoiled when the condenser is used as a by-pass or smoothing condenser.

Another aspect to be considered is shelf life; this refers to the deterioration that takes place when an electrolytic condenser is standing, even when it is not in use at all. The present-day objective in manufacture is to prolong shelf life as much as possible by increasing the stability of the dielectric film in order that all changes in its properties are minimized.

(e) Dependence of Condenser Properties Upon Conditions of Measurement and Use

None of the properties of an electrolytic condenser is an invariable quantity or independent of the conditions of use, or methods of measurement. Capacity, d.c. leakage, a.c. losses and useful life are all functions of the magnitude of the d.c. voltage, the time of application of this voltage, the working temperature and the magnitude and frequency of the a.c. voltage. The nature of these variations is expressed by means of curves which illustrate typical measurements.

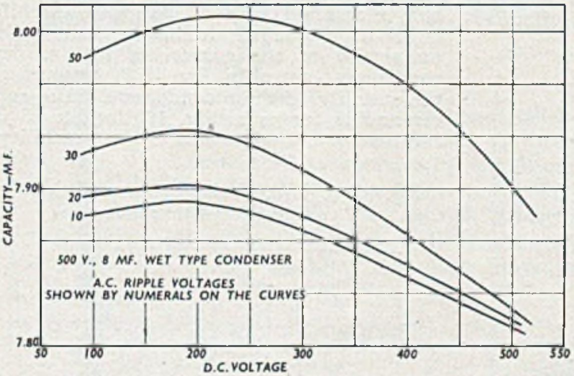


Fig. 157 (above).—Wet electrolytic condenser. Dependence of apparent capacity upon magnitude of D.C. polarizing voltage and of superimposed A.C. ripple voltage.

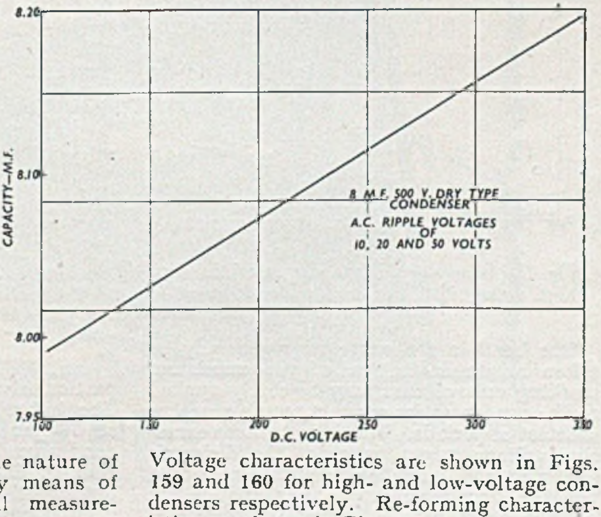


Fig. 158 (right).—Dry-type electrolytic condenser. Dependence of apparent capacity upon magnitude of D.C. polarizing voltage and of superimposed A.C. ripple voltage.

(i) Condenser Characteristics

The variation of capacity with the applied d.c. voltage and the time period of its application is not serious with aluminium electrolytic condensers. This is shown by the curves in Figs. 157 and 158 for wet-and-dry-type condensers of 8 mf. capacity 500 v.

Variation in capacity with temperature likewise is not large for most condensers over the normal working range of temperatures, but below freezing point the change becomes much greater and some forms of electrolyte and condenser construction show much larger changes than others at low temperatures. Generally, electrolytes containing ethylene glycol as the base, and particularly those condensers containing a large proportion of this material, exhibit best maintenance of capacity at the lower temperatures.

Change in capacity with time of the applied voltage becomes, in effect, the service life of the condenser, and the termination of this useful life is decided by the period when loss of capacity is greater than can be tolerated in the particular circuit in which the condenser is used.

