ANODIC FILMS FOR ELECTRICAL INSULATION

# LIGHT METALS

AUGUST 1945

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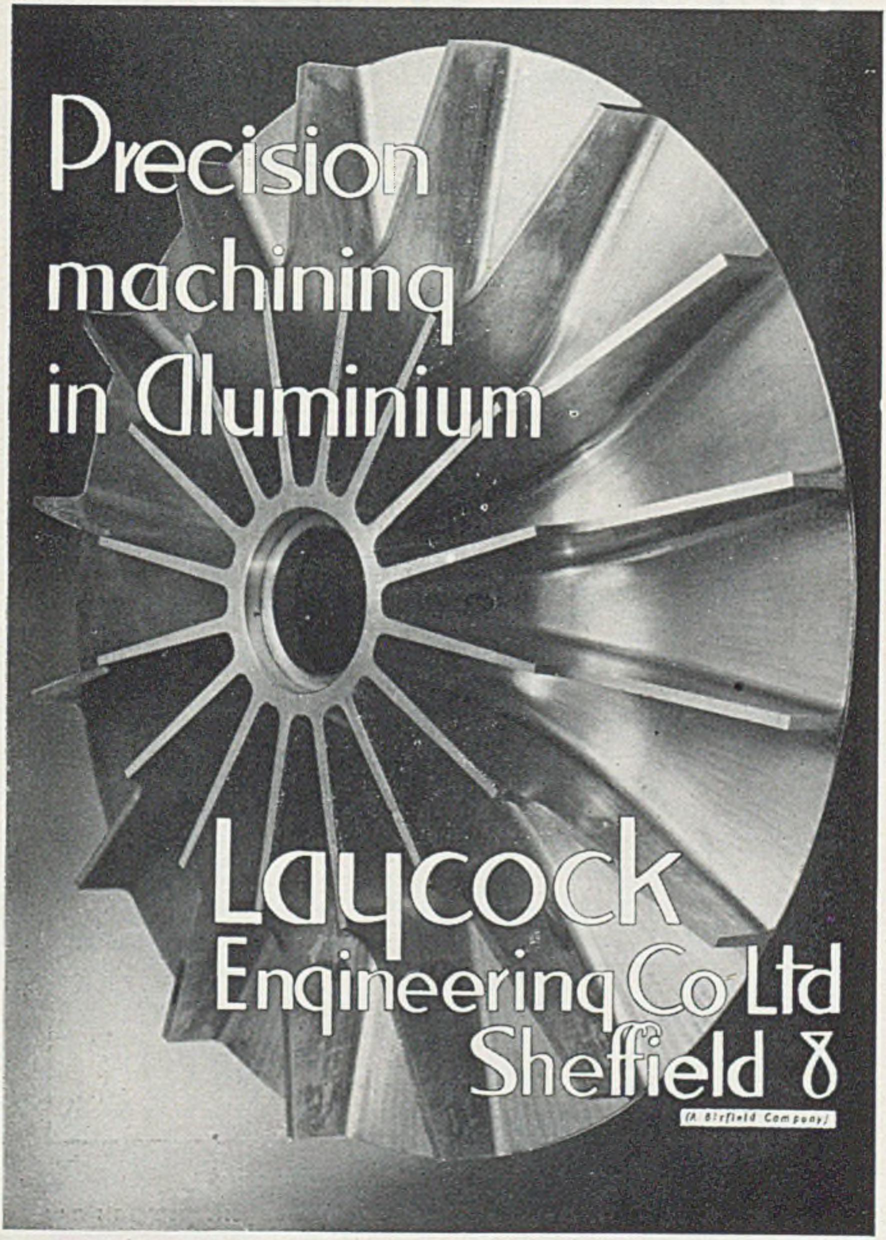


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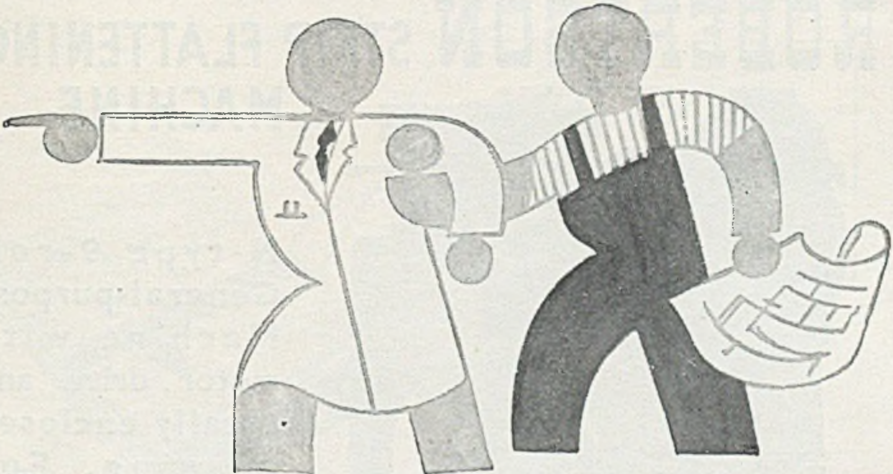
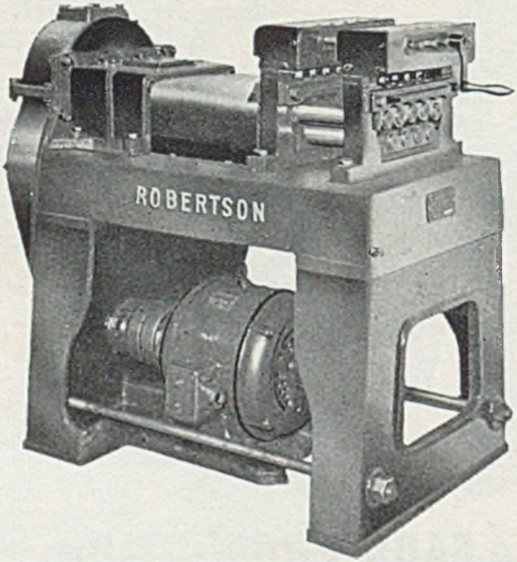
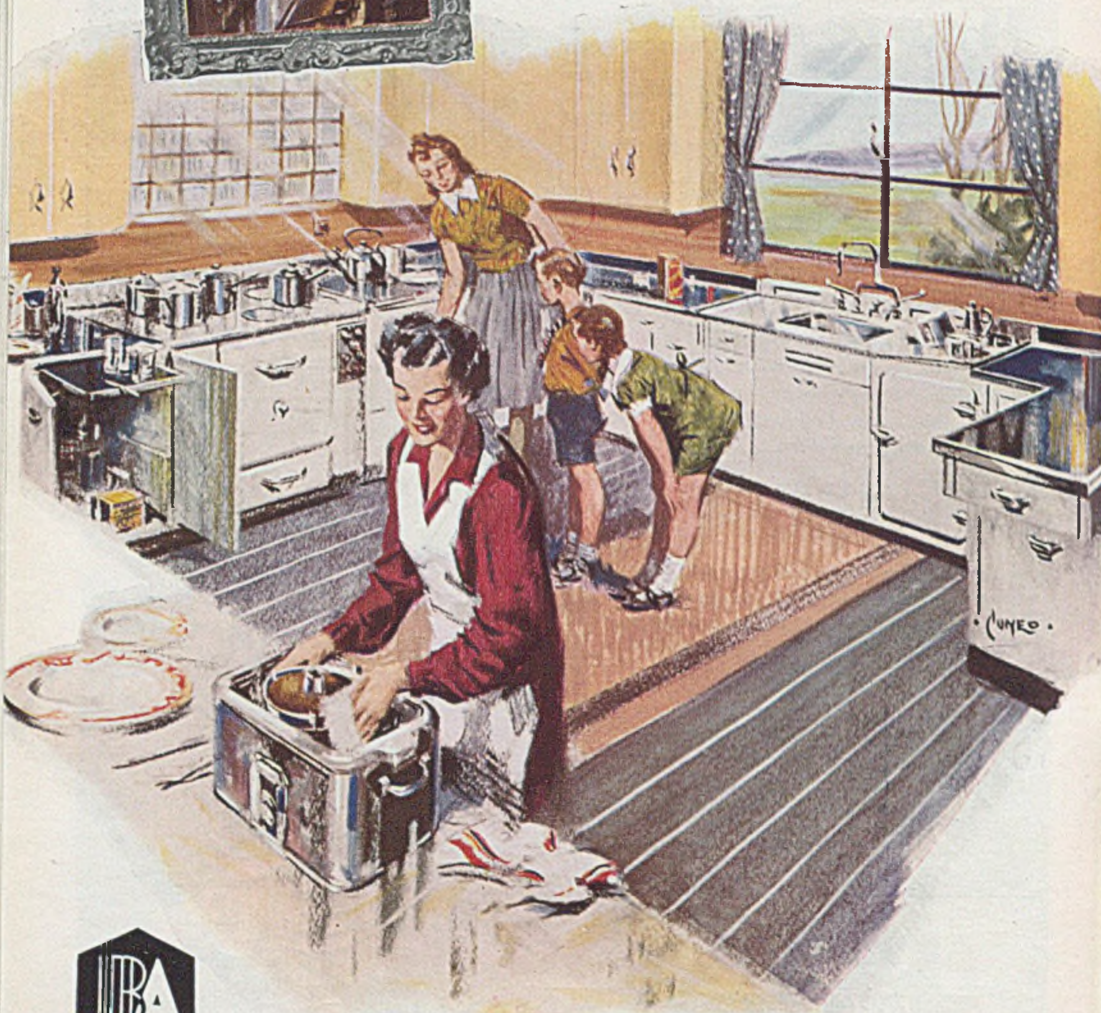



ROBERTSON

# KITCHEN TRANSFORMATION

The kitchen of fifty years ago spelt romance to the young but untold toil to the cook. There might be a cricket on the hearth, but there would be beetles in the wainscot, dust and heat everywhere, unnecessary waste of fuel and of human labour. The modern counterpart is an amazing contrast in light and space, handiness and hygiene. The old sleepily singing cast iron kettle and the massive saucepan have given way to the beautifully clean, featherweight aluminium equipment, good to look at and easy to cook with, pleasantest of pictures in a modern frame — *all within the lifetime of the British Aluminium Company Ltd.*




THE BRITISH ALUMINIUM CO. LTD. SALISBURY HOUSE LONDON WALL LONDON E.C.2

Telephone : CLErkenwell 3494

Telegrams : Cryolite, Ave. London

VOL. VIII. No. 91

AUGUST, 1945

LIGHT METALS

Proprietors:
TEMPLE PRESS LTD.

Managing Director:
ROLAND E. DANGERFIELD

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

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

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



# EDITORIAL OPINION

## Live Wires

AS an heroic gesture we blame ourselves for our deep ignorance concerning so many vital developments in the field of light-alloy application, and, imbued with this spirit of martyrdom, approach the broad territories embracing that vast and complex group of interests referred to as the electrical industries.

Part of the difficulty, of course, arises by reason of the fact that, not one, but a whole mass of industries is tied up under this general title, and, whether the product be a minute filament lamp for use in surgery, or a giant turbogenerator, each in its own field is of vital importance and, ultimately, of equal interest to suppliers of raw material. And here aluminium comes into the picture.

Undoubtedly the war has had much to do with that general incoherence which characterizes the technical literature and files of technical data covering the use of light metal in electrical engineering, but some responsibility must be laid at the doors of officials in the appropriate concerns, who, for reasons best known to themselves, have pursued a policy of "hush-hush" so extreme that even the Ministry of Information might be constrained to blush. Finally, as we have said before in these pages, even the aluminium industry itself has erred all too frequently by "sitting" on news of technical interest for so long that the egg became addled. The fault is not confined to any one country, nor, indeed, to any one group of interests; in this instance it happens to be rather more pronounced than usual.

It is quite certain that, during the past 10 or 15 years, masses of work must have been done in the use of aluminium windings for electrical machinery, the insulation of such windings consisting not of the ordinary organic media, or of the inorganic glasses which, we believe, made their appearance just prior to the war, but rather of anodic films. We are quite frankly unaware of the extent to which investigations were pushed in this country. Bollino, of Magneti Marelli, speaking at the Milan Conference in 1939, indicated quite clearly that, in Italy, at all events, the use of aluminium windings had been examined very fully on a production basis. Somewhat tantalizingly he glossed airily over his personal dislike for anodic insulation, complaining that on fast automatic winding machinery the film tended to crack and exfoliate somewhat more readily than stoved lacquer.

From that point onwards the subject seemed virtually dead until, from Russia, comes the next item of news. Now the interest here is twofold: first, various Russian workers appear to have set out, not only with the avowed intention of producing an anodic film suitable for insulating purposes, but, having done so, to have tried the thing out on a generous scale. We are left in some doubt as to how far successful large-scale laboratory prototypes have been adopted for commercial exploitation.

Upon the exuberance of some of the more recent Russian work we will not comment here, excepting to point out that, in its general make-up, it bears a strange resemblance to the systems in vogue in England in the middle of the 19th century and in U.S.A. towards the close of that epoch, periods in both countries coinciding with the dawn of an age of great commercial and scientific expansion. Rather more to the point in our present argument, is the odd reference to the use of specific aluminium alloys in an attempt to obtain an anodic film of superior elastic properties.

Now in this country we certainly know all about attempts made elsewhere to employ aluminium alloys in place of the pure metal for electrical conductor systems, within which term we include not only transmission lines, but machine windings as well; as to what work has been done here in the domestic utilization of such knowledge, however, we are quite ignorant. Fairly exhaustive and long-continued questioning of many electrical engineers of diverse standings in the profession, too, has revealed, by and large, an extraordinary ignorance of aluminium other than in its more banal aspects.

It is hoped that for the purpose of clearing up this position (and other muddles, too, of a like nature), A.D.A. will, at the earliest possible moment, institute effectual liaison between its own research organization and those of the electrical industries. We hope, too, that the live wires of this new association will, by pushing out information as fast as it comes to hand, discourage brooding.

## *Contents*

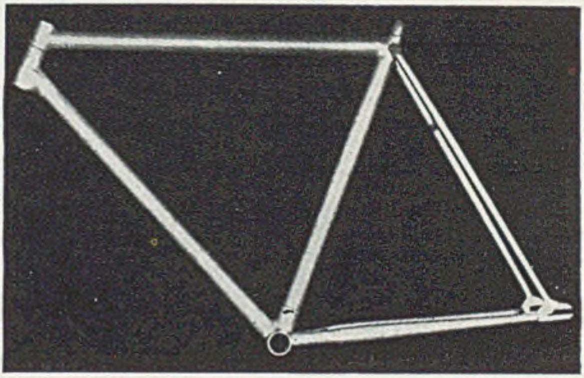


*"LIGHT METALS" is published in London, England, on the fourth Thursday of the preceding month.*

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

# LIGHT-ALLOY BICYCLES

*Concluding from "Light Metals," 1945/8/362, an Account of the Development and Present Status of the Aluminium Bicycle*



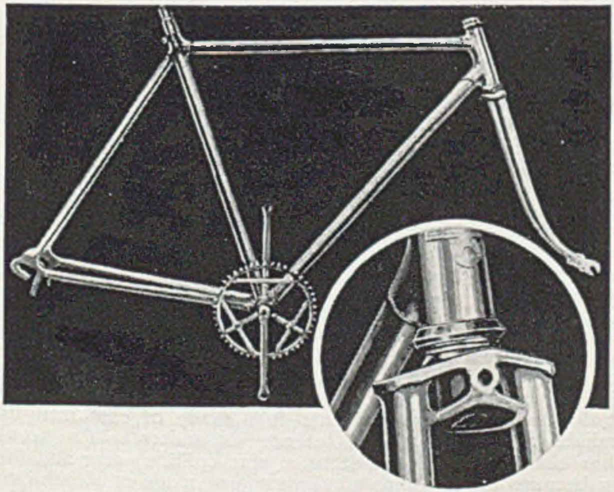


Fig. 5 (above).—Duralumin bicycle frame.

Fig. 6 (left).—The Fonteyn brazed duralumin frame. Shown in the inset is a close-up view of the fork crown.

BEFORE passing on once again to the story of the development of the aluminium bicycle, it might not be out of place to expand slightly upon the comments presented in the last paragraph of the opening section of this account ("Light Metals," July, page 362).

From what has been said already, and from what is to follow, it becomes abundantly clear that the problems involved are not merely technical, nor do they concern only variations in production methods. They are mostly concerned with the rider's reaction to the different "feel" of machines respectively in aluminium and in steel.

This statement is made in the full realization that we lay ourselves open to attack from those outside the bicycle industry. Professional cyclists, however, and manufacturers, are well aware of the somewhat cautious attitude which their colleagues generally adopt towards a bicycle which in any way departs from tradition. Now this attitude, whilst it may be condemned, cannot be ignored, and it is suggested that as the all-light-alloy bicycle is, now, all but a popular reality, lesser problems concerning production and assembly might, with advantage, be pushed a little into the background, whilst attention is given to the vague, but obviously urgent, "psychological" requirements of the user.

In following out the history, therefore, of the development of the light-alloy bicycle as we present it here, sight should not be lost of the interplay of the various factors involved, more especially as, even now, finality has not been reached.

The great difficulty which has always confronted the light-weight bicycle manufacturer, and one which is not yet completely solved, is that of producing a satisfactory light-alloy frame, and the subsequent history of the light-alloy bicycle is largely an account of the evolution of aluminium-alloy bicycle frames, successful from the technical point of view but not often from the angle of commercialization. Naturally, the high-strength light alloys must be selected; alloys of the duralumin type have mechanical properties after heat treatment of the same order as those of steel, and numerous attempts have been made in the past to build bicycle frames from duralumin tube which is available commercially. Many of these have, however, been unsuccessful, due to the difficulty of making satisfactory joints without reducing the strength of the alloy at these points. This requirement of avoiding greatly elevated temperatures automatically eliminates such processes as welding, which nullify the effects of the previous heat treatment, whilst low-temperature soldering is a highly skilled process, and one which, until very recently, did not always give satisfactory results. Most light-alloy fabricators still consider that low temperature or soft soldering is best left alone where resistance to high stresses and reliability are important criteria. Casting has been no solution to the problem, partly because of the lower mechanical properties achieved and partly because of the danger of fine cracking at the bends. The introduction of certain aluminium casting alloys of extremely high strength just before the war, and the experience which has been gained in the sand and die casting of these alloys into aircraft parts of similarly awkward section, used in conjunction with the radiographic and fluoroscopic methods of inspection for porosity, cracks and other defects which have been developed during the war to enable the stringent requirements of our armed forces to be met, lead one to conjecture whether the sand-casting process might not now be worthy of fresh study and experiment as a method of producing light-alloy bicycle frames.

Fig. 7.—Illustrated here is a set of duralumin mudguards.

That the idea of a successful foundry technique has not been entirely abandoned, is demonstrated by an illustration given in the first part of this account. The front fork shown there is probably a gravity die-casting, but, unfortunately, no further structural details are available.

However, to return to our historical discussion, the next development came in 1930, when the Delage concern in Paris commercialized an aluminium-alloy frame made from tubing assembled in lugs by a plug-expander method. It was really of composite construction. The tubes themselves were of aluminium alloy and these were expanded into lugs made of cast iron by means of interior expanders. The front forks, seat tube, rear (pillion) seat and the various stays were also made of aluminium alloy. This frame sold for about £5 10s. in English money.

Between 1930 and 1939, a number of different designs of aluminium frame was

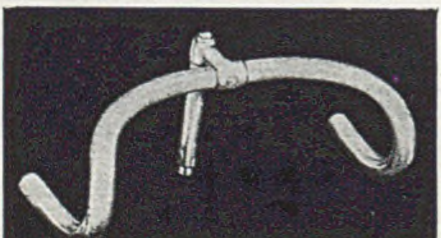


Fig. 8.—Designed for heavy duty, these racing handlebars are in duralumin.

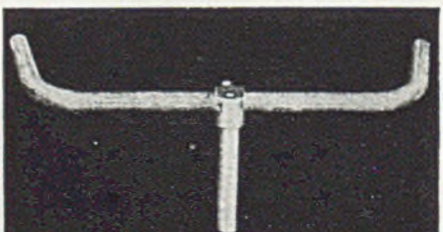


Fig. 9.—Duralumin handlebars with forged duralumin joint to give high strength.

| Description | Track-racing | Road-racing | Roadster | Touring | Current models in steel |
|---|---|---|---|---|---|
| Half-equipped frame with forks, head and bottom bracket bearings, cranks and chain-wheel .. .. .. .. .. .. .. | 2,950 gm. (6½ lb.) | 3,600 gm. (8 lb.) | 3,800 gm. (8½ lb.) | 3,900 gm. (8½ lb.) | 5,000–6,000 gm. (11–13 lb.) |
| Fully equipped bicycle .. .. .. .. .. | 6,900 gm. (15 lb.) | 7,900 gm. (17 lb.) | 8,850 gm. (19½ lb.) | 10,400 gm. (23 lb.) | 11,000–17,000 gm. (24–37 lb.) |

Detailed weights of the different types of bicycle in steel are not shown, as they vary according to the equipment fitted—number of brakes, mudguarding, lighting—but the usual range of weights is indicated showing the above-mentioned weight reduction of 4 to 6 kg. (9–13 lb.).

evolved, each with its own measure of success. Magri and Galmozzi in Milan built up a frame from aluminium-alloy tubing in which jointing was effected by means of expanders for the main frame and by welding in the case of the front and rear forks and the chain stay. The model sold for £11. Back in Paris, Oscar Egg produced a completely welded frame in duralumin tubing which retailed at £10 10s.

*The Delage Bicycle*

In 1933 came an important stage in the development of the light-alloy bicycle frame when M. G. Py invented a successful new method of construction, incorporating jointing by purely mechanical means. Duralumin frames built on this system were produced by the Anciens Etablissements Delage, of 12, Rue Honnet, Clichy, Paris. Such parts as rims, handlebars, seat pins, pedals, chain wheels, mudguards and other fittings were already available in light alloy and, by making use of these, it was possible to place ultra-light machines of various types on the French market. These have been well proved in use and they attained considerable popularity. A Delage duralumin bicycle, completely streamlined by an aluminium shell, was used by M. Berthet on September 9, 1933, when, on a Paris track, he covered the record distance (unpaced) of 48 km. 604 m. (30.2 miles) in the hour.

The essential feature of the Delage (or Py) frame was the use of duralumin tubes fitting into multi-directional sleeve joints or lugs in weldless steel tubing; lugs fabricated from formed and welded sheet were not strong enough to withstand the stresses of fitting and fastening. The duralumin tubes making up the frame were inserted by force into their lugs, making a really tight fit. By means of a chuck, the ends of the various duralumin tubes were then expanded and fixed so as to resist any force tending to pull them out. To allow the entry of the chuck, the lugs were pierced opposite the branches, the aperture being afterwards filled in by means of an autogenously welded piece of sheet under conditions in which the temperature did not exceed 150 to 180 degrees C. A partially slit tapered and shaped sleeve of duralumin tubing served as an internal reinforcement to the whole assembly, which was also pinned diametrically for additional security. The method of jointing will be clear from the drawings in Fig. I ("Light Metals," 1945/8/360). One of the conditions indispensable to a successful job consisted in the very accurate machining of the lugs and tubes, which had to be carried out to within a hundredth of a millimetre (0.0004 in.).

The rigidity of the structure was ensured by a method of fixing according to which the saddle and head lugs were riveted to the light-alloy tubes, the head lugs being held also by two shoulder pieces against the internal reinforcing sleeve. The diameters and gauges of the duralumin tubes were calculated so that RI and EI would be greater than in the case of tubes in the usual type of steel frame, I being the moment of inertia, R the ultimate tensile strength, and E the modulus of elasticity. These are the components which determine resistance to tensile and torsional stresses and the amount of deflection.

In practice, a half-equipped frame was first assembled, consisting of the duralumin frame fitted with front forks, ball-bearing cups in chromium steel for the steering, bottom bracket spindle and bearing shells in nickel-chromium steel, and the chainwheel and cranks, these last three parts being in duralumin. The cranks were increased in section, particularly at the base, to make up for the lower modulus of elasticity of the light alloy. It was found that the Delage half-equipped frame weighed at least 2 kilog. (4½ lb.) less than its counterpart in all ferrous metals.

To produce the complete Delage machine, use was made of duralumin fittings wherever possible. Thus, handlebars were machine-formed, using jigs and chucks, from duralumin tubing heat-treated but not age-hardened. They were fitted with joints in forged or machined duralumin, and stems in duralumin tubing. Mudguards and mudguard stays, racing and roadster pedals, single- and double-threaded hubs, seat pins, and saddle frames were all in machined duralumin. Wing nuts for fastening the wheels, brake levers, cranks, and chainwheels were in forged duralumin. Accessories such as the luggage carrier were made without difficulty in the same material. Wheel rims were made either in duralumin or in magnesium alloy, these materials showing great advantages over steel not only in their lightness but also by reason of their flexibility, which was comparable to that of wood.

The net result of this intensive aluminization was a considerable reduction in weight, of the order of 9 to 13 lb., according to the type of bicycle. The table on the preceding page gives detailed figures.

Thus, fully equipped touring machines in duralumin with three-speed gear and luggage carrier weighed 10.5 kilogs. (23 lb.), compared with 16 to 18 kilogs. (35 to 40 lb.) for corresponding machines in steel. The weight reduction was particularly noticeable as regards the rims, handlebars, hubs, chainwheels and cranks, ranging from 400 to 600 gm. (0.9 to 1.3 lb.) for each of these components. In general, the reduction in weight obtained was 25 per cent.

Due to this reduction in weight, users were able to report that an important stage had been reached in the direction of effortless riding. For example, a trip made previously at an average of 10½ m.p.h. could be covered at 13½ m.p.h. without extra effort; in another case, the length of the daily run was increased without effort from 93 to 137 miles; whilst in a third case an extra 13 to 15 lb. of useful weight could be carried, which was greatly appreciated in this instance, as the rider was a cycle-camper.

Accompanying illustrations show some of the Delage models and their duralumin fittings. Experiments are stated to have been carried out by Delage on the use of magnesium-alloy tubing for the construction of the frame, by which means it was hoped to achieve an even greater reduction in weight. Details and results are, however, lacking.

*Strength of the Delage Frame*

A systematic study of the behaviour of Delage bicycles over a period of several years confirmed that the strength of the machines was actually greater than that of similar steel models. In addition, static tests were carried out both under the conditions specified for Army bicycles and also under conditions corresponding more to actual usage. With supports under the front and rear fork tips, in the first instance, the loads were distributed over the centre portion of the top tube by means of steel sleeves 15 cm. (5.9 ins.) long, and in the second they were borne by the seat tube. The tests were made on a duralumin frame built of 25/28 mm. (0.98/1.1-in.) tubing, and a steel frame of 26/28 mm. (1.02/1.10-in.) tubing, these being the standard dimensions used in building steel and duralumin bicycles of the same type. Results obtained are tabulated below.

Dynamic tests on the road gave full satisfaction and their results have been confirmed by hundreds of users and by highly qualified test riders working over bad surfaces and under the most exacting conditions.

The flexibility of the duralumin frame was found to act as a very efficient shock absorber for the effects of road jolts and vibrations. The frame tubes and other duralumin parts were supplied in the polished state, which ensured considerable resistance to corrosion and an extremely pleasing appearance.

| Duralumin | | | Steel | | |
|---|---|---|---|---|---|
| Load | Height | Deflection | Load | Height | Deflection |
| First Series of Tests | | | | | |
| kg. (lb.) | mm. (in.) | mm. (in.) | kg. (lb.) | mm. (in.) | mm. (in.) |
| 0 (—) | 572 (22.52) | 0 (—) | 0 (—) | 572 (22.52) | 0 (—) |
| 50 (110) | 570 (22.44) | 2 (0.079) | 50 (110) | 571 (22.48) | 1 (0.039) |
| 90 (198) | 568 (22.36) | 4 (0.157) | 90 (198) | 568 (22.36) | 4 (0.157) |
| 100 (220) | 567 (22.36) | 5 (0.197) | 100 (220) | 567 (22.32) | 5 (0.197) |
| 160 (353) | 565 (22.24) | 7 (0.276) | 160 (353) | 564.5 (22.22) | 7.5 (0.295) |
| 170 (375) | 564 (22.20) | 8 (0.315) | 170 (375) | 563 (22.16) | 9 (0.354) |
| Second Series of Tests | | | | | |
| 0 (—) | 572 (22.52) | 0 (—) | 0 (—) | 572 (22.52) | 0 (—) |
| 50 (110) | 570 (22.44) | 2 (0.079) | 50 (110) | 571 (22.48) | 1 (0.039) |
| 90 (198) | 568 (22.36) | 4 (0.157) | 90 (198) | 568 (22.36) | 4 (0.157) |
| 160 (353) | 565 (22.24) | 7 (0.276) | 160 (353) | 564.5 (22.22) | 7.5 (0.295) |
| 200 (441) | 563 (22.16) | 9 (0.354) | 220 (485) | 560 (22.04) | 12 (0.472) |
| 225 (496) | 561.5 (22.10) | 10.5 (0.413) | | | permanent deformation |
| 252 (551) | 560 (22.04) | 12 (0.472) | | | |
| | | no permanent deformation | | | |

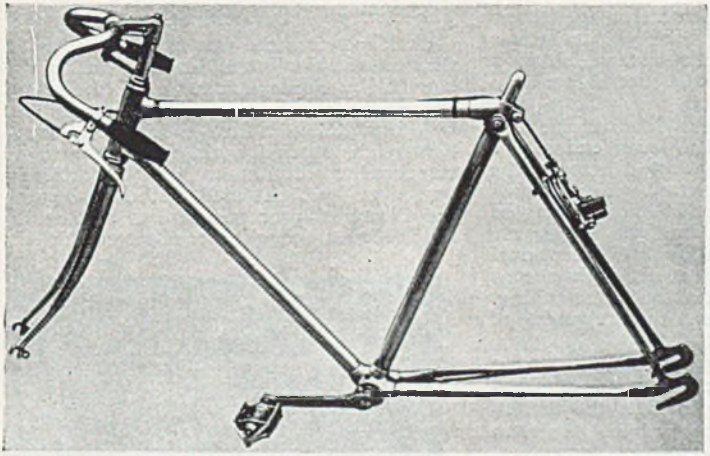


Fig. 10.—With the exception of cranks, pedals and brakes, the front fork and frame assembly shown here is entirely in light alloys.
*(Courtesy High Duty Alloys, Ltd.)*

*The Caminargent Bicycle*

Somewhat similar in principle, but making use of octagonal, instead of round, duralumin tubing, was the Carminargent frame produced in France a year or two after the Delage model by the Etablissements Caminade, Paris. Like the Delage, no welding was employed, and the frame was built up from (octagonal) tubes held in multi-directional lugs, but, in this case, the fixture was by means of bolts, the bolting arrangements being carefully designed to avoid any possible weakening at the joints. The head tube and top and bottom lugs were pressure die-cast in aluminium alloy, whilst the bolts were made in hard aluminium alloy. The duralumin tubes were plugged with vaseline-covered corks to absorb vibration, and, therefore, to reduce the danger of failure by fatigue. In addition, this served to prevent the ingress of moisture. A good grip and accurate alignment were obtained by the use of split lugs and, if necessary, the frame could be dismantled and reassembled without difficulty, whilst the replacement of damaged tubes was a simple matter.

The steel employed in ordinary good-class bicycle tubing is tested for a shear strength of 60 kg. per sq. mm., but the duralumin used by Carminargent would support only 42 kg. per sq. mm. The specific gravity of the light metal was, however, only 2.7 as com-

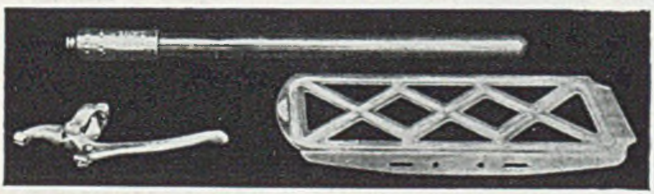


Fig. 11 (left). — Brake lever, pump and luggage carrier in duralumin.

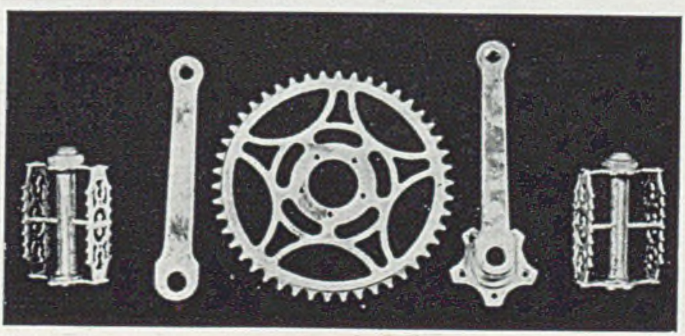


Fig. 12 (right). — Chain wheel, cranks and pedals in duralumin.

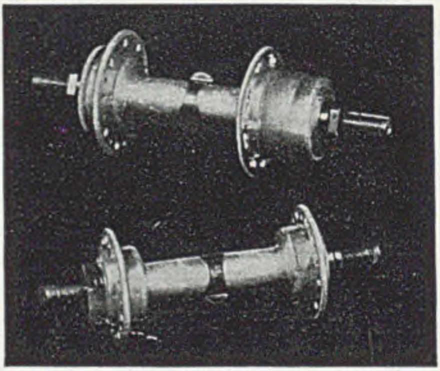
pared with 7.8 for steel, which made it possible to increase the tube section when employing aluminium alloy and yet obtain a product with a lower weight for higher total resistance.

The construction of the Caminargent fork head is interesting. The lower end of the steel tube (one of the few steel items in the machine) had a flange pierced with a number of holes, the aluminium lug taking the forks being cast on to this. The fork blades were in Almasilium, an alloy of exceptional toughness and flexibility, although not so suitable as duralumin for the frame tubing. Almasilium was also used for the tubing of the rear forks.

So far as possible, all fittings were in light alloy, and the result was a considerable saving in weight; in fact, the Caminargent road-racing model weighed less than $13\frac{1}{2}$ lb. This machine sold for 1,750 francs, which compares very favourably with 1,450-1,650 francs for a first-class steel-frame model of any well-known French make on the market at that time. A Caminargent track-racing machine was marketed for 1,550 francs. Two examples of the Caminargent bicycle and of the lugs and other component parts are illustrated.

*The Fonteyn Duralumin Frame*

Shortly before the war it was announced that an all-duralumin frame was to be handled by Fonteyn and Co., Ltd., of 19, Percy Street, London, W.1. Manufactured by Pierre Colin, a well-known continental lightweight specialist, the frame was to be composed of duralumin tubes completely brazed up by a patented method known as the Cavaprud process. It was claimed to have been thoroughly road-tested for six



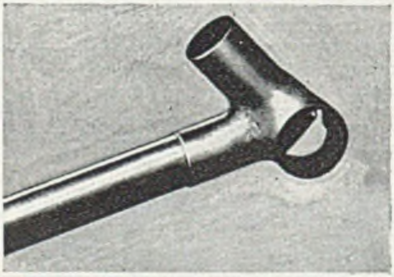
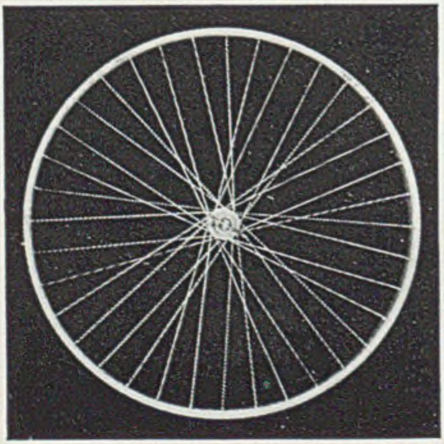


Fig. 13 (right).—Showing how a duralumin tube fits into the bottom brake (see Fig. 5).

Fig. 14 (below).—Wheel with rim, hub and wing nuts in duralumin.

Fig. 15 (above).—Forged duralumin hubs. These components are highly stressed; strong wrought light alloys have shown themselves adequate to meet the demands of Service requirements.



months, with completely satisfactory results. Fully guaranteed, the frame was to cost £9 15s., or a complete machine could be obtained for £21 10s. In appearance, the frame was similar to a brazed-up steel model, but, in weight, it was considerably lighter.

*Hiduminium Bicycles and Accessories*

In the bicycle field, English light-alloy manufacturers and fabricators have made considerable headway, and, before the war, a considerable quantity of home-produced cycle accessories in light alloy were being sold in this country. The most popular items were handlebars, handlebar stems, seat pillars, lamp brackets, and butterfly-pattern wing nuts. The Reynolds Tube Co., for instance, manufactured a very popular range of these accessories in Hiduminium RR56 at competitive prices. The wing nuts were fitted with a hardened serrated steel washer to afford the grip, and were supplied in a highly polished finish. The remaining items were supplied either polished in natural colour or anodized and dyed, whilst the handlebars could also be obtained with a black or ivory celluloid covering. The weights of these components were as follow:—

| | |
|---|---|
| Handlebars | From 9 oz. upwards, according to size |
| Lamp bracket | ¾ oz. |
| Wing nuts ... | 1¼ oz. per pair |
| Seat pillars ... | From 4 oz. upwards, according to size |

These accessories were exhibited at the Bicycle and Motor Cycle Show in 1935, and quite definitely took the public eye.

Reynolds also exhibited an experimental type of aluminium-alloy sports bicycle, which created great interest. With the exception of the spokes, cranks and bearings, which were in steel, the entire metal part of this bicycle was constructed in Hiduminium RR56. The frame tubes were joined by a new method, involving sweating and soldering into lugs, the Alusol low-temperature soldering process being employed. The strength of the Hiduminium alloy is not diminished by heating to 200 degrees C. or so, which was one reason for its choice in this particular instance. The gauge of metal employed was varied to suit the differing requirements of components. Gauge 18-20 was used for the tubes; 16-20 for the forks; 18 for the chain stays; and 19 for the seat stays.

The weight of this machine was 18¾ lb., but it was emphasized that this was the first test machine and that it was not built with a view to reducing weight to the lowest possible limit. The strength and shock-absorbing characteristics of the frame and the general feel of the machine were claimed to be excellent. It was stated that experiments were in hand for the manufacture of aluminium-alloy cranks, but that these would be of much stouter section than normally because of the whip of the metal.

Fig. 16.—The "Superleggera" model bicycle of the Italian "Gloria" concern. Note in particular the double frame construction. This assembly weighs about 8 kilos.