The variation in d.c. leakage with the first three determining conditions, provides the most useful evaluation of electrolytic condensers. Variation with applied voltage is referred to as voltage characteristics, with time as re-forming characteristic and with temperature as thermal characteristic. Voltage characteristics are shown in Figs. 159 and 160 for high- and low-voltage condensers respectively. Re-forming characteristics are shown in Fig. 161 after a period of 100 hours' idling time. Thermal characteristics are shown in Fig. 162. The three qualities are fundamental characteristics of all electrolytic condensers.

The changes of electrical losses, that is a.c. losses, with the same three factors are generally more analogous to the changes in capacity with these factors than they are to changes in d.c. leakage. This is shown in the curves in Figs. 163 and 164 for wet- and dry-type condensers respectively.

(ii) Voltage Characteristic

The voltage characteristic is controlled mainly by the voltage at which the dielectric coating has been formed on the anode of the condenser. The point at which the leakage current begins to rise rapidly with increasing d.c. applied voltage, usually bears a direct relationship to the forming voltage. In certain applications in which the electrolytic condensers are used as regulating condensers, a construction is required in which the rise of leakage with voltage follows a very steep curve.

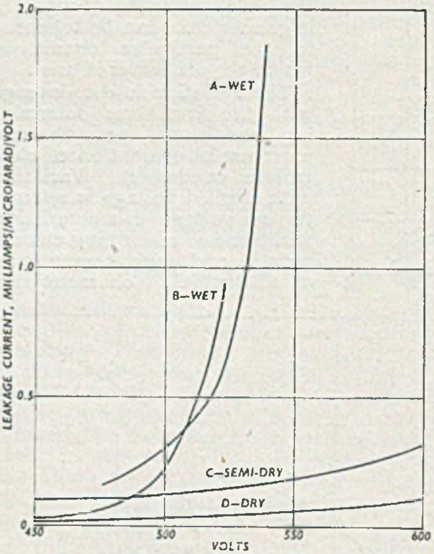


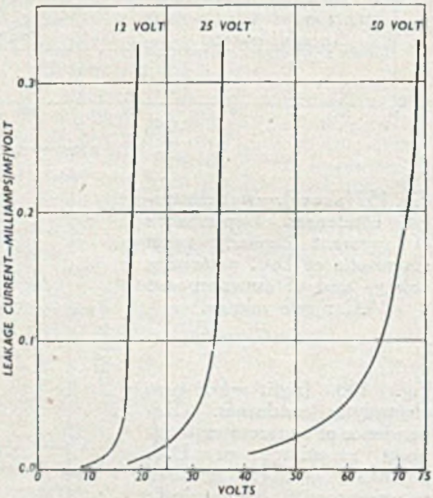
Fig. 159 (above).—Voltage characteristics of high voltage (500V) electrolytic condensers.

The bend in the curve may generally be taken as an indication of the maximum working voltage that may be safely applied to the condenser for anything more than the shortest of periods. This is so because excessive voltage might puncture the dielectric and also the large leakage current would produce over-heating. The shape of the voltage characteristic curves is, therefore, some guide on the construction of the condenser, the manner in which it will behave under operating conditions and the type of use to which it should be put.