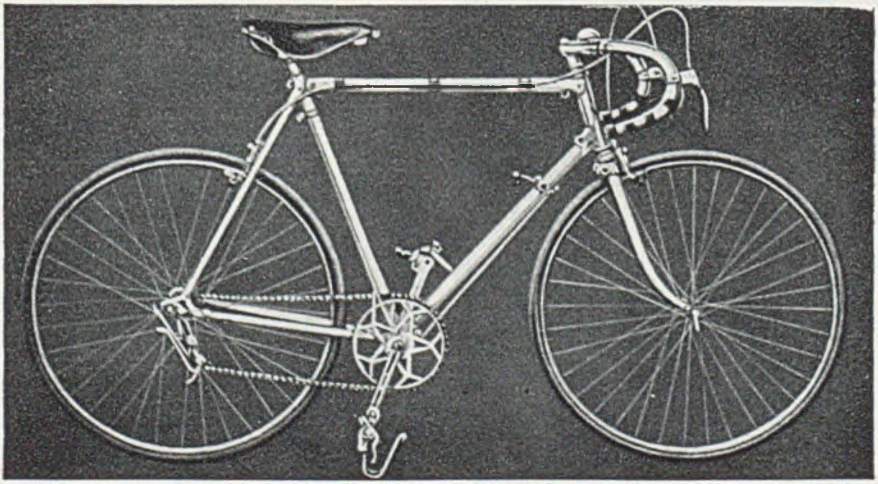


Fig. 17.—The Caminargent sports model, a description of which will be found in the text. This assembly is virtually 100 per cent. light metal.

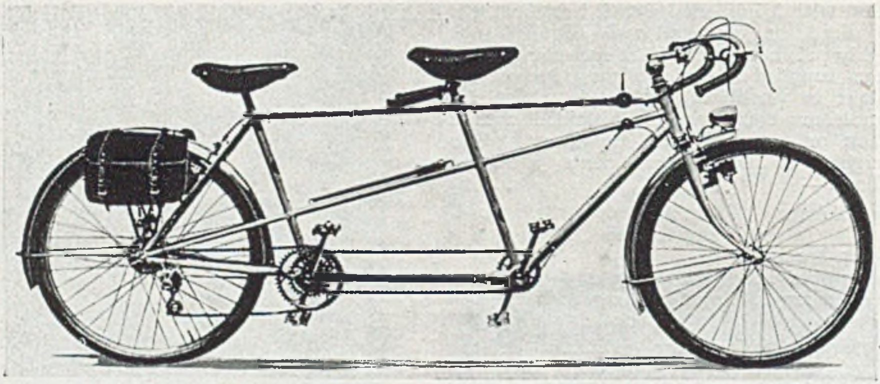


Fig. 18.—All-aluminium tandem; weight 19 kilos.
*(Courtesy Revue de l'Aluminium and Aluminium Union Limited).*

The "Birmingham Mail" of August 22, 1935, published information to the effect that light-alloy bicycles were being manufactured on an experimental scale in Coventry, and that manufacture was to be undertaken on a much larger scale. The alloys used were of the Hiduminium type and, although no details of the method of joining the frame were disclosed, it was stated that the method employed was new.

Fig. 19.—A Caminargent bicycle. The touring model shown here weighs, when fully equipped, 22.9 lb.

The following weight comparisons were drawn between these bicycles and those of steel construction:—

| | |
|---|---|
| Light-alloy racing model ... | 16 lb. |
| Steel frame racing model ... | 22 lb. |
| Light-alloy touring model... | 20 lb. |
| Steel frame touring model... | 30-35 lb. |

Known as the Shortland system of construction, it is understood that the method of jointing the frame consisted of sweating or brazing tubes of Hiduminium RR 56 into lugs cast into the same alloy. The frame was claimed to be immune from distortion and whip in use, and it was priced at £5.

Three other exhibits of interest were shown at the 1935 Bicycle and Motor Cycle Show. Two consisted of aluminium bicycle frames completely fitted up with duralumin parts. They both weighed 12 lb. One, manufactured by Armstrong Cycles, Ltd., was priced at 15 guineas, while the other, shown by the Wearwell Cycle Co., Ltd., cost 16 guineas.

The third exhibit was a series of light-alloy bicycle components and accessories shown by the Constrictor Tyre Co. Wheel rims for tubular and wired-on tyres, wheel hubs, wing nuts, seat pillars, pedals, toe-clips, chain wheels and components of calliper brakes and of the "Osgear" derailleur units were exhibited in the "Conloy" aluminium alloy.

At the Lightweight Cycling Exhibition held in the same year (1935), the Tabucchi Tyre Co., Ltd., exhibited a number of light-alloy rims of the patented Fiamme design made in England in the Hiduminium RR 56, duralumin bicycle frames with a jointing mechanism reminiscent of the Py system, together with a range of duralumin pedals, chain wheels, calliper brakes, handlebars and stems, and wheel hubs fitted with duralumin spoke flanges.

On the Derailleur stand were to be seen

Fig. 20 (above).—Caminargent all-light-metal bicycle; touring model, with balloon tyres.

Fig. 21 (below).—Caminargent bicycle; ladies' model, with semi-balloon tyres.

Cyclo models which could be supplied with duralumin parts as an extra and Simplex models with duralumin sprockets.

A reference to the use of magnesium alloys in bicycle frame construction occurs in Beck's book on the Technology of Magnesium and its Alloys, where there is illustrated the lower bracket of a bicycle frame, quite conventional in appearance, but built-up from magnesium-alloy tubes and a magnesium-alloy casting. It is stated that the results obtained justify the expectation that this frame could be placed on the market at an economical price.

The value of light metals is, of course, not limited to the manufacture of standard accessories. Illustrated is a gasfitter's bicycle in which the specially designed front and rear carriers were built-up of aluminium-alloy tubing and sheet with a consequently far smaller addition to the weight of the machine than would have been the case had steel been employed. Nor is the use of aluminium limited to single-seater bicycles. Illustrated is a light-alloy tandem machine of French origin weighing only 19 kg.

To summarize, it would appear that light alloys have already found ready application in such components as handlebars, handlebar stems, chain wheels, lamp brackets, seat pillars, wing nuts, stays, mudguards and brake levers. Less universal application has been made of light-alloy rims and hubs, cranks, pedal parts and saddle components. The following list gives a rough idea of the difference in weight to be expected between similar components in steel and in light alloy. The actual weight saving will, of course, differ from one fabricator to another, but this list may serve as a rough guide:—

| | Weight saved. oz. | Per. |
|---|---|---|
| Handlebars ... ... | 4 | each. |
| Saddle ... ... | 8 | each. |
| Brakes (calliper or hub) ... ... | 14 | pair. |
| Chain wheel ... ... | 6¼ | each. |
| Sprockets or derailleur | 2 | set. |
| Pedals ... ... ... | 4½ | pair. |
| Toe-clips ... ... | 2½ | pair. |
| Wing nuts ... ... | 1½ | set of 4. |
| Seat pillars ... ... | 2 | each. |
| Wheel hubs ... ... | 3½ | pair. |
| Wheel rims ... ... | 14 | pair. |
| Lamp bracket ... | 1½ | each. |

Fig. 22.—The Caminargent all-light-metal bicycle; Roadster model.

Fig. 23.—Caminargent all-light-metal bicycle; road-racing model weighing 17 lb.

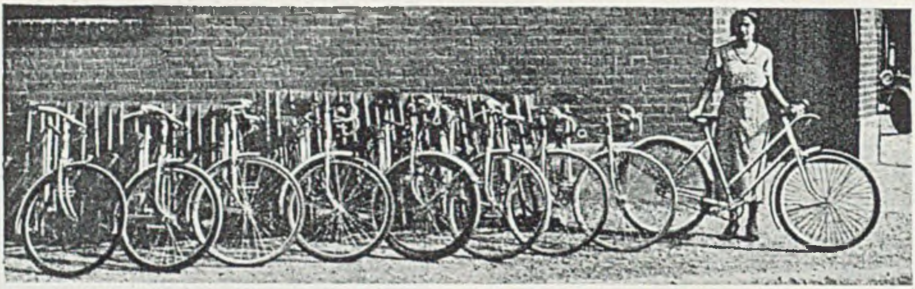


Fig. 24.—Group of duralumin bicycles by Delage.

The forms in which light alloys are employed may be summarized as follow:—

Tube.—Frame, handles, carrier, pump, rims.

Sheet.—Chain wheels, lamp brackets, saddle and pedal parts.

Sections.—Brake levers, mudguards, saddle frames, stays.

Strip.—Mudguards.

Castings.—Frame lugs, bottom bracket lugs.

Forgings and stampings.—Cranks, wing nuts.

Rivets.—Saddles.

The greatest problem which besets the designer of the all-light metal bicycle lies in the construction of the frame. Small numbers of aluminium frames have been produced which have been tried by the acid test of reliability and performance on the road, and which have given every satisfaction. The price, moreover, has not always been prohibitive, although it must be admitted that a satisfactory method of fabrication suitable for mass production at a low price has yet to be evolved. Progress which has been made during the war years in the low-temperature soldering of aluminium and in the casting of the light alloys offers two possibilities for trial and experiment.

A question which naturally arises is to what extent the mass production of light-alloy bicycles would appeal to the cycling public and what sales of such ultra-light machines could one reasonably expect to be reached. In answer, one can only offer conjectures, but the popularity of the light roadster bicycle leads one to conclude that the public is already cognizant of the advantages of light machines. Before the war, some 1,200,000-1,500,000 bicycles were being sold each year in the British Isles alone. Of these, perhaps 50 per cent. were light roadsters and 10 per cent. were machines in a still lighter category. The sales of ultra-lightweight machines, in which every attempt was made to reduce weight irrespective of comfort and cost and, indeed, sometimes of serviceability, amounted to something like 15,000 or perhaps 1 per cent. of the total sales. Successful adaptation of light-metal construction to this 1 per cent. might rapidly lead to the aluminization of the 10 per cent. pseudo lightweight machines, after which an extension of aluminization to a big percentage of the

Fig. 25.—Front and rear carriers on this fitter's bicycle are built up of aluminium tube and sheet.

Fig. 26.—Bicycle by J. A. Phillips and Co.. Ltd. The frame in this instance is of steel, but mudguards, pedals, hubs, front and rear cable brakes (calipers and levers), adjustable stem, handlebar bend and wing nuts are all in light alloy.

remaining machines in the popular class would be only a matter of time.

The "Allgemeine Automobil Zeitung" for 1942/43/5 refers to the fact that the need for economy in petrol in the Axis countries at the time had largely inhibited the development of the privately owned motorcar, but had, simultaneously, emphasized the need for reduction to the greatest possible extent of deadweight. These arguments led to the appearance of many more bicycles on the roads.

The Garribaldina-type bicycle of the Italian Gloria concern was provided with a conventional steel frame, but with forks, mudguards, handlebars and hubs in light metal. This bicycle weighed about 10 kilos. In the case of the Orix and Taurus types, produced by this concern, the whole construction was in light metal, particularly the frames. In this instance, the weight of the machine was reduced to 8 kilos. In the "Superleggera" model, certain assembly difficulties associated with the replacement of steel by light metal were overcome by the use of a double frame.

In "A tire d'ailes," by Georges Houard (Société d'Editions Aéronautiques, Paris, circa 1944), is illustrated a front fork in A.P.M. alloy, weight 430 gms. The alloy in question, which in the heat-treated state has a tensile strength in excess of 40 kg./mm.$^2$, contains 4.5 per cent. copper, 0.45 per cent. titanium and 0.2 per cent. magnesium; with iron and silicon as impurities. The fork illustrated in Fig. 2 in the first part of this account ("Light Metals," 1945/8/360) is probably a gravity die-casting, in which case the tensile strength is 35-42 kg./mm.$^2$, proof stress 22-25 kg./mm.$^2$, elongation 10-18 per cent. and Brinell hardness 100-115.

One point of interest in the development of the light-metal bicycle is worth noting. Most light-alloy developments appear to revolve around the achievements of German and American inventors, with French, Italian and Swiss names also in the running. English names are generally well outpaced, although one would suggest that, in most cases, published accounts underrate the English-contributed nucleus and overrate the German and American padding. However, in this case, the position is very much reversed. The development of the light-alloy bicycle does not appear to have given rise to any surge of high-speed, over-enthusiastic invention, but to have limited itself to sober straightforward development. French names appear highest on the list of contributors, as one might expect, as bicycle racing is one of the principal national sports of France, comparable in popular interest to, say, boxing in this country. Italian and Swiss inventors have worked on the problems, but sound development, particularly in the mass production of bicycle components and in the commercialization of attractive anodized and dyed metal, is mainly the result of English concerns. It is to be hoped that the easing of restrictions on men and materials will enable English manufacturers to go ahead in this small corner of industry in which they have already achieved so important a position.

Fig. 27.—In this later model of the Phillips bicycle, which was exhibited at the Exhibition "Aluminium—From War to Peace" at Selfridges, not only are the components listed in Fig. 26 (above) in light alloy, but, in addition, the chain wheel is also in light metal.

# *Future of the*
# Light-alloy Foundry Industry

*The war years, which have seen grow to maturity the aluminium and magnesium foundry industry in this country, have left as a legacy many severe economic problems which must be resolved at an early date. In the Eighth Edward Williams Lecture, presented at the Annual General Meeting of the Institute of British Foundrymen, on June 16, W. C. Devereux, F.R.Ae.S., M.I.A.E. (Chairman and Managing Director, High Duty Alloys, Ltd.; Managing Director, Magnesium Castings and Products, Ltd.), discussed the nature of these problems and means of approach to their solution. A synopsis of and commentary upon his paper is presented here*

THE Institute of British Foundrymen is to be congratulated upon its choice of 1945 Edward Williams lecturer, for Colonel Devereux, of High Duty Alloys, Ltd., and associated companies, is not only notable among light-metal pioneers as such, but, as his pronouncements always show, is also a publicist of commanding views. His subject —the future of the light-alloy foundry industry—is topical. The industry, having energetically tackled war production on an immense scale with unquestioned success, now asks itself—What of the Future? It may be suggested that Colonel Devereux's topicality is, indeed, enhanced by the recent exhibition—"Aluminium—War to Peace"—presented by Messrs. Selfridge under the ægis of the Aluminium Development Association.

Devereux is initially concerned with putting forward the idea of integration of the industry with national and industrial economy, for as he says, "The light-alloy foundry industry has no separate future, nor has the foundry industry, nor even the metal industry. All are part of the global total of British industry and, moreover, are strongly influenced by industry and trade throughout the world."

British industry as a whole is faced with unusual problems arising out of the ironic position, that, having conquered the Nazi menace, we have become for the first time in history a debtor nation. In addition we have heavy domestic commitments as a consequence of enlightened reforms in social services, leading to higher standards of living, full employment and better educational facilities. These obligations can only be met by continuing tremendous industrial effort to increase productivity from limited man-power and capital. To make the problem even more difficult for British industry, the average American worker produces twice the wealth per hour as the British worker. It will be seen, therefore, that the problem is for bosses and workers alike to solve.

Devereux gives credit to the teams of managements, technicians and workers who have manned the new efficient war foundries, which, whilst showing as great an efficiency as those of the United States, have a doubtful chance of maintaining that efficiency, depending, as they do, on orders for sufficiently large numbers of castings. This is the crux of the problem: if he had said no more, the lecturer would have performed a useful service in so far as he relates the industry to national, and world, economics. For any young industry tends to think of itself as something apart and easily becomes either self-consciously superior or inferior; both attitudes, it may be suggested, are unhealthy.

The lecturer then described the growth of the industry necessitated by the war, giving, incidentally, an interesting estimate of the aluminium foundry industry structure: three firms each with an output in excess of 5,000 tons a year produced 25,000 tons in the peak output stage, seven or eight firms producing between 1,000 and 5,000 tons a year gave about 16,000 tons, while 20,000 tons were the result of the activities of 600 hundred firms of less than 1,000 tons peak year capacity.

In some respects the magnesium foundry expansion was even more spectacular. Die-cast incendiary bombs were produced at the


HIDUMINIUM
ALUMINIUM ALLOYS
This picture shows a 35,000lb. Chambersberg air operated drop hammer, stamping radial engine crank-cases, one of the many forgings made in Hiduminium and supplied to Aircraft and Aero-engine Constructors.
AT THE SERVICE OF THE NATION
HIGH DUTY ALLOYS LTD. SLOUGH

# In peace as in war

WE CARRY ON THE TRADITION FROM OPERATIONAL TO COMMERCIAL AIRCRAFT

**CRANKCASES, PISTONS, REDUCTION GEAR CASES, CYLINDER BARRELS ETC. TOGETHER WITH MANY AIRFRAME COMPONENTS ARE AMONG THE HIDUMINIUM RR. ALLOY FORGINGS WHICH WILL FLY THE NEW AIRCRAFT THE VICKERS "VIKING."**

# Hiduminium

ALUMINIUM ALLOYS

HIGH DUTY ALLOYS LTD SLOUGH

peak rate of 4,327,000 per month, while the weight of other magnesium castings was about 700 tons monthly. As Devereux points out, however, the light-alloy foundry industry has been producing comparatively large castings in both aluminium and magnesium alloys, but indicates that therein does not lie the future " bread and butter " of the industry. The industry is also well equipped with plant designed for small and medium-sized aircraft castings, nicely suited for the production of components for the rehousing programme and automobile construction. Production units dealing with larger castings should be " an asset for the shipbuilding, railway and mechanical engineering fields."

The industry is a complicated structure of concerns of widely varying size and types of production. The structure is so complex, indeed, that Devereux found it necessary to base most of his remarks on the conditions obtaining in the larger foundries; the Rolls-Royce Company's foundries are described as an example in which mechanization and ingenuity were applied to achieve extremely high outputs.

The Rolls-Royce Merlin crankcase is given as an outstanding example of the sort of highly stressed complicated casting turned out in quantity, and produced, be it noted, very largely by girls. At the present controlled price of virgin aluminium the casting is being made for below 2s. 3d. per lb.

But, Colonel Devereux points out, using secondary alloy of high quality, the casting could be made for less than 1s. 7d. per lb. The commercial implications of this price differential are not commented upon, but as users of light-alloy castings will want to buy at the lowest price, producing foundries will be compelled to found these cheaper materials, admittedly adequate for many applications. Secondary ingot production depends, of course, on availability of suitable scrap arising in many cases from fabricating processes in which virgin metal is essential, or is thought to be essential at present. It seems that a curious situation may arise in which primary aluminium, largely replaced by secondary, will have a limited use in merely replacing actual losses of metal in circulation. Perhaps the metal statistics of the industry would show the above consideration to be absurd, but nevertheless it surely is certain that price complications are bound to be encountered. There is, one feels, an unresolved problem here.

The question of price is fundamental in any considerations of the industry's future, and Devereux reiterates his previous plea that no tariff barrier against oversea suppliers of cheap light metals shall threaten the existence of a large and real industry.

It is not absolutely clear if by the words " light metal " in the statement the speaker intended to include magnesium within the terms of his discussion. One could have wished that he had been more explicit in this respect, for cheap magnesium is of little interest to an expanding industry if the use of fabricating " know-how " is conditioned by the supply of metal under restrictive licensing agreements. Devereux makes the tantalizing statement that although the controlled price of magnesium ingot is, at present, 1s. 6d. per lb., high-purity Canadian ingot could now be sold in this country for 1s. 2d. per lb. Some of Colonel Devereux's audience probably questioned (silently) as to who would sell it and on what terms!

But this is a diversion; Devereux's main theme is clinched by his statement that this country cannot afford *not* to take the fullest advantage of the great asset of the light-alloy foundry industry. Mechanization alone did not provide the answer, for it must be remembered that metallurgists did a good job not only in developing new high-strength alloys but in utilization in the so-called secondary alloys.

In reviewing the field of magnesium casting alloys, Devereux pays tribute to American research on the effect of very small impurities on the corrosion resistance of magnesium. He states that the work of Dr. Hanawalt leads to an understanding of the corrosion behaviour of the ultra-light alloys, and with the necessary high-purity magnesium now available in commercial quantities, great opportunities are presented for the use of magnesium alloys in many hitherto unsuitable applications.

The light-alloy foundry industry is dependent upon research—new alloys, new casting processes, new methods of mould and die-making, together with market study, human relations and welfare must all be energetically studied. Technically, however, it is most important not to lose the spirit of initiative and exploitation of discoveries and inventions that was a feature during the war years.