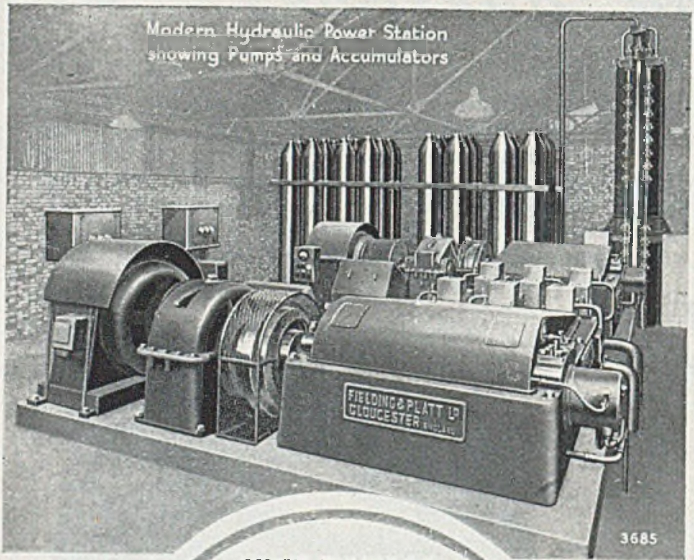
(iii) Re-forming Characteristic

The variation in leakage current with time of application of the applied voltage constitutes one of the most important characteristics of an electrolytic condenser. It is a direct measurement of the stability of the dielectric film, because any deterioration of the film in the working electrolyte of the condenser that may occur when not in use, will need to be repaired by re-forming action when the voltage is applied. Excessive repair will cause excessively large leakage, during the repairing period. With a stable film the current drawn by the condenser when the voltage is first applied will decrease very rapidly to the ultimate limiting leakage current. The most stable and most useful condenser, therefore, is one in which the leakage current is not only normally low, but is restored to this low value rapidly after a prolonged idling period. The uniformity of the curves for 500 v. dry condensers, given in Fig. 165, emphasizes the stability of these condensers. The corresponding curves in Fig. 166 for the 25 v. condensers show rather lower stability, particularly after 12 months' idling period. The fact that when these tests are repeated at 75 per cent. of the rated voltage the condenser shows no such apparent deterioration, indicates that there has been some deterioration of the film in the electrolyte. This phenomenon is observed to a much greater extent in wet electrolytic condensers.

Fig. 160 (below).—Voltage characteristics of low voltage electrolytic condensers.



The film stability judged in this way gives quite a good measure of the ability of the condenser to give a long shelf life. This is quite apart from the operating life of the condenser, which, in addition to the factors already mentioned, is also controlled by the amount of electrolyte in the condenser. Thus construction having a considerable bulk of separator between the electrodes and which,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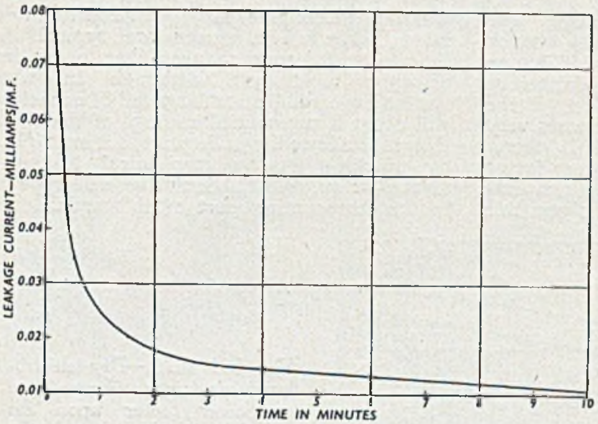


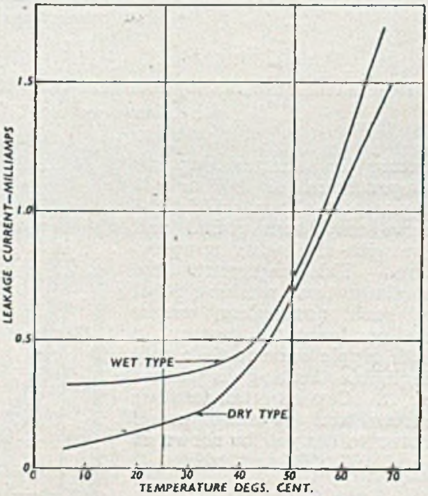
Fig. 161 (left).—Re-forming characteristic of 8 mf. 500V dry-type electrolytic condenser.

therefore, contain much electrolyte, give a longer service life before the electrolyte is exhausted.

(iv) Thermal Characteristic

For normal uses the thermal characteristic is not very important, unless the rate of rise of the leakage curve, with temperature, is very sharp. The utility of thermal characteristics is, therefore, mainly limited to applications concerned with extremes of temperature. A condition may arise when increase in temperature, due to its position in an equipment, may give rise to so much increase in leakage current, that still further increase in temperature may be caused. Progressive rise in temperature and, ultimately, breakdown, may occur. Such an occurrence is unlikely with modern condensers as illustrated by the curves in Fig. 162. The thermal characteristic with respect to a.c. losses may be more serious from this point of view, because the condenser may be required to pass a considerable amount of ripple current if it is used as a reservoir or smoothing con-

Fig. 162 (below).—Thermal characteristics of electrolytic condensers.



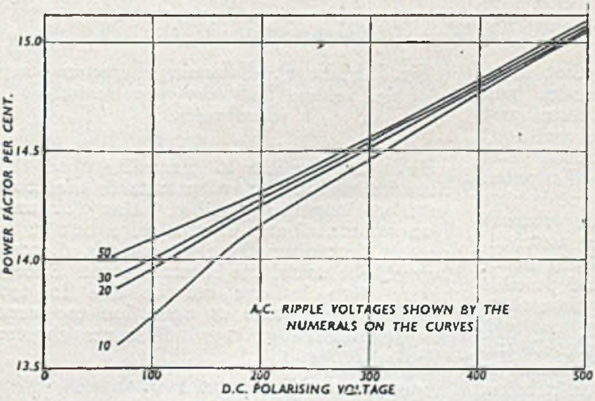


Fig. 163 (left).—Wet electrolytic condensers. Dependence of power factor upon the polarizing voltage and the superimposed A.C. ripple voltage. (See also Fig. 157.)

denser on a.c. rectifier circuits. The corresponding heat is generally much greater than when the energy loss is due to d.c. leakage. An unstable and dangerous condition may be quickly reached, if the power factor of the condenser increases very much with rise in temperature. It is, therefore, advantageous if the power factor characteristic falls with increasing temperature. In many modern dry electrolytes this feature is attained up to temperatures of 50 or 60 degrees C. above which the curve may turn round and rise with increasing temperature. This represents the maximum safe working point of such condensers, unless the condenser is passing so little ripple current that only negligible heating is caused by it. Capacity temperature curves and capacity power factor values will be shown in Figs. 167, 168 and 169.

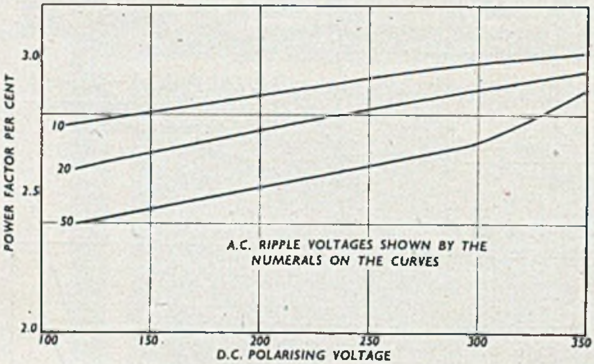


Fig. 164 (left).—Dry electrolytic condensers dependence of power factor upon the polarizing voltage and the superimposed A.C. ripple voltage. (See also Fig. 158.)

(v) Time Characteristic

The quality of an electrolytic condenser has to be determined by a study of all the characteristics detailed above. In general, condensers that have etched or similarly treated anodes will be broadly similar in performance and characteristics to those made without such treatment, but the reduced size means a reduced capacity for dissipated heat, so that the use of such condensers in circuits where much ripple current is involved, must be carefully watched. Further, in any case, the smaller bulk means smaller quantity of electrolyte and possible shorter life. Fig. 170 gives the time characteristic or life curves of dry and wet electrolytic condensers at 50 degrees C. and 500 v. The useful life is usually taken as the point at which the capacity falls below a certain percentage, say 90 per cent. of the rated value. The curves are typical in showing the larger changes that occur in dry-type condensers, although in wet condensers a sudden and large fall of capacity will occur if substantial wastage of the electrolyte is allowed to take place, for example, by sparking or by mechanical leakage. (Note.—Figs. 166-170 inclusive will appear in the forthcoming part of this article.