In conclusion, Colonel Devereux's final words may be quoted in full: " High among our plans must rank the means of attracting to our industry young men and women of ability to ensure a continuous supply of new blood at all levels. Conditions of work and pay must bear comparison with those of other industries. If we can fulfil these objectives, and I do not believe there is any doubt that we can do so by hard work, initiative and imagination, then, provided British industry as a whole goes forward with vigour and efficiency, the light-alloy foundry industry will play its part creditably and those in it will be proud to be foundrymen. . . . "

# A CAR FOR BETTER DAYS

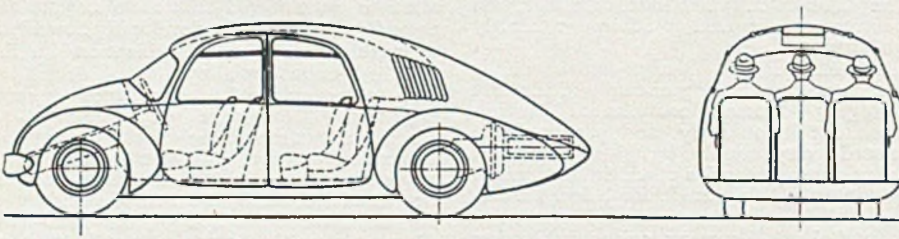
## *Writing in "Automobilia," June, 1945, Adrien Paul Indicates the Part to be Played by Light Alloys in the Car of the Future*

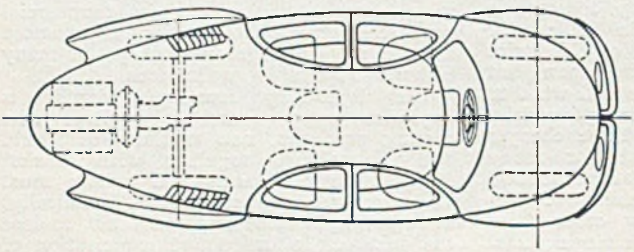
IT is an axiom, although one not always followed, that the car should be made for the passengers. It certainly should be built around their safety and comfort, and be able to put up a good cross-country average speed. Under the head of safety we include a good view for the driver, first-class brakes and road holding: the last is a function of the centre of gravity, rigidity of the chassis and body, as well as steering, suspension (preferably independent for each wheel), and the size and pressure of the tyres.

Apart from the basic requirements of safety, the comfort of the occupants depends upon several things. Seats must support the body properly, passengers and driver should not be cramped, and the car must be at once weatherproof and well ventilated—but the passengers are to be insulated from noise, fumes and draughts. With all these points in mind A. Paul has sketched out a specification to yield most of the features desired.

In his view the body is, in essence, no more than a hull to accommodate the passengers and their luggage, house the engine and transmission, and provide the necessary wheel at each corner for steering and driving. In the interests of low frontal area and low build a horizontally placed 12-cylinder engine is located at the back, driving the rear wheels, thus eliminating the propeller-shaft tunnel of the former car and giving an unobstructed floor.

The mechanical details of the car need not be touched upon here, but the general arrangement of the body, and particularly the seating and ventilation, are of considerable interest. Paul originally hoped to construct his body shell and chassis in one piece by casting it in light alloy, but has reluctantly abandoned the idea of using some material such as Alpax gamma because bulky castings may be expensive when used for anything but very large production runs, and repair costs in the event of a crash are likely to be prohibitive. Accordingly, he has chosen Duralumin as a material for the "skin" of the body exclusively, except for a pair of 8-18 stainless steel bars, spring-mounted at the front of the car, to act as bumpers. Duralumin is chosen because it is available in all the forms required—in sheet, in strip, and in a large variety of rolled and extruded sections. For the side panels and doors, however, Duralinox may be employed as it is slightly lighter than

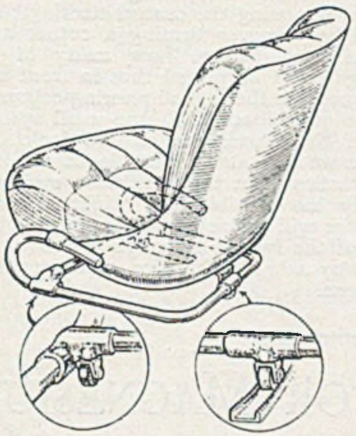




Illustrated above are side and rear views of the post-war car as visualized by Paul; a plan is shown at the left.

Duralumin, and, according to the author, more easily worked.

Possibly, too, this construction might prove in the end to be lighter than making the whole thing as a casting, since although Alpax gamma has a density 5 per cent. lower than that of Duralumin, the gain by its use is really illusory as its strength is about two-thirds of that of the latter. It is probable, therefore, that for a given strength Duralumin would turn out lighter in the end. Perhaps for the mass-production body of the future we may be able to look to the plastic materials reinforced with paper laminate, wood veneer, or eventually, perhaps, metallic bondings.



Seat design for the car as described in this account. The two small inset sketches show the arrangement adopted for adjusting the position of the seat to the driver's convenience. Although not specified as such in the article, it is clear that this assembly offers an excellent chance for the utilization of light-alloy tube and extruded section.

A properly streamlined body is a very roomy affair, and Paul's car takes full advantage of the aerodynamic shape in eliminating the running board and building the body out to the full width. Six passengers are accommodated, each having a separate bucket seat arranged en echelon in two rows of three. The disposition of the "staggered" seats and the rear mounting of the engine have permitted a body profile conforming to the requirements of a proper aerodynamic form. The bracket has been kept narrow, the floor low, and by reason of the special ventilation arrangements, it has been possible to keep the body extremely small for the accommodation provided, and thus keep down skin friction. This can become quite important at the higher speeds. Unlike many designers of so-called streamlined cars, the writer realizes that a good "entry" and clean front are more important than a long tail. He emphasizes, too, that the underside of the car must be flat, unbroken and parallel with the ground, and as near to the road as possible. By abandoning a conventional honeycomb radiator he has kept the air-flow unbroken over the upper part of the car and, by keeping the floor line low, has reduced to a minimum the air stream passing beneath the car and so avoided an area of turbulence below the vehicle which can have a considerable slowing effect.

Some cars in the past have been unpopular by reason of their lowness; passengers have had to bend down when getting in and out. To avoid this the designer has gone to considerable lengths. In the ordinary way this disadvantage would have been more pronounced in the Paul motorcar than in a normal sports saloon by reason of the pronounced "tumble home" of the upper half of the body. However, in the car under discussion, the doors not only conform to the body sides all the way up, but follow the curve round, thus merging into the roof. In this way persons can get in and out quite easily without bumping their heads. But Paul has gone even farther. Each of the outer seats not only slides in the normal way, but is pivoted to turn rearwards and inwards on runners. These seats, moreover, are connected to the door mechanism by a rack-and-pinion device. Accordingly, once the latch is undone, the passenger has only to press back in his seat to be automatically swivelled round towards the already open door. He has then only to stand up and he is in the street. Although ingenious, it would seem this arrangement is "too clever by half," for should a passenger drop, say, a cigarette end into the guide rail, he might find that not only would his seat not go back, but the door would stick. Willing helpers from without would wrench the rack and pinion mechanism and the door hinge, and costly repairs would ensue. One might expect, too, that, as in certain pillarless saloons in the past, to which owners have fitted sunshine roofs, the whole body would be unduly weakened owing to the encroachment of the doors into the roof. This disadvantage would not occur in fact, because the centre portion of the roof consists of a stout box-section member or channel running the entire length of the car, from a point above the windscreen down to the rear window. This member has a twofold function. Primarily a stiffener, it also arranges an ingenious means of air conditioning.

Ventilation is one of the things which designers have, in the past, rather neglected.

All too many provide winding windows in the doors and possibly an opening screen, and decide that their job is done. Except for signalling and asking the way, the windows of the average car are seldom opened; certainly they do not provide ventilation in the true sense of the word.

Strictly, this consists of allowing fresh air in and taking stale air out, in accordance with the passenger's command. In the normal way, opening two windows at opposite sides of the car contributes little to ventilation but causes a particularly unpleasant draught. Clearly the trouble is one of too much pressure and too little direction. Another difficulty, particularly with the streamline body, is to arrange air intake and outlet points in such a way that the smooth air flow over the body is not disturbed.

In this instance the designer utilizes the box section strengthening member mentioned above. Air enters this conduit at a point above the windscreen with considerable force (since that area is a zone of high pressure when the car is in motion). The amount is controlled by the driver by means of a shutter. The air so entering has two functions. The first of these is ventilation. Situated in the sides of the ventilation channel, one above each of the four outer seats, are four little air scoops controlled by the passengers. Being pivoted in the centre like butterfly valves, these scoops may be turned by remote control, either to give an extractor effect or to inject a stream of fresh air from outside. In any event no draught is caused, because the air stream follows the line of the body sides and is thus prevented from blowing upon the passengers direct.

One may criticize this Utopian vehicle on a number of accounts; a rear engine car has more disadvantages than Paul would admit. He suggests, for example, that luggage, spare wheel, and accumulators could all be placed underneath the "bonnet" at the front. But doing so would entail either removing the central steering column entirely or never turning a corner at all. It is hard to see how many of these things could be placed thus in front of the car, because the central steering column can make quite inaccessible the small space left when the wheels are on full lock. The doors we have already mentioned as possibly unpractical, but the ventilation system certainly has possibilities. Light alloys and plastics will undoubtedly play a part in the car of the future, although to what extent and by what techniques still remains to be seen.

# Welding Fluxes for Magnesium

*A Brief Note is Presented on Some Recently Patented Flux Compositions Designed to Overcome Special Difficulties Encountered in Welding Certain of the Newer Ultra-light Alloys*

FLUXES for the welding of magnesium and magnesium-base alloys are covered in British Patent No. 567,725, February, 1945, by Magnesium Elektron, Ltd.; it cross refers to the same company's patent No. 511,137, which covers magnesium-base alloys containing zirconium. It was found that the welding of such alloys in sheet form is difficult because, with many fluxes, there is an accumulation of solid particles of some foreign substance, presumably zirconium oxide, on the surface of the molten metal. Consequently, the company experimented with addition agents in the flux, with a view to converting the foreign substance into a fusible slag, but these experiments were not entirely successful. However, at the same time, certain fluxes having low melting point enabled satisfactory clean welds to be obtained. It is suggested that these fluxes melt and, therefore, shield the metal at a sufficiently low temperature before any appreciable quantities of zirconium oxide are formed. The fluxes have been designed to provide sufficient fluidity at the welding temperature to ensure maximum covering of the metal to prevent oxidation, so that the flux will not have to deal with oxidation products.

The patent states that satisfactory welding of these zirconium-containing alloys can be achieved with the following fluxes:—

| | Flux A. P.c. | Flux B. P.c. |
|---|---|---|
| Lithium chloride ... | 25 | 25 |
| Potassium fluoride ... | 10 | 10 |
| Potassium chloride ... | 35 | 20 |
| Sodium chloride ... | 30 | 45 |

Some variation in the percentages of the constituents is permissible, but the flux should be substantially fluid above about 550 degrees C., although it may not be completely liquid until it is above 600 degrees C.

The patent covers fluxes falling within the following limits of composition:—

| | Per cent. |
|---|---|
| Lithium chloride... | Between 21 and 40 |
| Potassium fluoride | ,, 5 and 15 |
| Potassium chloride | ,, 15 and 40 |
| Sodium chloride ... | ,, 26 and 50 |

Certain of these constituents can be formed during the welding. For example, lithium fluoride and potassium chloride together can replace lithium chloride and potassium fluoride together, whilst the flux still contains the same amount of the chemical elements concerned. Accordingly, the invention embraces in its scope fluxes that fall within the following range, in which the elements themselves are expressed in percentage limits:—

| | |
|---|---|
| Lithium ... ... ... | 3.5 to 7 |
| Potassium ... ... | 11 to 31 |
| Sodium ... ... ... | 10.2 to 20 |
| Chlorine ... ... ... | 38 to 81 |
| Fluorine ... ... ... | 1.6 to 5 |

Expressing fluxes A and B in this manner, they become as follows:—

| | Flux A. P.c. | Flux B. P.c. |
|---|---|---|
| Lithium ... ... | 5 | 5 |
| Potassium ... ... | 25 | 17 |
| Sodium ... ... | 12 | 18 |
| Chlorine ... ... | 55 | 57 |
| Fluorine ... ... | 3 | 3 |

These compositions naturally exclude minor quantities of oxides, other impurities, water or carbon dioxide that the flux may absorb from the atmosphere.

The whole of the flux preferably should be composed of the compounds or elements specified. However, small amounts of intentional additions are permissible of certain non-deleterious substances, such as barium chloride. The invention, therefore, covers a flux containing at least 95 per cent. of the compound specified. The field to which applicable, namely, welding, includes the fusion joining of metal by all forms of gas or electric welding.

Fluxes are a commodity upon which the efficiency of welding is largely dependent. No existing composition entirely satisfies all requirements, therefore new products are not merely welcomed, but the continued research behind their development, as indicated by the foregoing patent extract, is much to be commended.

In order to cater for those whose interests in magnesium alloys and magnesium-alloy fabrication are new, a word may be added on the technique of welding magnesium joints. As is implied in the foregoing notes, the use of correct fluxes is essential, but it should be pointed out that this is only one factor in the successful production of welds. A recent publication of the American Magnesium Corporation gives a summary of welding operations in the following terms:—

(1) Clean and brighten edges of seam to be welded. Bevel or notch edges of heavy sections. (2) Preheat work where the bead is to be started. Preheat welding rod. (3) Apply flux to welding rod and to underside of seam. (4) Rack weld. (5) Straighten out buckles. (6) Cover tacks with flux. (7) Weld seam. (8) Straighten out buckles. (9) Remove flux by citric-acid treatment.

It is, however, in the removal of flux residues from the weld that the permanent success of the welded joint lies, for it will have been noted that the fluxes are mixtures of chlorides. It is vital that excess flux be removed from the weld and that flux contained within the surface of the weld metal be removed also. In the presence of moisture, chlorides have a strong corrosive action with magnesium alloys to such an extent that destruction of a sheet component may easily take place if such salts are not removed.

When the welded component has cooled, therefore, it should be lightly scrubbed with a soft brush and then completely immersed in hot water and allowed to soak so that flux particles in hidden portions may be dissolved. This hot bath should consist of running water to prevent concentration of chlorides in the washing bath. The American Magnesium Corporation suggests, as a second cleaning operation, the immersion in a 1 per cent. solution of citric acid; with an organic acid solution of this strength there is considerable evolution of hydrogen which assists in loosening foreign particles from the weld metal. Although the reaction appears to be a vigorous one, in actual fact a 10-minute immersion in the solution results in a metal loss equal to only about one-thousandth of an inch. To assist the scrubbing action of the gas, it is advisable to rock the component in order that all parts of the joint are acted upon. The component is then removed and washed thoroughly in cold water; trimming of the weld joint, which is the next process stage, should then be inspected for further flux inclusions, which, if present, must be removed by lightly scrubbing again. A dip in cold 2 per cent. caustic soda solution will neutralize any hydrochloric acid that may have been formed due to hydrolysis of chlorides. A careful water rinse must again take place.

If the component is to be stored to await sub-assembly, it is strongly recommended that, as a whole, it be given a protective treatment, such as the acid dichromate dip.

# ALUMINIUM—— *from* WAR TO PEACE

*As a supplement to the review of the exhibition "Aluminium—from War to Peace," published in the July issue of "Light Metals," pages 321-341, we present here a list of exhibitors, together with a short note of the various items exhibited by each. The list is arranged alphabetically and, whilst it is thought to be reasonably complete, no responsibility can be accepted for omissions. Concluding the list will be found a number of exhibits, the suppliers of which have not, to date, been ascertained with certainty :*

C. A. Abrey, Ltd.—Nursery furniture, comprising cot, chairs, table and tea trolley.

Acorn Products, Ltd.—Anodized table lamps and shades.

Air Control Installation, Ltd.—Two castings and propellers.

Allen and Hanburys, Ltd. — Operating table, surgical instruments.

Alumax, Ltd.—Hollow ware of various types.

Alumilite and Alzak, Ltd.—Anodized bowls, decorative "Diana" panel in five-colour anodizing.

Aluminium Plant and Vessel Co., Ltd.—Juice presses.

Aluminium Window Co., Ltd.—Casement windows.

Anotints, Ltd.—Anodized vases.

Amac Refinements, Ltd.—Sanitary toilet cabinet.

Arc Manufacturing Co., Ltd.—Cots.

Ascot Gas Water Heaters, Ltd.—Ascot water heater.

Benjamin Electric, Ltd.—General lighting throughout the exhibition, including fluorescent lighting, electric ceiling fittings and reflectors for industrial and domestic use.

J. Beresford and Son, Ltd.—Tip-up hand-basins.

Birmetals, Ltd.—Aluminium alloy dinghy.

Fredk. Braby and Co., Ltd.—Milk churn.

Bristol Aeroplane Co., Ltd.—"Hercules" aircraft engine.

British Aluminium Co., Ltd.—Anodizing—quality sheet, etc., employed in Exhibition features.

British Pressed Panels, Ltd.—Window.

B.T.H. Electric Co., Ltd.—Vacuum cleaner.

Bulpitt and Sons, Ltd.—Hollow ware of various types.

Burnley Aircraft, Ltd.—"Burnley" engine units, square gas-heated household copper.

H. Burns and Co., Ltd.—Vase-type table lamp and shade.

R. Cartwright and Co., Ltd.—Door fittings.

Cellon, Ltd.—Special lacquers to match anodic finishes. Paints for aluminium house.

Centrup, Ltd.—Aluminium package kitchen unit (gas), bookshelves, cupboard, aluminium kitchen and bathroom unit.

Clarke-Chapman and Co., Ltd.—Searchlight reflector and bathroom mirror, bath in aluminium with specially anodized surface.

Collapsible Tube Mnfrs. Assn.—Collapsible tubes.

John Dale, Ltd.—Hollow ware of various types. Wall plaques, decorative fire-screen.

De Havilland, Ltd.—"Gipsy Queen II."

Desoutter Bros., Ltd.—Artificial limbs and various electric tools.

M. C. Dizer, Ltd.—Vacuum cleaner.

E.D.P. Production, Ltd.—Film strip projector.

Ewart and Sons, Ltd.—The Ewart New Empire water heater.

Ferranti, Ltd.—Electric fire.

Foil Rollers Assn.—Foils for insulating, wrapping, embossing, etc.

J. Starkie Gardner, Ltd.—Seal beaten from sheet, mural study—the Aluminium Story to design by Ralph Lavers. Study comprising curved bay window with anodized aluminium wall panels, writing desk, revolving chair, lamp; wrought decorative panel door machined from walled aluminium slab with surround. Bathroom comprising aluminium anodized wall panels, bathroom fittings, wall panels illustrating fabrication and processing of aluminium.

General Gas Appliances, Ltd.—New connector radiant.

Grantham Boiler Co., Ltd.—Drying cupboards.

Gyproc Products, Ltd.—Insulating plaster board faced with aluminium.

Hague and McKenzie, Ltd.—Hollow ware of various types.

Harborough Construction, Ltd.—Domestic wringer and household steps.

Harland Engineering Co. — Expanding pelmet.

High Duty Alloys, Ltd.—Garden furniture and wheelbarrow, companion set, garden chair.

Hoover, Ltd.—Vacuum cleaner.

Hoskins Sons, Ltd.—Household trolley.

I.C.I. Metals, Ltd.—Lamp standard.