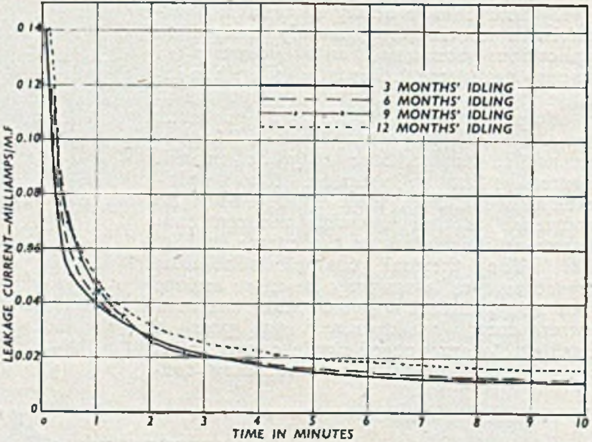
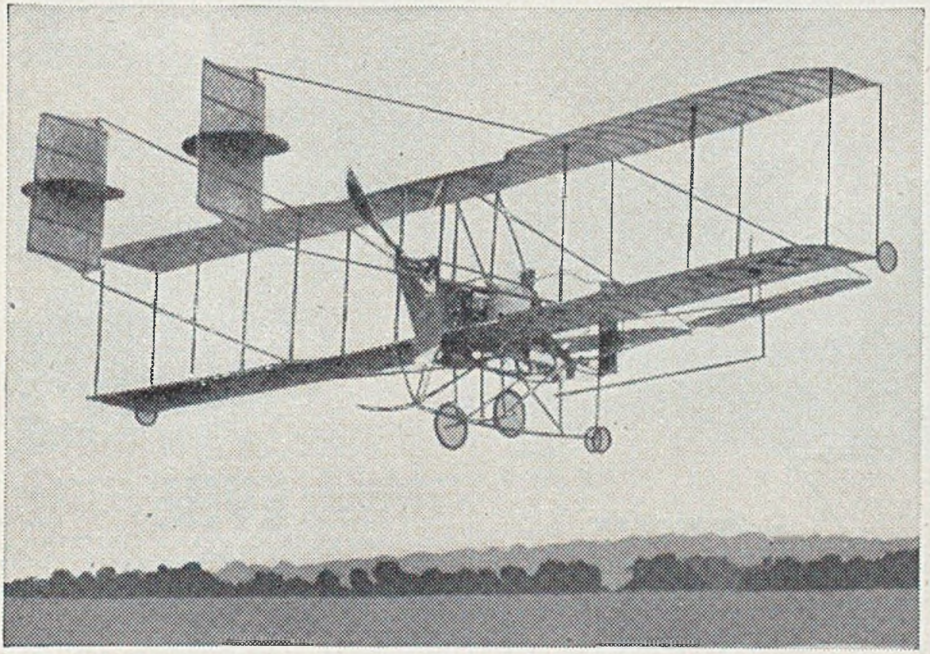


Fig. 165 (above).—Reforming characteristics of high voltage (500V) dry type electrolytic condensers.

It is not possible to generalize upon the question of life but, with suitable use, two years or longer is possible. Many circumstances contribute to this life, but it is certain that when the electrolyte is all consumed, the useful life is terminated. Excessively high leakage current due to too high a temperature or operation too near the breakdown voltage will cause shorter life.

(To be continued).

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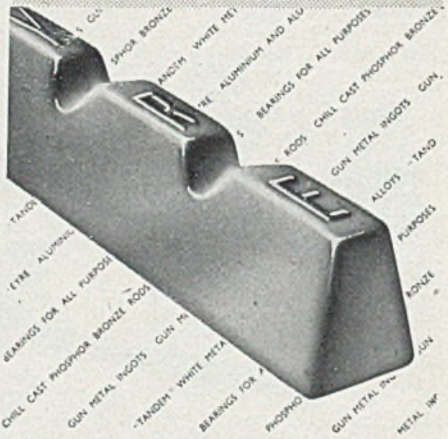
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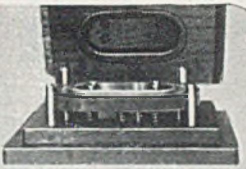