E. and E. Kaye, Ltd.—Garden chair, hotel hat and coat stand, tubular stool and glass top round table (tubular).

Lea Bridge Industries, Ltd.—Upholstered chair.

Lines Bros.—Toy motorcar, other toys, including railway engine, small motorcars and aeroplane. Perambulator and doll's pram.

London Aluminium Co., Ltd.—Hollow ware of various types. Two aluminium repoussé vases, cocktail shakers.

J. Mandleberg and Co., Ltd.—Aluminium printed cloth.

Metal Box Co., Ltd.—Vegetable rack, linen basket.

Metal Products, Ltd.—Cigarette lighters.

D. Napier and Sons, Ltd.—" Sabre " engine.

New Geyser, Ltd.—The " Villa " circulator.

New Welbeck, Ltd.—Vacuum cleaner.

Newton, Shakespeare and Co., Ltd.—Hollow ware of various types.

Northern Aluminium Co., Ltd.—Cocktail stool, typist's chair, two armchairs with fixed arms, waste paper basket, " Sunray " clock, extending ladder, showcases.

Perkinson Stove Co., Ltd.—" Renown " cooker (anodized).

Perry Barr Metal Co., Ltd.—Folding wall table for use on shipboard.

J. A. Phillips and Co., Ltd.—Bicycle.

Piston Mnfrs. Assn.—Composite exhibit of pistons.

The Plessey Co.—Car and wireless components.

Exors. of P. Pritchard, Esq.—Racing hydroplane.

Radiation, Ltd.—The Radiation water heater, health ray heater, " Nocturne " portable heater.

Rawlplug Co., Ltd.—Electric hammer and mechanical hammer.

Redwing, Ltd.—Aluminium electric kitchen to design of E. R. Gilbert.

E. S. and A. Robinson, Ltd.—Special printing for text of murals, etc.

Reynolds Tube Co., Ltd.—Cycle fittings.

Rolls-Royce, Ltd.—" Merlin 61 " aircraft engine.

Rowntree and Co.—Foil wrapped confectionery.

J. V. Rushton, Ltd.—Anodized vase. Electric fire in anodized aluminium, anodized desk lamp with universal adjustment, lamp standard and shade, cabinet ashtray.

Salopian Engineers, Ltd. — Aluminium tubular scaffolding.

Sankey-Sheldon, Ltd.—Ship's furniture, comprising writing desk and wall cabinet, wash-stand, chest of drawers.

Stiles Engineering Co.—Juice presser.

Universal Boiler and Engineering Co., Ltd. —" Verseo " electric wash boiler and wringer.

Wardle Alloys, Ltd.—Toy constructional set.

E. R. Watts and Sons, Ltd.—Scientific instruments.

Wiggins-Sankey, Ltd.—Casement window.

Williams and Williams, Ltd.—Casement window.

Wilson and Mathieson.—Cast heated domestic copper.

S. Wolf and Co., Ltd.—Electric drills.

J. Wright and Co., Ltd.—The " Luma " heater.

**Unclassified.**—Curtain rails and fittings, valves, couplings, propellers, wall cabinet, garden rake, shooting stick, figured tray, chased trays, large bowls, ashtrays, table lamp, canisters, small anodized pails, tankard, coal tongs, nutcrackers, knitting needles, horseshoes, racing plates, vase, coffee percolator and tray, pen and ink stand, notepaper rack, cigar case.

# ALUMINIUM AND MAGNESIUM IN THE ELECTRICAL INDUSTRIES

*Continuing his Account from "Light Metals," 1945/8/287, B. J. Brajnikoff Passes to a Consideration of the Theory and Practice of the Use of Aluminium Insulated by Anodic Treatment for Electrical Windings*

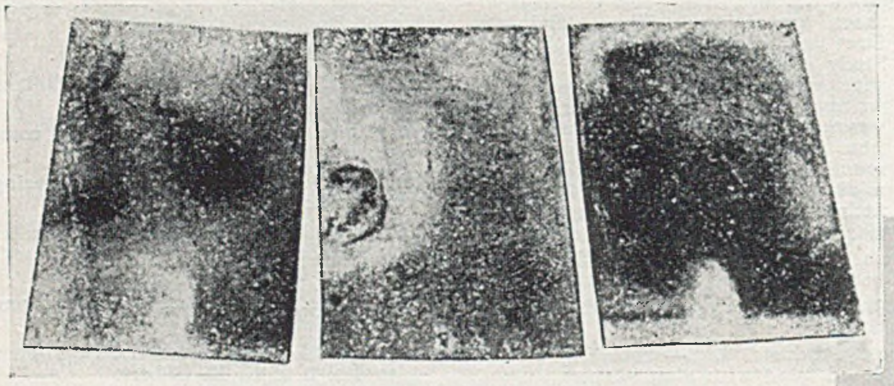
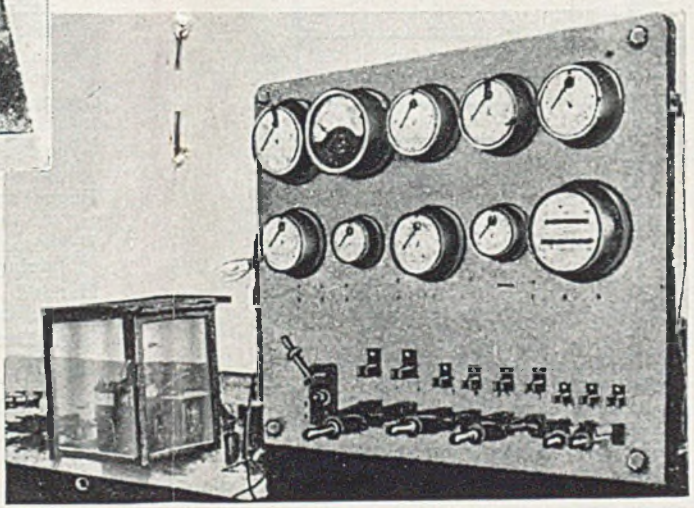


Fig. 1 (above).—Local defects in anodic film due to non-uniformity of the electric field when operating the bath at high current density. Fig. 2 (right).—View of the experimental switchboard for control of anodic baths. (Russian Electrotechnical Institute.)



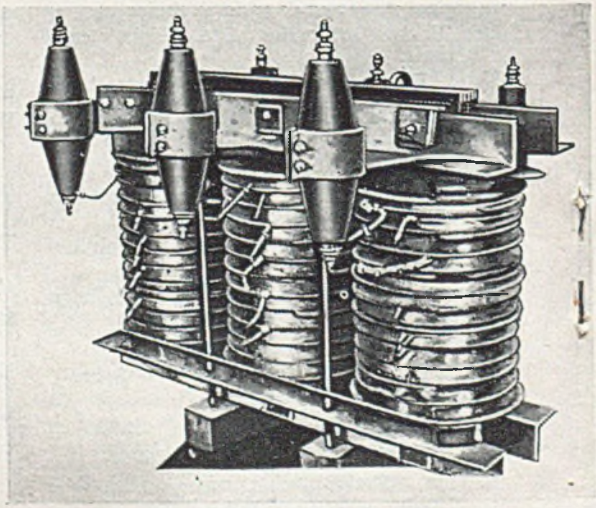


Fig. 3 (right).—Three-phase power transformer (transformation co-efficient 6,600/38 volts, 2.0 kVA) with anodized aluminium winding.

ELECTRICAL materials have played a vital role in the progress of modern engineering. Their characteristic properties, in the final analysis, determine the service qualities of electrical machinery apparatus, and transmission and distribution equipment, both from the standpoint of design and construction, and in regard to economy and reliability of performance under service conditions. On the nature of such materials depends the dimensions of electrical machines and installation components, as well as the maximum output which it is possible to obtain from a single unit.

The never-ceasing process of developing novel applications of electrical equipment to the diverse branches of industry, communications, transport, household, agriculture, and other fields, has transformed the modern generating stations and their working aggregates, into colossal structures, compared to which the "cyclopian" steam engines of a short while ago, appear as toys.

The vast territories embraced by the service of electrical energy derived from one or several power stations, interlinked with each other, make it imperative to raise the electromotive force to a very high level for operating long transmission lines. The latter circumstance, naturally, necessitates new and still more exacting formulations of electrical-construction materials, both in the domain of conductors and that of insulators. Conversely, every notable discovery or advance achieved in the technology of electrical materials serves as a fresh stimulus for further improvements in design and construction of plant.

*Inorganic Versus Organic Dielectrics*

The various electric insulating substances widely used nowadays, such as papers, textile fabrics, natural and synthetic rubbers, resinoids, oils and numerous other compounds, notwithstanding very considerable achievements in insulation technique for the past decades are, as yet, still not free from a number of inherent drawbacks.

To begin with, the cost of these materials themselves, as well as the expense connected with the operation of the technological processes for insulating current-carrying components is, generally speaking, rather appreciable; moreover, many of these substances are, at the moment, in short supply. A relatively low dielectric strength and non-uniformity of structure inherent in these substances compel the designer to make allowance for a considerable thickness of insulation, which leads to an increase of

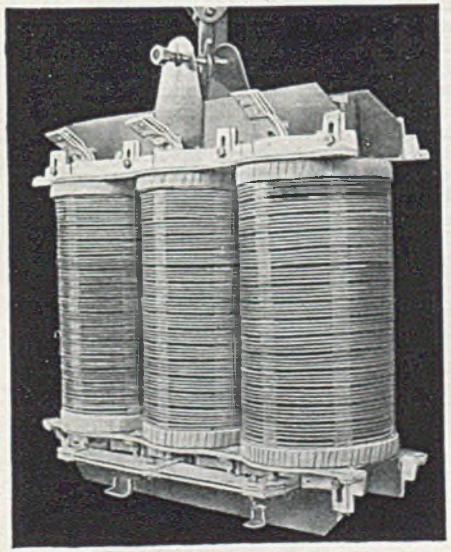


Fig. 4 (above).—Three-phase core-type power transformer (partially assembled) with aluminium windings anodized by the "Oxal" method, as practised in Italy.

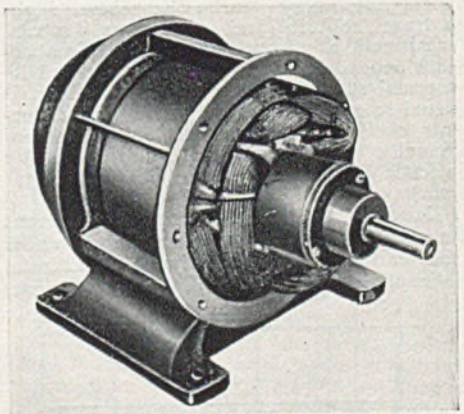


Fig. 5 (above).—Asynchronous motor (220 volts, 2.5 kw.) with stata winding of anodized aluminium.

overall dimensions and weights of the resultant products. The thermal stability of most organic materials is relatively low, a factor which usually restricts the permissible current-load of the insulated conductors, apart from the fact that their heat conductivity is extremely small, which impedes the release and dissipation of the heat evolved by the flow of current in the circuit. In addition, these materials are subject to ageing, are often hygroscopic, and sometimes not too resistant to the action of chemical reagents occurring in the atmospheres of urban districts and in the neighbourhood of electrical machinery.

In the light of these considerations, it is not difficult to deduce that increased interest displayed of late in dielectric substances of inorganic nature is fully justified. Of mineral dielectrics in use for the construction of electrical apparatus, mica and asbestos have secured the widest sphere of application as materials offering distinct advantages owing to their high stability to heat. In a large number of types of electrical machinery (turbo-alternators, high-voltage motors and generators, special machines) a primary requirement is absolute dependability of the insulation and its thermal stability. In these instances, it is usual to employ mica due to its high dielectric coefficient (from 4 to 8) and exceptionally great resistance to rupture by electric discharge (about 2,000 kilovolts/cm.)

Mica is used in the form of numerous composite dielectric materials, known under the various trade names, such a Micanite, Micapholium, etc. However, world

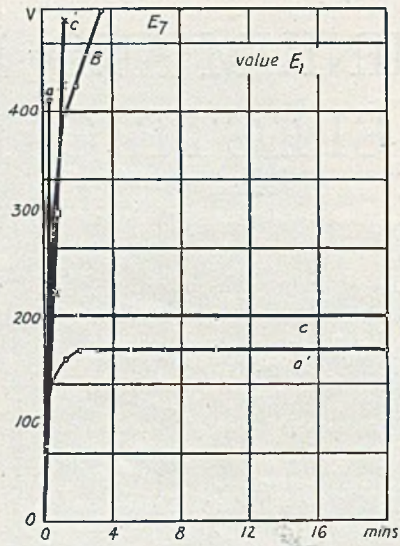



Fig. 7.—Curves for formation voltage for anodic baths operating on direct current (curves a, b and c), and for alternating current (curves a′ and c′). Curves a and a′ refer to $Na_2B_4O_7$ baths, curve b to $(NH_4)_2CO_3$, and curves c and c′ to $NaHCO_3$ baths.

reserves of suitable grades of mica are limited and, moreover, this substance is rather costly on account of difficulties associated with its geological occurrence and winning. Further, micas of various origins exhibit different physical and dielectric properties, varying in dielectric strength, permittivity, dielectric losses, mechanical characteristics of breaking strength, hardness, flexibility, cleavability, as well as chemical and thermal stability. Again, the tangential properties of mica (i.e., along the cleavage plane) differ appreciably from those in a direction perpendicular to the cleavage plane, an aspect which, in a number of cases, has to be considered in problems of design. Thus, it may be seen that mica is costly, in comparatively short supply and, owing to its peculiar crystalline structure, its application is much hindered. The bonding of mica composite dielectrics, as, for instance, Micanite, is a labour-consuming process, and such composites represent the materials deprived of a number of advantages inherent to natural mica in spite of any increased uniformity obtained.

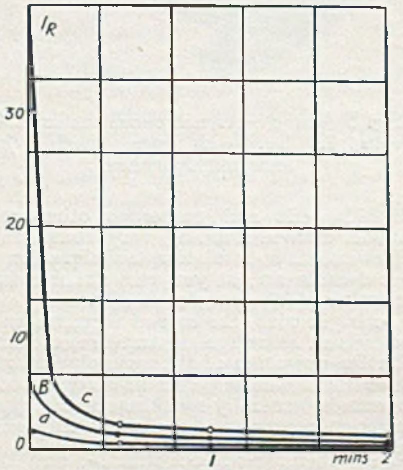



Fig. 6.—Formation current curves for anodic baths with alkaline electrolytes: a, $Na_2B_4O_7$; b, $(NH_4)_2CO_3$; c, $NaHCO_3$.

Compared with the latter, they show a lower stability to heat and spark action, are more compressible, and are subject to ionization and ageing. Asbestos is hygroscopic, frequently contains semi-conducting admixtures, and forms a loose, voluminous insulation, which is very imperfect from the dielectric point of view.

*Film of Aluminium Oxide as Dielectric*

In the search for insulating substances free from the shortcomings enumerated, we find an entirely new principle in the utilization of films formed on, and by, the conductor itself. In addition to dielectric films of the oxide type, certain metals can also be insulated by films of sulphides and by means of salts of organic acids. Such dielectric films produced on the surfaces of metals are distinguished by the possession of extremely interesting insulating and physico-chemical properties.

Amongst the oxides of the metals and semi-metals, are represented both perfect insulators as well as semi-conductors, possessing a complex mechanism of conductivity. The special behaviour displayed by these oxides is advantageously utilized in electrical technology, where, for example, peculiarities in the conductivity of copper oxide is turned to good account in rectifying alternating current. The breakdown of lead peroxide is utilized in the lead interrupter, whilst coatings of iron oxide serve to insulate the laminæ composing the cores of transformers and rotors. Silicon oxide in its various forms, notably as quartz, is one of the most valuable dielectric materials and possesses certainly other electrical characteristics of vital importance to the industry.

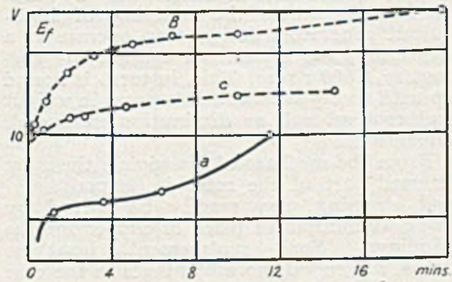
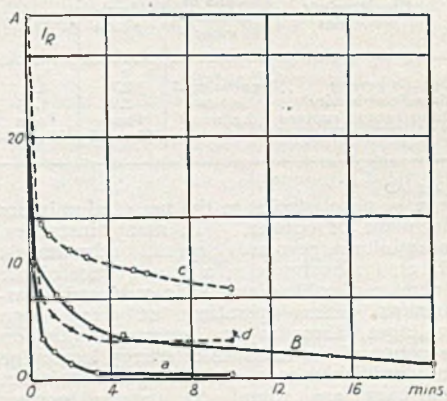



Fig. 8 (above).—Formation voltage curves for acid electrolytes: a, $H_2SO_4$ and direct current; b, $(COOH)_2$; c, $H_2CrO_4$ and alternating current. Fig. 9 (right).—Formation and current curves for acid electrolytes: a, $(COOH)_2$ and direct current; b, $H_2SO_4$ and direct current; c, $H_2CrO_4$; d, $(COOH)_2$ and alternating current.

Magnesium oxide, again, peculiar for its high melting point and thermal stability, is widely used as an insulating material in electrical furnaces, both of the resistance and induction types. Other oxides or mixtures of oxides, particularly of the rare earth metals, have, in the past, found use both as insulators at normal temperatures and as conductors at very high temperatures. At the moment, however, aluminium oxide from the structural standpoint attracts the greatest interest.

In so far as we are concerned with the study of the relative merits of aluminium and copper in electro-technology, it is appropriate, in the first instance, to summarize the fundamental properties of both metals. This has been done in synopsis form in Table 1, the values in which refer to the materials in the form of hard-drawn (unannealed) wire.

Analysing values, we arrive at the following conclusions: (1) In all cases where the designer is restricted by overall dimensions of the projected equipment, the use of copper offers great advantage, as for identical cross-sectional areas of both metals an aluminium conductor will offer a resistance to the flow of electric current about 1.65 times greater than that of a copper conductor. This consideration is frequently to be reckoned with in the designing of




machines and apparatus for heavy current loads. On the other hand, if it be possible to cope with a slight reduction of electro-conductivity, then the replacement of copper by aluminium to the same cross-sectional area will give a weight reduction of some 66 per cent. (2) To substitute for the copper conductor an aluminium conductor of equivalent electro-conductivity, we have to provide an aluminium cross-section 1.6 times larger. In this event, the weight of the aluminium conductor will be half that of the copper conductor.

Thus it follows that, if we be restricted to only a small degree in regard to cross-section, as in the case of overhead transmission lines, we are in a position to obtain a conductor the weight of which is halved, and which makes possible lighter construction of line supports and insulators and facilitates erection and repair work.

With respect to the comparative cost of insulation as normally employed in practice, this will be slightly higher for an aluminium conductor of equivalent electro-conductivity, as the periphery of the aluminium wire will be 1.28 times greater than that of the copper wire. Nevertheless, this limitation may readily be offset by the following consideration. A series of recent investigations have shown that, taking into account the better heat dissipation of the aluminium conductor (associated with increase of diameter), the accepted rates of 1.67 between copper and aluminium in terms of their respective conductivities can be reduced by at least 10 per cent., with a corresponding saving in insulation cost.