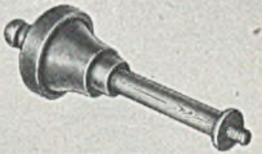

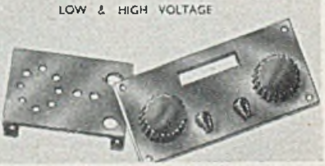
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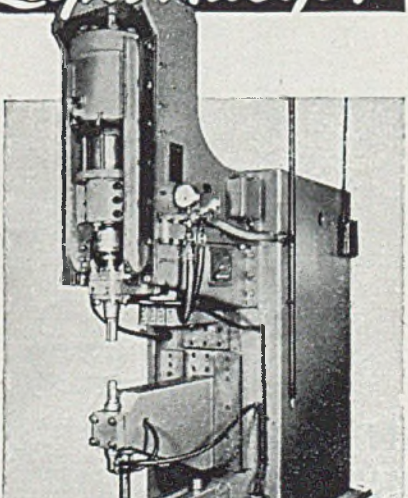
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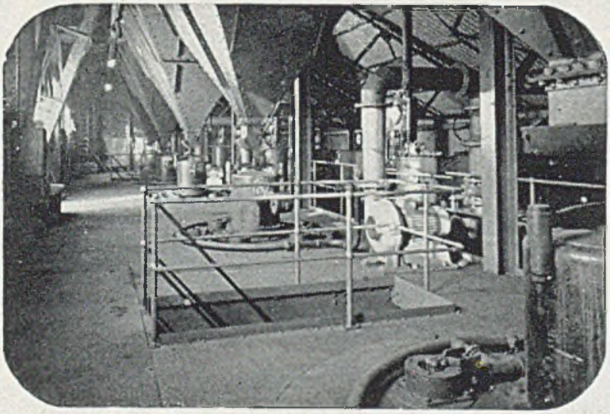

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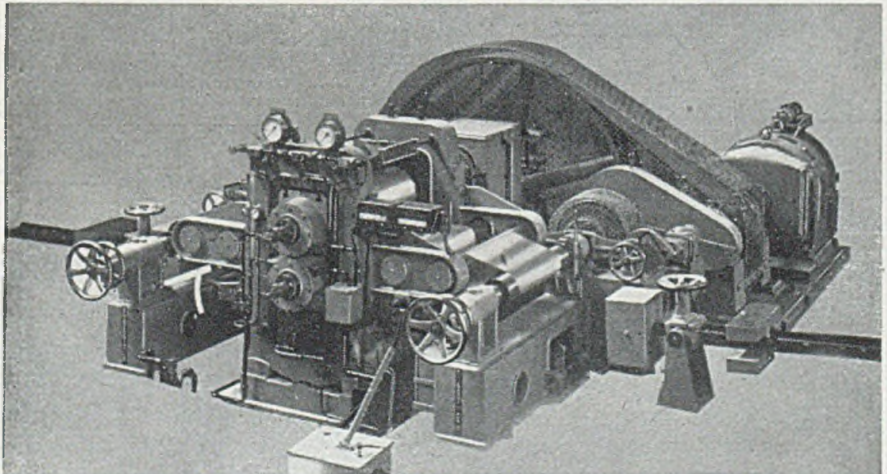

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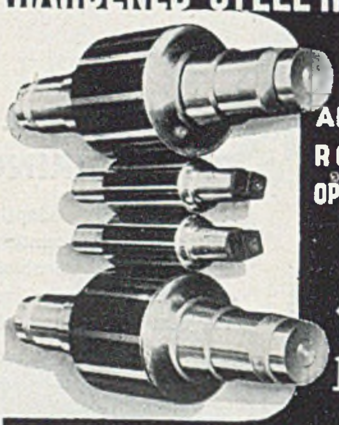

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