Hence, in all the cases where there are no objections from the standpoint of compactness of the machine structure, there can be no obstacles to the use of aluminium in place of copper. In many instances, aluminium possesses special advantages. Thus, for example, as a consequence of the increase of cable diameter in overhead transmission lines operating at very high voltages, there is an important gain on account of the decrease of energy losses due to diminished corona discharge; aluminium bus-bars are found to possess greater resistance to arcing than copper bars; this may be attributed to the protective action of the film of aluminium oxide, as well as to the greater heat capacity of the light metal (0.2 Calorie/kg. per degree C. for Al. as against 0.1 Cal./kg. per degree C. for Cu), and its greater heat of fusion (77 Cal./kg. for Al compared with 43.3 Cal./kg. for Cu).

Table 1.

| Characteristic properties | Units of measurement | Aluminium | Copper |
|---|---|---|---|
| Specific gravity .. | grams/cm.$^3$ | 2.7 | 8.9 |
| Specific resistivity .. | $\mu\Omega$ cm. | 2.9 | 1.75 |
| Resistance to rupture | kg./mm.$^2$ | From 20 to 22 | From 40 to 44 |

Even without the oxide insulation, aluminium can be advantageously employed in place of copper for the winding of rotors of high-speed electrical machines with the object of reducing weight and so decreasing mechanical stresses in the body and teeth of the rotor. The windings are held in position by means of suitable bindings, usually of iron wire, which, again, may be replaced by an appropriate aluminium-base alloy, such, for instance, as aldrey. Use of aluminium is also of value for the winding of load-moving equipment of various types (for example, lifting magnets, etc.), and for the wiring and winding of electrical apparatus for aircraft.

Table 2.

| $\gamma$—Series | | $\alpha$—Series |
|---|---|---|
| Hydrargilite.. .. | $Al(OH)_3$ | — |
| Bauxite .. .. | $AlO_2H$ | Diaspore |
| $\gamma$—Aluminium oxide | $Al_2O_3$ | Corundum |

In particular, windings of rotors for high-speed turbo-generators offer especially wide possibilities for the utilization of light metal. Substitution of copper by aluminium facilitates the building of high-output generators designed to operate at a speed of 3,000 r.p.m., as against the customary 1,500 r.p.m. This, in turn, is bound up with a very substantial decrease in weight and cost as well as diminution in overall dimensions.

From the mechanical viewpoint, the most stressed part of the rotor is its periphery, and stressing may readily be halved by using aluminium in place of copper for the windings. Such replacement, however, offers, in general, no advantages in the case of small-diameter rotors, for, assuming the wire be insulated in the usual manner (i.e., not by means of an anodic film), the increased slot diameter required to accommodate light-metal windings of equivalent conductivity leads to serious reduction in the strength of the rotor teeth. In the case of large-diameter rotors, the effects of increased slot width need not be so significant.

Turbo-generators with outputs from 50 MVA to 7,500 MVA, running at 3,000 r.p.m., with standard insulated aluminium

Table 3.

| Additions | | Breakdown potential $E_d$, volts | Breakdown potential $E_d$ during bending around loop 10 mm. diameter, volts |
|---|---|---|---|
| Metal | Per cent. | | |
| Lead .. .. | 3 | 280 | Appearance of a crack |
| Tin .. .. | 5 | 50 | Appearance of a crack |
| Manganese .. | 3 | 280 | Appearance of a crack |
| Copper .. | 2 | 200 | 200 |
| Copper .. | 5 | 260 | 200 |
| Copper .. | 6.5 | 220 | 200 |
| Magnesium .. | 3.5 | 400 | Appearance of a crack |
| Iron .. .. | 3 | 300 | Appearance of a crack |
| Cadmium .. | 3 | 280 | Appearance of a crack |
| Aluminium, cast | — | 300 | Appearance of a crack |
| Aluminium, rolled | — | 370 | Appearance of a crack |
| Silicon. copper | 20.3 | — | Appearance of a crack |
| Ternary system | 3 | 280 | Appearance of a crack |

windings, have demonstrated the advantages of light metal in this regard and encouraged designers to extend still further the range of its application.

One of the most important advantages of aluminium is its ability to be easily coated with a reliable insulating film of its oxide. Such a film, which is quickly formed on the surface of freshly cut aluminium within a small fraction of a second, prevents further penetration of oxygen into the body of the metal and guards against the onset of corrosion. At the same time, it should be borne in mind that this very layer of aluminium oxide creates well-known difficulties in the soldering of aluminium and is the cause of the unreliability of electrical contact between aluminium components.

Table 4.

| Nature of treatment | Breakdown potential prior to corrosion, volts | Breakdown potential after onset of corrosion, volts | Loss in weight, per cent. |
|---|---|---|---|
| Unanodized .. | — | — | 75.09 |
| Unanodized .. | — | — | 44.9 |
| Unanodized .. | — | — | 52.25 |
| Anodized by means of A.C. | 250 | 240 | 8.67 |
| Anodized by means of A.C. | 200 | 180 | 10.03 |
| Anodized by means of D.C. | 660 | 340 | 9.52 |
| Anodized by superimposed A.C. on D.C. .. | 730 | 600 | 3.13 |

The insulating properties of this oxide film have been known for a long time. Thus, as far back as 1903, Hopfelt put forward the suggestion that the natural film be used as a dielectric to insulate aluminium conductors in contact with each other where potential differences not exceeding a few tenths of a volt were involved. Where, however, differences of potentials approach an order of practical importance, it is necessary to augment the thickness and mechanical strength of the film and to improve its dielectric properties.

Despite a good deal of work devoted to the subject, and numerous patents, the wide use of aluminium-oxide insulation has been hindered owing to the two following reasons: (1) Its inadequately high dielectric strength and practical difficulties in increasing this by merely increasing the thickness of the oxide layer; (2) difficulty in producing a film of aluminium oxide of sufficient elasticity to ensure ready winding.

In a great measure these difficulties have been surmounted by the systematic researches conducted since 1930 at the Russian Electrotechnical Institute. Improved dielectric strength combined with higher elasticity as achieved here open up extensive possibilities for the utilization of the oxide insulation in the construction of a large number of electrical machines and apparatus.

It has been established that it is perfectly possible to obtain (as a minimum) the equivalent replacement of copper by aluminium, that is, with a machine of the same overall dimensions without alteration of design. It is also feasible to derive from the machine identical power and other electrical characteristics, with simultaneous reduction in weight. Further, if we are prepared to make certain allowance for a slight decrease of efficiency (if a machine be redesigned this decrease might possibly be quite negligible), and permit working at higher temperature, then it is possible to get, with the same overall size of machine, power outputs 50 per cent. to 75 per cent. greater than with copper winding and ordinary insulation.

Particularly important properties of the oxide insulation are in application to machines designed to meet varied conditions of service under heavy load requiring a high starting torque (motors for coal-cutting machine, crane motors, and the like), where efficiency characteristics play no essential role, whereas momentary overheating represents the main cause of damage.

Table 5.

| Nature of treatment of the test-pieces | Change in weight gm. | Breakdown potential prior to corrosion, volts | Breakdown potential after 128 days of corrosion, volts |
|---|---|---|---|
| Unanodized .. | 0.1116 | 0 | 0 |
| Unanodized .. | 0.1256 | 0 | 0 |
| Unanodized .. | 0.1051 | 0 | 0 |
| Anodized by means of D.C. | 0.0313 | 1,000–1,200 | 1,000 |
| Anodized by means of D.C. | 0.0006 | 340 | 550 |
| Anodized by means of A.C. | 0.0056 | 240 | 330 |
| Anodized by means of A.C. | 0.0094 | 180 | 270 |
| Anodized by superimposed D.C. on A.C. | 0.0348 | 600 | 650 |

It is of special importance to point out that, in the same manner, oxide insulation can be obtained on a suitably constructed bi-metal, such as copper-aluminium. This circumstance is of obvious advantage, as the production of a bi-metallic conductor (copper with an aluminium cladding), duly anodized, affords a possibility of combining the high electroconductivity of copper with the valuable qualities of aluminium oxide insulation, namely, vanishingly small thickness, thermal stability, high heat conductivity, and good mechanical strength.

The various methods designed to produce a high quality film of aluminium oxide fall into three principal groups: (1) Thermal treatment, i.e., by heating aluminium to incandescence in air or oxygen, (2) purely chemical methods, (3) electro-chemical methods based on the anodic polarization of the metal. Purely chemical treatments are less effective than these last, and thermal methods of treatment, as demonstrated by Tareeff's experiments in the Russian Electrotechnical Institute, are unsuitable for practical purposes.

Before discussing the oxide insulation of aluminium, its specific advantages and limitations, it is essential to consider the fundamental properties of $Al_2O_3$, which have a vital bearing on its electrical utilization, and to draw a comparison with the potentialities of other metallic oxides as dielectric materials.

In chemical constitution the oxide of aluminium is identical with corundum and the precious stones, ruby and sapphire, being distinguished by great hardness, thermal stability (its fusion temperature is 2,050 degrees C.), chemical stability, mechanical strength (compression strength 6,000 kg./cm.$^2$), high dielectric coefficient (about 12), and high heat conductivity (of the order of 0.05 calorie/cm., per second, per degree C.); for the sake of comparison it may be pointed out that, for instance, for mica the heat conductivity is equal merely to 0.0008 cal./cm., per second, per degree C.

Magnesium has something in common with aluminium with regard to oxidation; thus, it may be anodized. Of special interest is the possibility of oxidizing cast ultra-light alloys to any desired thickness by treating for a suitable period in superheated steam. By this means we are enabled to obtain very light insulated metal components of highly intricate shapes. The oxide of magnesium, MgO, is a dielectric material of great thermal stability, possessing at the same time a high thermal conductivity. It may also be made to serve as an insulator in the form of compressed masses. In this regard, experiments at the Russian Electrotechnical Institute are illuminating. These concerned tubular heating units consisting of metal tubes with coaxial nichrome elements embedded in powdered MgO.

Investigation of the properties of compressed magnesium oxide has revealed that specific gravity and dielectric strength increase, and the specific volume and surface resistivity decrease as the pressure is increased during the compression process. It has been found that the relationship between specific resistivity $\rho$ and specific gravity d of the compressed oxide is governed by the formula:—

$$\rho = e^{a - bd}$$

Where: e is the base of the natural system of logarithms, and a and b are constants.

Calcined magnesite may be used as a cheap insulating material. The peculiar dielectric properties of magnesium oxide deserve the closest attention of the research worker in order to bring fully to light its potential utility in electrical engineering.

On heating, the oxides of lead alter in composition according to the scheme:—

$$PbO_2 \longrightarrow Pb_3O_4 \longrightarrow Pb_2O_3 \longrightarrow PbO,$$

these transformations being accompanied by considerable increase in specific resistivity. This fact is utilized in the construction of lead interruptors, in which electrical puncture of a layer of lead peroxide $PbO_2$ involves local overheating, and the formation of the monoxide PbO possessing high resistivity, thus arresting the passage of the electric current at a given point. A composition formed of lead peroxide and glycerine has a specific volume resistivity of the order of $10^{10}$ ohms. to $10^{11}$ ohms. per cm$^3$, and a specific surface resistivity of $10^{10}$ ohms. to $10^{11}$ ohms., with a dielectric strength up to 4,000 volts/mm.

Table 6.

| Aluminium conductor, 1 metre long 1 mm. diameter. Thickness of the film, microns | Electrical resistance $\rho$, prior to corrosion | Electrical resistance $\rho_1$, after corrosion |
|---|---|---|
| Unanodized specimen | 0.0336 | 0.0346 |
| 11.8$\mu$ | 0.0345 | 0.0344 |
| 19.9$\mu$ | 0.0413 | 0.0413 |
| 11.8$\mu$ | 0.0358 | 0.0356 |

Mention should also be made of iron oxide, which, in the form of a natural film, can sometimes be used to insulate thin sheet-iron laminations in building up armature and transformer cores, with the object of cheapening and simplifying production when the power capacity of the machines is small. In this connection the Parker process for the treatment of iron is interesting. By this means there is obtained a black, strongly adhering layer, a few hundredths of a mm. thick, capable of protecting iron from corrosion even at high temperatures, and furnishing an insulation, the dielectric strength of which, depending on the duration of treatment, ranges from 50 volts up to 400 volts and over. This suggests the application of parkerized iron wires and strips as inexpensive reasonably high-temperature resistance elements.

*Advantages of Aluminium Oxide Insulation*

Investigation of aluminium conductors, oxidized by the appropriate method, reveals the following important advantages:—

(1) Low cost and simplicity of the insulating process, requiring no expensive insulators or products which are often in short supply. (2) Thinness of the insulation layer for windings. The film of aluminium oxide amounts to a few hundredths or even thousandths of a mm., as against the whole millimetres or, less frequently, tenths of mm. in the case of ordinary insulation. This circumstance implies that slots or grooves may be filled with minimum waste of space, thus ensuring maximum compactness of winding and a good coefficient of slot filling in the construction of electrical machines. For example, by replacing copper by anodized aluminium in the stator of an experimental asynchronous motor at the Russian Electrotechnical Institute, the filling coefficient was raised from 0.35 to 0.57, that is, its value rose by 63 per cent., thereby compensating the decrease of the specific electro-conductivity of the aluminium coils. (3) The temperature range, which the oxide insulation can withstand under service conditions, is limited only by the melting point of the aluminium itself; in any case this safe temperature level is not below 400 degrees C. (4) The thermal conductivity of aluminium oxide is very considerable; thin layers offer quite a negligible resistance to the passage of heat. This circumstance, combined with the possibility of obtaining windings of extreme compactness (easily attained by arranging anodized bus-bars of rectanglar cross-section to fit closely with one another), ensures excellent conditions for heat transfer from the interior of the coils to the periphery and its effective dissipation by radiation and convection. (5) The coefficient of thermal radiation for the oxide film is higher than that of aluminium metal.

The factors enumerated under (3), (4) and (5) afford the possibility of applying considerably greater current densities to conductors and windings made of anodized aluminium. Thus we may obtain either increase in the power output of a machine without altering its overall dimensions, or, for the same power, a reduction in cost, size and weight. (6) Satisfactory physical properties, including the mechanical strength and hardness. (7) The chemical stability of aluminium oxide also offers substantial practical advantages. It may be noted that the anodized aluminium windings can successfully work in an atmosphere laden with water vapour; at the same time, the film gives to the metal effective anti-corrosive protection.

As to the shortcomings of aluminium oxide insulation, they comprise:—

(1) Limited elasticity and flexibility, (2) difficulty of obtaining a layer of oxide which possesses a dielectric strength higher than a few hundred volts.

*Photocells, Rectifiers and Condensers*

The use of aluminium metal and alloys, magnesium metal and alloys and compounds (particularly oxides) of these metals in photocells, rectifiers and condensers, has, in part, already been dealt with in past issues of "Light Metals."

The utilization of anodized aluminium offers special advantages in the following wide sphere of applications:—

(i) Winding of electrical machines, apparatus and transformers, particularly those requiring minimum deadweight and designed to meet large overloads of brief duration. Air-cooled transformers for welding and windings for high-speed rotors in electric locomotives, etc., are good examples.

(ii) Windings for magnetic cranes, telphers, and similar equipment.

(iii) Separators and screens for mining.

(iv) Coal-cutting machines.

(v) Conductors and bus-bars in overhead transmission systems, affording good corrosion resistance, increased heat dissipation and reduced corona losses.

(vi) Windings for measuring, controlling and regulating instruments and devices designed to work in humid atmospheres.

(vii) Leads and windings for electric furnaces.

(viii) Wiring and winding for apparatus used in aircraft.

(ix) Spacers (in the shape of anodized aluminium plates and strips) for insulating elements of collectors, commutators, separate parts of sectionalized bus-bars of large cross-sectional area; spark plugs.

(x) Conductors for low voltage networks, where anodized aluminium or its electrically suitable alloys, and more especially, Aldrey, have already proved their merits.

(xi) Conductors for equipment employed for the heating of soils in agriculture.

(xii) Replacement of lead sheathing by aluminium for electrical power cables, with the object of reduction in deadweight.

(xiii) Windings for electrical resistance elements for heavy current loads.

(xiv) Conductors for indoor and outdoor wiring exposed to the action of fumes, vapours, and other corroding agents.

(xv) Condensers, including types designed for power-factor correction.

The insulating film produced on aluminium by anodizing can be made to possess a variety of qualities: it may have a greater or smaller thickness, colour distinction, various absorption properties, and different values of dielectric strength for the identical thickness of the oxide layer, or alternatively, the same breakdown potential for various thicknesses. However, the basis of all these modifications is the oxide of aluminium having a definite chemical constitution and crystalline structure.

Now it is firmly established that there exist two principal series of modifications of aluminium oxide, in which water is found not in the absorbed state, but in chemical combination, namely, the γ-series and the α-series, as presented in Table 2. On heating up to about 200 degrees C., hydrargilite passes into bauxite, and as a result of calcining bauxite up to 300 degrees C., there is obtained the γ-oxide.

Study of the γ-series has been considerably advanced by the recent derivation of böhmite (which is a constituent of bauxite), and of bayerite, which is the analogue of hydrargilite. To this γ-series also belongs the electrolytically formed oxide of aluminium, which constitutes its non-hydrated modification. Evidence for this is furnished by comparison of the röntgenograms of the anodic film and the γ-modification obtained by calcining of böhmite and bayerite.

The earlier conception of the film as having the composition $Al_2O_3.H_2O$ or $Al_2O_3.2H_2O$, should be entirely abandoned, for such hydroxides, on heating even at 300 degrees C., would have lost their water content, which is not the case during the calcination of the anodic layer. The structure of the film is characterized by an exceedingly small grain size. Only at a very high temperature level, namely, within the range from 900 degrees to 1,000 degrees C., does the oxide yield a clearly defined Debye-Scherer diagram giving a clue to the interpretation of its structure. Investigation of anodic films by Alexandroff and his collaborators by gravimetric methods have demonstrated the formation of the anhydrous modification, and X-ray diagrams obtained by the same workers have indicated a microcrystalline structure approaching that of the amorphous state.

The data given here refer to films produced in oxalic acid baths; films from chromic acid, sulphuric acid, or other electrolytes, tend to include in their composition foreign matter from the bath.

Apart from the specialized films required for electrolyte rectifiers and condensers, the films of aluminium oxide designed for general insulating purposes demand the selection of somewhat specialized electrolytes and techniques for their formation. Great rapidity of film formation may preclude the possibility of obtaining films of appreciable thickness and dielectrc strength in view of the fact that within a few seconds or minutes the resistance of the bath becomes excessive. Thus, for example, the film of aluminium oxide formed at 500 volts during three minutes in a solution of ammonium carbonate gives in the dry state a dielectric strength from 230 to 250 volts, the film formed by treatment in sodium bicarbonate at 500 volts for one minute displays a breakdown potential of 150 volts. But these films are porous, lack strong adhesion to the metal and show poor specific volume resistivity. These disadvantages are also aggravated by the necessity of using direct current at the high potential of 500 volts, which renders this mode of formation uneconomical. Still lower value of dielectric strength are exhibited by films derived from a 2 per cent. solution of borax; such films formed by direct current at 3A. and 150 volts for a period of 8 minutes, or at 3A. and 165 volts give a breakdown potential of O volts.

Electrolytes which are capable of yielding good quality films of aluminium oxide display formation voltage and current of formation of quite different characteristics and belong to the acid class, as may be observed from Figs. 8 and 9 respectively. By inspection of Fig. 8 it is seen, first, that the voltage of formation rarely exceeds 200 volts and, secondly, that the course of the formation curve alloy is distinguished by a slow and more or less uniform growth. The behaviour of the formation voltage in sulphuric acid is indicated by the curve a (d.c.), that in oxalic acid by the curve b, and in chromic acid by the curve c (a.c.).

Comprehensive studies of the dielectric possibilities of the aluminium-oxide film, conducted at the Russian Electrotechnical Institute under the direction of Alexandroff, in conjunction with several other scientific research institutions, have been marked by considerable achievements both in the technique of the electrolytic production of the film and in improving its electrical properties, thus enabling it to serve as a thermally stable and electrically reliable insulator. In these studies, side by side with the examination of the properties of aluminium oxide and of the fundamentals of the mechanism of its formation, attention has also been focused on the development of methods to raise the elasticity as well as the resistance to abrasion of the derived films, an aspect which has a vital bearing on their practical utility in electrical engineering.

In so far as the main object of these researches was to obtain a dependable insulation for electrical windings, and as information on the relationship between the methods for producing the oxide films and their dielectric strength is extremely scanty, it has been decided that in investigating the problem of the various conditions of the oxide film formation, special attention

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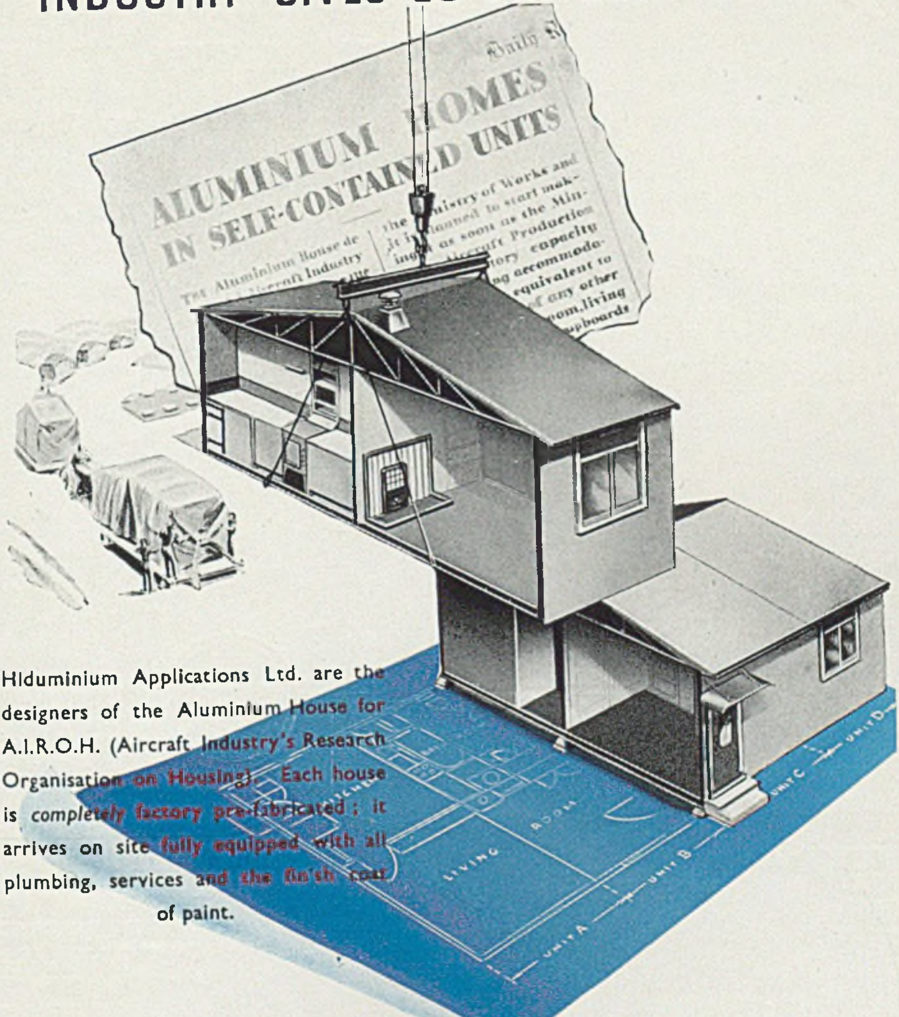


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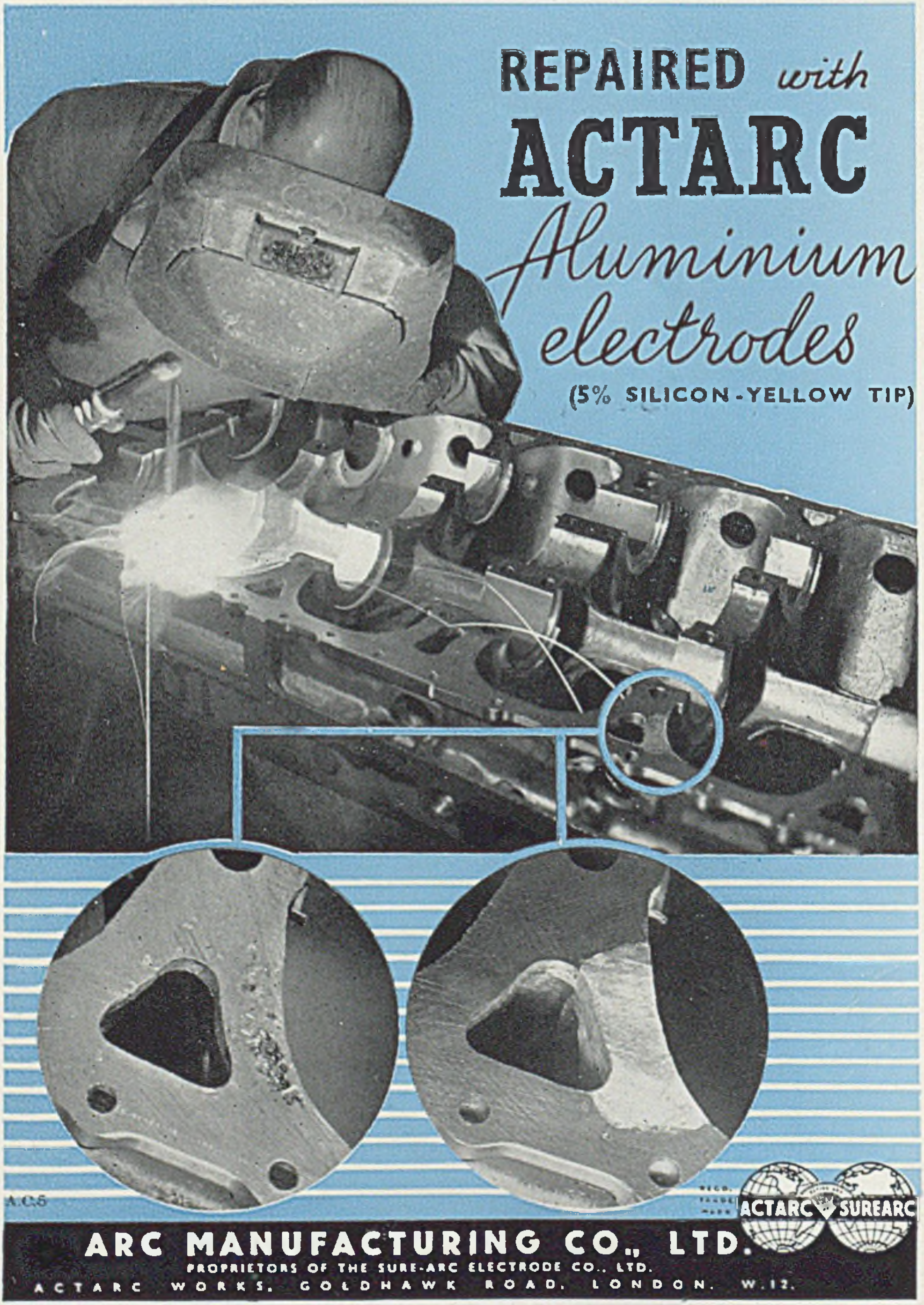
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should be paid to the characteristic property of breakdown potential.

It is to be noted that the measurement of this value, is not free from certain difficulties. Sometimes, as a consequence of the interplay of different factors, the oxidized aluminium surface gives, at various points, different values for $E_d$. Non-uniformity of the oxide coating may occur on one and the same specimen, for example, as a result of uneven distribution of the lines of the electric current, or increase of current density owing to local overheating of the electrolyte, due to method of purification, non-uniform agitation, and other details, which often elude the attention of the operator.

In the case of minor fluctuations of $E_d$, an average value of the measurements at

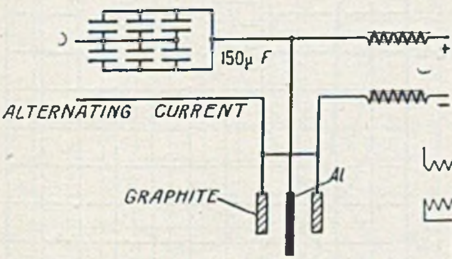



Fig. 10 (above).—Wiring scheme for superposition of direct current and alternating current by means of condensers and chokes.

several points was taken. In certain instances, for example, at high current densities and with a lengthy period of the formation, there may occur at the areas of greatest non-uniformity of the field local injuries to the oxide film, as illustrated in Fig. 1.

Increase of breakdown potential with direct current conforms, generally, up to a certain limit, to an approximately linear function of the formation time, on reaching which subsequent increase of $E_d$ slows down. With a higher current density there is an increase in the efficiency of the film formation process which is accelerated. At low current densities, film formation almost ceases, for the velocity of the solubility of aluminium exceeds the speed of film formation.

The production of oxide films having a more or less appreciable thickness from chromic acid is rather different and requires long treatment. The chromic films normally display no specially distinguishing qualities with regard to flexibility or dielectric strength.

Films from oxalic acid baths are formed very rapidly and uniformly, the best operating temperature being 40 degrees C.; the coatings produced possess good electrical qualities and mechanical strength. The fumes from the oxalic acid bath are not too excessive, although, in large-scale operation, the provision of proper ventilation is advisable. Films of aluminium oxide derived from oxalic acid exhibit a beautiful yellow-gold tint, which becomes darker as the thickness of the film increases, passing from the light-gold to yellow-brown. Even to a less-experienced eye, the thickness of the dielectric film on a given specimen may, at a glance, be clearly distinguished which, together with the quite original colour of the oxide layer obtained from oxalic acid, represents a definite technical advantage.

### *The Influence of Current*

The experiments on the production of the films at the Russian Electrotechnical Institute were carried out with the application

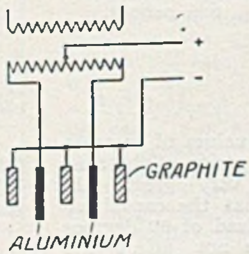



Fig. 11 (left).—Wiring diagram for superposition of direct current on alternating current by means of transformer.

of (1) direct current at various potentials, (2) alternating current at different frequencies and pressures, and (3) superimposed alternating current on direct current (so-called "ripple" current). For the purpose of these researches the following types of installations were used:—

1. Direct current: (a) 120 volts regulated by means of a rheostat; (b) dynamo, direct current, 750 Volts, 25 kW, with regulation of excitation.

2. Alternating current: (c) Transformer 120/500 volts, 8 kVA, with regulation of potential by means of rheostat on the low-voltage side; (d) high-frequency generator at 1,000 cycles/second, 250 Volts, 5 kW., with regulation of excitation; (e) high-frequency generator at 500 cycles/second, 120 Volts, 2 kW., with regulation of excitation.

From all these sources, current was led in and connected to independent terminals on the general distribution switchboard, upon which were mounted all measuring and indicating devices, including rheostats for regulation of current and rheostats controlling the excitation of the direct current machines as well as those of the high-frequency generators.

For the superposition of direct current on alternating current, use was made of the two following schemes. The diagram in Fig. 10 shows the arrangement with the application of condensers and chokes. This scheme is applicable only for small values of current; with large currents the capacity of the condensers has to be made very great. It should be pointed out that the capacitive current, having a phase lead of 90 degrees relative to pressure, does not affect the process. For part of the laboratory experiments and for work on a semi-industrial scale, the arrangement as shown in Fig. 11 was used. In this case the anode is led in to the mid point of the transformer, allowing for the simultaneous anodizing of only two aluminium plates.

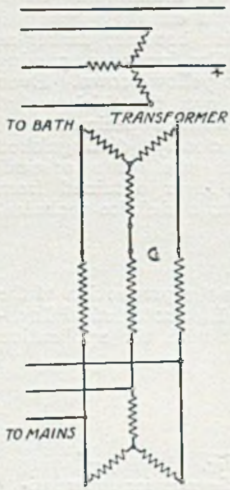
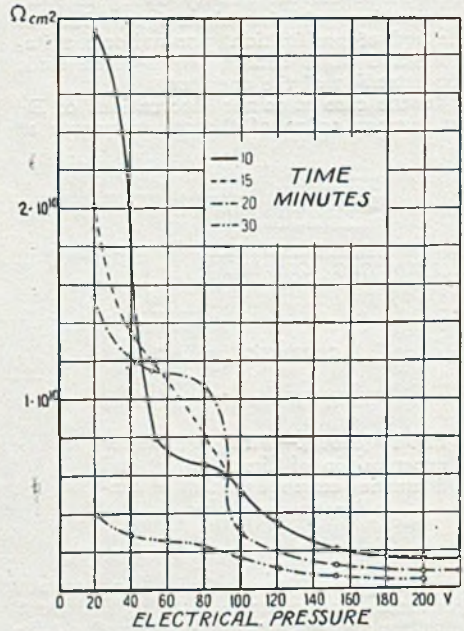



Fig. 12 (left).—Wiring diagram for superposition of direct current on alternating current with voltage regulation by means of potentiometer.

Fig. 13 (right).—Relationship between voltage and resistance of anodic films with different formation periods.

The scheme as presented in Fig. 12 should be considered as the most perfect arrangement, as it permits of smooth and easy regulation and superposition of the direct current on the alternating current.

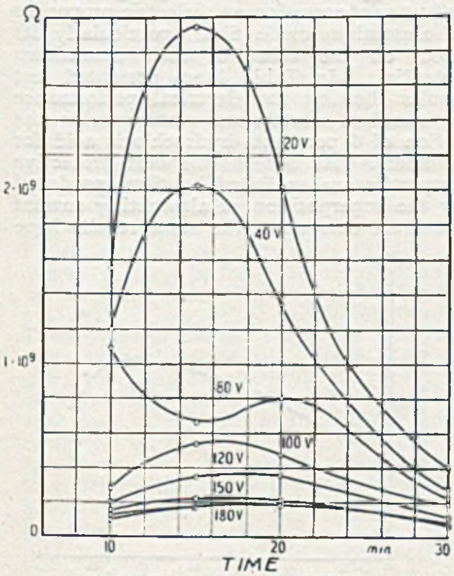
In an arrangement of this kind, pressure regulation is readily effected by the potential-regulator, and the transformer, the transformation coefficient of which equals unity, permits the carrying out of the superposition of the respective currents. This scheme is capable of modification: if the secondary winding of the transformer be provided with a suitable number of taps; then the application of the potential-regulator can be obviated. For the pilot plant experiments at the Russian Electrotechnical Institute the transformer was made to the following specifications: 220/220 Volts, 30 k.V.A., the winding of the secondary circuit consisting of 110 turns, from which, beginning from the fiftieth turn, there were taken 30 taps, each of which was brought out over one alternate turn of the winding. Such a transformer affords regulation of pressure from 100 volts and over. The limitations of the scheme with the application of a single transformer, dispensing with the potential-regulator, are, first, the raising of the voltage by jumps, and, secondly, the break of the circuit at the moment of switching over.




Stirring of the electrolyte was effected by blowing air through a rubber tube pierced with small holes, placed at the bottom of the bath. As cathode material, aluminium, lead, iron, carbon and graphite electrodes were tested. With high current densities there is observed a partial destruction of the electrode, the occurrence of which is especially pronounced in chromic acid baths. The most satisfactory cathode material proved to be graphite, the next suitable substance being carbon with a high content of graphite.

Although the available literature contains indications of the application of different currents to the oxidation process, these data are scattered and fragmentary. In the planning of these researches it was, therefore, considered that one of the primary tasks should be the correlation and sifting of the whole existing information and the experimental checking up of the influence of the various kinds of currents and their combinations on the process of anodizing.

The work at the Russian Electrotechnical Institute has been guided by the following principal requirements:—(1) Speed of film formation; (2) the lowest possible operating voltage as the safest and most readily available; (3) possibility of carrying out the anodizing of several conductors simultaneously; (4) production of films possessing the maximum flexibility; (5) most uniform



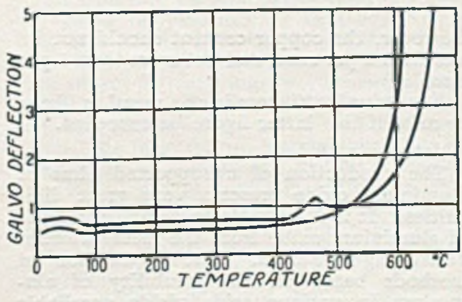




Fig. 14 (above).—Relationship between resistivity of anodic film and its period of formation. Fig. 15 (right).—Resistivity—temperature curve for anodic film.

coating of the entire surface of the object undergoing treatment; (6) minimum expenditure of electrical energy.

The difficulty of the task was confined not only to the diversity of possible types of currents and their combinations, but was also complicated by the circumstance that the process of film formation proceeds in different ways in various electrolytes. The relationship between the dielectric strength of the film produced and the time of its formation is not clearly discernible, and even the measurement of the value $E_d$ itself is bound up with inevitable errors.

In order to render the experimental results more easily comparable, all types of current were, first of all, subjected to tests in connection with films derived from the oxalic acid bath, which, after a series of investigations, was found to occupy first place with respect to the high qualities of the oxide films obtained from it.

Of special interest are the following characteristic observations. The superposition of direct current on alternating current results in an accelerating effect on the process of the film formation. The various electrical pressures in the combination direct current/alternating current display a quantitatively characteristic action, which is specific for a given individual current.

The superposition of alternating current on direct current is particularly useful for producing films in the typical valve electrolytes with a high formation voltage.

For the purpose of obtaining an oxide film with a dielectric strength of 300 volts it is possible to use (in the oxalic acid bath) alternating current at ordinary power frequency (50 cycles/second). Alternating current affords the possibility of a simultaneous anodizing of two or more aluminium wires, and requires the introduction of no special cathodes.

*Anodizing Aluminium-base Alloys*

Of the aluminium-base alloys there was examined the film formed on duralumin having the composition: 4.1 per cent. Cu, 0.22 per cent. Si, 0.83 per cent. Fe, or with a slightly lower copper content, from 3.79 per cent. to 3.76 per cent. of Cu.

The velocity of oxidation of duralumin in the oxalic acid bath is slower than that for unalloyed aluminium, and the oxide layer has a greyish-blue colour, but a very substantial advantage of the film so produced on duralumin is its flexibility. The duralumin film also possesses high dielectric strength (which is secured with better results by the application of direct current), and shows no cracks on bending.

Next were investigated the specific effects of the various alloying elements in duralumin, namely, magnesium, copper, manganese and iron. The effects of tin and lead were also examined. Alloys were prepared in a fireclay crucible with a flux containing 15 per cent. LiCl, 45 per cent.

KCl, 30 per cent. NaCl, 7 per cent. KF, 3 per cent. $NaHSO_4$. All the alloys were rolled to 1 mm. thickness and annealed. The results of anodizing by the application of alternating current are given in Table 3.

The experiment showed that the flexibility of the oxide film on duralumin is conditioned by the presence of the copper constituent.

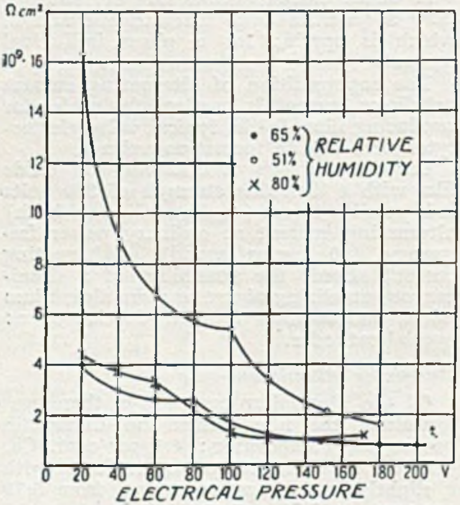



Fig. 16 (above).—Relationship between resistivity of anodic film and atmospheric humidity.

Fig. 17 (right).—Relationship between breakdown pressure of anodic film and current density for 500 cycle supply.

However, the copper content should not be less than 2 per cent. and not more than 5 per cent.

Excessive brittleness in the metal is likely to arise if this latter figure be exceeded.

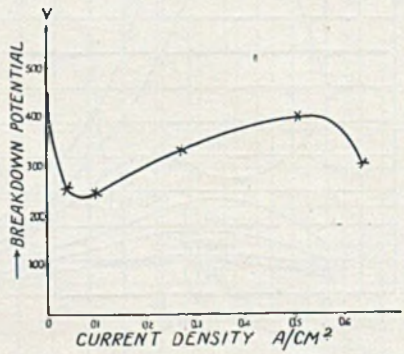
*Thickness of Film*

The production of unsupported films of aluminium oxide presents very great difficulties. It is impossible to detach the layer of aluminium oxide from the metal without destroying the film. The application of methods based on the solubility of aluminium in various acids yields unreliable results, in view of the possibility that, simultaneously with the dissolving of aluminium, there may also occur a slight solution of the oxide film itself. The most dependable results in determining the thickness of films are given by means of measurement on properly etched specimens.

The thickness of oxide films produced on aluminium may fluctuate from 1$\mu$ up to 0.5 mm., depending on the method and the duration of treatment. Films of aluminium oxide are distinguished by their very considerable hardness. According to many workers, $\gamma$—$Al_2O_3$ approaches corundum in hardness.

From the electrotechnical standpoint a very serious shortcoming of anodized films is their brittleness, evidenced by the fact that an anodized aluminium conductor can be bent safely around a radius not less than about 30 times its own diameter. Sharper bends result in cracking of the film.

From the viewpoint of electrical technology a most interesting aspect is the influence of corrosion on dielectric properties of aluminium oxide films, particularly its effect on the value of their breakdown potential. In Table 4 are presented test results showing the electrical performance of anodized aluminium plates under the action of 5 per cent. hydrochloric acid for 19 hours. As is seen, the best protective properties are exhibited by films produced by the superposition of alternating current on direct current. The same results have




been obtained by several other workers, including Setoh and Miyata, who recommend, in addition to anodizing, supplementary treatment by steam at elevated pressure. Undoubtedly, in certain instances, the protective power of the oxide films can be enhanced by the subsequent application of suitable coating media, such as lanoline, drying oils, varnishes, enamels, paraffin, and other organic compositions, which are capable of effectively sealing the pores of the film, and thus form a tough, tenacious envelope that completely bars the ingress of corrosive agents.

In Table 5 are tabulated the results of tests on the behaviour of aluminium prior to and after anodizing, with various combinations of current, before and after the onset of corrosion caused by a 5 per cent. solution of sodium chloride. The area of the immersed portion of the aluminium plates was equal to 60 cm.² Control measurements of the test-pieces were made periodically, the values given in Table 5 are the results obtained after continuous immersion in the corroding medium for four months and eight days.

Alexandroff and his associates have, so far, been unable to ascertain the reasons for the increase of the breakdown potential in experiments Nos. 5, 6 and 7. The other method of testing aluminium conductors consisted of subjecting specimens 1 metre long and 1 mm. diameter to an intermittent spray of 10 per cent. NaCl at 50 degrees C. The spray operated for a period of 30 mins., with a break interval of 2 hours, giving an aggregate spraying time of 120 minutes during 24 hours; the total duration of testing was 15 days. Determinations of the electrical resistance of the test-pieces were made prior to and after the test.

From Table 6 it is seen that the electrical resistance of the anodized aluminium conductors was not increased. The dielectric strength of these specimens as well as that of the oxide-insulated conductors subjected to testing in the humidity chamber, with 1 per cent. $SO_2 + 5$ per cent. $CO_2$, at 50 degrees C. for a period of 15 days, remained unchanged and displayed breakdown-potential values of a satisfactory order. These results show that the corrosion resisting qualities of the anodic films are quite good and adequate for the protection of aluminium conductors. This performance may be regarded as particularly gratifying in view of the fact that all the specimens were not given supplementary treatment with organic coating media after anodizing.

*Conductivity of Anodic Films*

Measurement of the electrical conductivity of the films was performed by the application of the method of relative deflections with a Siemens-Halske galvanometer having a sensitivity of $4.5 \times 10^{-9}$ V.

The relationship between electro-conductivity and the voltage impressed on the oxide film, and the dependence of the electro-conductivity of the film on temperature were determined with Saladin's apparatus with photographic recording. Aluminium, with the film of oxide formed on it, served as one electrode, the other consisting of mercury, powdered graphite, or aluminium foil. The resistance of the film was related to 1 cm.$^2$ of the surface area and a given thickness of the oxide layer, but not to the unit of thickness. As current strength falls with time, its value was determined twice: first after 30 seconds, and then again after a lapse of 3 minutes.

Resistance as measured by means of the mercury electrode showed a greater value than that measured by the graphite electrode, the difference being particularly great at low potentials and becoming smoothed out at higher pressures. This may probably be explained as being due to easier penetration of graphite into the pores of the film. Sometimes, however, the position was reversed, and the resistance determined by the graphite electrode was higher than that reckoned with the mercury electrode.

The nature of the applied electrode has no influence on the character of the performance curves. The electrical resistance of the anodic film varies with the change of the voltage in a very peculiar fashion. Films produced with various formation periods and, consequently, having different thicknesses, display analogous, but not parallel, curves, which tend to approach one another in the region of 100 volts and over. At a potential of 80 volts the curves exhibit a characteristic point of inflection, as is evident from Fig. 13. Inspection of the curves reveals that, in the case of the film formed in 30 minutes, the point of inflection was shifted towards 100 volts; this means, therefore, that the greater the thickness of the oxide film, the farther the characteristic point of inflection is located in the curve plotted along the axis of electric pressures. The simplest explanation for the existence of the inflection point would be that at potentials up to 60 volts, the conduction current is conditioned, mainly, by the migration of ions of the electrolyte remaining in the pores of the oxide. In the higher region, within the pressure range from 60 volts to 80 volts, when all the free ions of the electrolyte are already used up, resistivity becomes independent of voltage. At a potential above 80 volts, there begins to emerge the true conductivity of the oxide film itself, and, consequently, the resistance again falls.

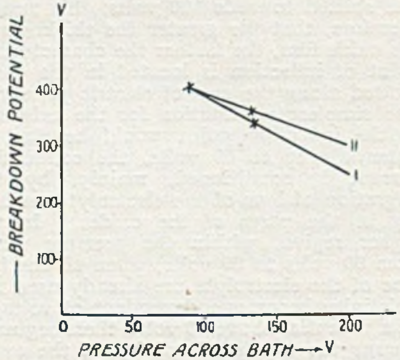
Washing of the film for 24 hours in water at room temperature, or in boiling water for two hours, with the subsequent drying for 24 hours at 130 degrees C., made with the object of removing the adsorbed electrolyte, did not alter the characteristic nature of the performance curves. This proves that the electrolytic conductance of the oxide film is conditioned by the electrolyte contained not in coarse interstices or pores of its structure, but within the fine capillary channels, with respect to which the operations of washing and drying are quite inadequate.

A possible alternative explanation for the occurrence of the point of inflection in the curve may be based on the fact of the penetration of graphite or mercury into the oxide film. However, on this assumption, the resistance drop, especially with the application of the graphite electrodes, should have been irreversible. Yet, in reality, this is not the case, and, therefore, such a hypothesis has to be discarded.

On the other hand, even by replacing the graphite by aluminium foil on the wire serving as the cathode, the inflection of the curve still remains; consequently, it is not due to the penetration of graphite into the film, but must be attributed to some different factor.

The idea that at pressures over 80 volts there takes place a partial dielectric puncture of the oxide film (namely, that of its outer porous layer), leading to the resistance fall, is also not confirmed, as, after such breakdown, change of conductivity should be irreversible, whereas actually it is not observed.

Note should be made of the fact that the resistance of the oxide layer does not increase with time of formation, i.e., with the thickness of the film. The relationship between resistance and formation period, determined at various potentials, show the maximum resistance for a forming time of



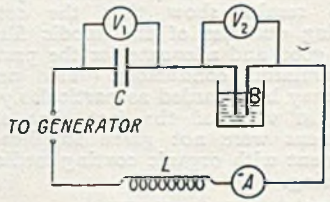

15 mins., as is indicated in Fig. 14. At 20 volts this maximum is most pronounced, but with increase of pressure the difference in resistance values is flattened out, and the curve assumes merely a slight concavity. At 80 volts, the resistance of the 15-minute film is not only not higher, but is even lower than the resistance of 10- and 20-minute films.

The maximum of the performance curves is attributed to specific conditions of film production. Up to the 15 mins. formation period, thickness of the film conforms to the linear law of increase with time, whilst density remains constant, after which the oxide layer, although still growing in thickness, becomes porous, and, in consequence of dielectric puncture and sparking, becomes more electro-conductive.

Testing of the heat stability of the films of aluminium oxide has demonstrated that from 400 degrees to 500 degrees C. electro-conductivity is practically unchanged. This stability is affected only by approaching the region from 515 degrees to 575 degrees C., when, as seen in Fig. 15, conductivity of the films begins to rise rapidly.

Analysis of these values reveals that the character of the performance curves in all cases is identical, but, at the same time, clearly indicates that, first, as the relative humidity increases, the conductivity of the oxide films correspondingly shows a rise, and, secondly, that as the relative humidity rises, a point of inflection of the curves moves in the direction of the smaller values of voltage. With 51 per cent. relative humidity the point of inflection is located at 100 volts, with 65 per cent. humidity it stands at 80 volts, and with a relative humidity of 80 per cent. the inflection point is found shifted towards a still lower pressure at 60 volts. The dependence of the

Fig. 18 (left).—Effect of raising potential difference at terminals of anodic bath upon the breakdown strength of anodic films, formed with 500 cycle A.C.: Curve I, values for low current densities; curve II, values for high current densities. Fig. 19 (below).—Wiring diagram for anodizing bath supplied with high frequency: A, ammeter; B, bath; C, condenser; $V_1$ and $V_2$, volt meters; L, inductance.




locus of the point of inflection on the relative humidity indirectly corroborates the fact that, generally, the nature of the performance curve is conditioned by the conductivity of the electrolyte adsorbed in the pores of the oxide film.

*Anodizing by High-frequency Alternating Currents*

Normally the process of electrolysis employs direct current. However, in the case of the anodic oxidation of aluminium, it has been shown that better results may conceivably be obtained by superimposition of alternating current on direct current, or by the use of alternating current alone. The film of aluminium oxide produced in this way is distinguished by higher elasticity, which property is of special importance for the insulation of windings.

The electrical and thermal conditions of anodizing by high-frequency current are radically different from the respective conditions of the usual electrolytic process. Fundamentally, these operating conditions are bound to exert a marked influence on the structure of the oxide, and it could be expected that, under conditions of oxidation by high-frequency current, the oxide film should be more dense and of smaller grain size; in consequence, the resultant films should possess distinctly superior characteristics of electrical and mechanical strength as compared to the ordinary films.

A notable contribution in this field has recently been made by the researches of Walter and his collaborators, whose expressed object was to ascertain the possibility of conducting the anodizing process by means of the high-frequency alternating currents. The experiments, as carried out by these investigators, employed frequencies of 500, 13,000 and $10^6$ cycles per second. As the working electrolytes, aqueous solutions of sulphuric acid, and of oxalic acid, were used.

Anodizing by current at a frequency of 500 cycles/second does not differ markedly from the same process with current at commercial frequency (50 cycles/second). It is worth pointing out two peculiarities observed in these experiments: (1) dependence of the properties of the oxide film on current density, and (2) dependence of the characteristics of the film on the voltage at the terminals of the bath.

At low current densities, from 0.005 A./cm.$^2$ to 0.05 A./cm.$^2$, and at about 0.5 A./cm.$^2$, with the passage of the same quantity of electricity through unit area of the surface, the resultant oxide film is of uniform thickness, having a dielectric strength from 350 volts to 450 volts. At current densities between the range 0.005—0.05 A./cm.$^2$ and 0.5 A./cm.$^2$, uniformity of the film is unattainable and its breakdown potential in this case is lowered, as may be observed from Fig. 17.

In the formation of the anodic film with a potential difference at the terminals of the bath within the limits of 50 volts to 200 volts, the raising of this pressure had no drastic influence on the qualities of the coating. Nevertheless, it should be mentioned that, in the event of elevating the potential, but keeping the density of the formation current and the quantity of electricity per cm.$^2$ of the electrode surface constant, there occurs a slight deterioration in dielectric strength, as shown in Fig. 18.

No regular relationship has been detected between the dielectric strength of the film and the quantity of electricity passed through a unit area of the aluminium surface within the interval 1 amp.-minute per 1 cm.$^2$ to 18 amp.-minute per 1 cm.$^2$ It is legitimate to suppose that already, prior to the passage of 1 amp.-minute per 1 cm.$^2$ there is established some dynamic equilibrium in the formation of the film, whereas further increase in its thickness and elevation of its breakdown potential cease. Moreover, with such large quantities of electricity, the resulting oxide film in its external aspects displays a non-uniform and pitted appearance.

As regards the mechanical strength of the film formed at a frequency of 500 cycles/second, particularly its flexibility, it was possible to obtain only the results of qualitative tests, which indicate that its elasticity is somewhat higher than that of the film produced under the same operating conditions with current at 50 cycles/second, and considerably higher than that of films produced by direct current. Quantitative data could be derived only by a special testing method, the development of which has recently engaged the close attention of various investigators, including those attached to the Russian Academy of Sciences.

In carrying out anodizing by current at a frequency of 13,000 cycles per second, a high-frequency generator with a frequency range from 13,000 to 20,000 cycles/second was used.

With a terminal pressure at the high-frequency generator of 160 volts and with current strength in the circuit at 5-6 amp. difference of potentials at the bath terminals remained neglibly small, thus rendering the process inoperative. This may probably be attributed to the fact that, compared to the total resistance of the generator, the resistance of the bath was so low that the voltage at its terminals was inadequate. An attempt to apply a higher potential with the aid of an oscillatory circuit connected in series to the high-frequency generator gave no positive results.

The circuit for an anodizing bath operated at 13,000 cycles per second is illustrated in Fig. 19. The difficulty entailed may be judged from the fact that at moments of resonance the current strength in the oscillatory circuit reached 3 amps., the difference of potentials at the condenser plates C attaining peak values of 1,500 to 2,000 V., and yet the voltage across the bath was still extremely low. Only by means of a preliminary brief treatment by current at 50 cycles/second was it found possible to anodize the same aluminium plate by current at 13,000 cycles/second supplied straight from the high-frequency generator.

As a result of such pre-treatment by current at 50 cycles frequency, there was formed on the aluminium electrode a layer of oxide with a resistance sufficient to obtain at the bath terminals the pressure required for continuing the process by high-frequency current. There was then observed an intense liberation of gas at the anode which flowed brightly. The pressure in the bath soon after the start reached 70 volts, rising in certain instances to 110 volts (with a potential at the generator of 160 volts), but, in the course of the process, quickly falling to 25 volts. Provided that the process was carried on for a sufficiently long time, the voltage drop continued, though slowly, right down to 10 volts. Throughout the process the current strength was kept at a constant value. The pressure drop in the bath repeatedly occurred in all the high-frequency experiments. In baths operating at a frequency of 50 cycles/second, or with direct current, then, as the thickness of the oxide layer grows, the potential difference across the bath terminals increases.

It was also found that distribution of the high-frequency current on the anode surface was extremely uneven, regions of greatest current density lying along the edges and being so graduated as to stain the anode surface with a more or less dark semi-ellipse, the convexity of which was directed downwards. The colour in the middle of the anode differed only slightly from that observed directly after preliminary treatment with 50 cycle current, and, furthermore, the lighter area exhibited only the same dielectric strength as it had shown directly after the preliminary treatment. The breakdown voltage of the darker elliptical area, however, was considerably higher. Alteration of the interval between cathode and anode during the course of treatment did not result in any improvement in the uniformity of current distribution, the cause of which is probably due to skin effect. The dark semi-ellipse disappeared only with the application of electrodes in the shape of narrow strips from 0.25 cm. to 0.5 cm. wide, in which case, evidently, current lines, crowded at the edges, merge into a single whole. With cathodes 1 cm. wide there could be clearly discerned (particularly at the upper boundary line) the characteristic colour distribution of the oxide film, whilst with cathodes 1.5 cm. wide this distinction became quite sharp.

By employing narrow aluminium strips as cathodes and current densities of 2.5 A./cm.$^2$ to 3 A./cm.$^2$, it was possible to anodize successfully with current at 13,000 cycles/second, without recourse to the preliminary treatment at 50 cycles/second. A good quality film, of grey colour and uniform texture, having a dielectric strength of 300 to 350 volts, was obtained. Such films appear to be much more flexible than those obtained with 50 cycle current.

Another noteworthy feature associated with the use of current at 13,000 cycles/second is the following interesting phenomenon: with a current density of 3 A/cm.$^2$ the process starts by the appearance of a steady bright glow at the anode; after a minute or two this passes into an intense sparking at its entire surface. If the current density be gradually decreased, it will be observed that the sparking at the anode quickly ceases, giving way to a silent glow, until, in a few seconds, sparking is resumed again. This periodicity persists right up to the end of the treatment. The period of silent glow becomes longer as current density decreases, say from 20 seconds of glow with 5 seconds of sparking for a density of 1 A./cm.$^2$ up to 1 minute of glow with 1 second of sparking at 0.8 A./cm.$^2$ No sparking at the anode occurs with a density of 0.5 A./cm.$^2$ During the intervals of sparking, current strength rises a few tenths of an ampere, whereas the voltage falls.

Experiments on the anodic oxidation of aluminium by the application of current at a frequency of $10^6$ cycles per second yielded no positive results. Although the difference of potential at certain points of the oscillatory circuit reached a peak value of 1,500 volts, and a current strength of 1.5 amps. was attained, no film was formed.

As the form of an alternating current is a matter of great consequence, special care was taken throughout this experimental work to adhere to currents of pure sine form at all the high-frequencies employed. The lack of positive results in the application of alternating current at one million cycles per second should be attributed, first of all, to the fact that, judging by the experiments with the current at 13,000 cycles, in this instance, also, the voltage at the bath terminals was vanishingly small and, consequently, incapable of effecting any electrolytic action. Moreover, even assuming that the conditions for obtaining the necessary pressure across the bath were realized, it is quite possible that the interval of semi-period, during which the aluminium electrode acts as the anode, might be shorter than the time of the electrochemical reaction of forming of the oxide, so that anodic oxidation fails to take place.

*Practical Applications*

The dielectric strength of the anodic film is unaffected by temperatures up to 500 degrees C. At normal temperature, the breakdown potential at various points on the oxide film has, generally speaking, different values, the mean value of the disruptive potential at 19 degrees C. being about 394 volts, the maximum plus or minus deviation from this average value being 150 volts. For each temperature level breakdown takes place at a new point on the film area, and tests have demonstrated that the average breakdown potential for the temperature range 140 degrees to 500 degrees C. is about 372 volts with the same maximum plus or minus deviation of 150 volts. Further, it was found that, under the standardized conditions in experimental production on a semi-industrial scale, fluctuation of the breakdown potential for films of aluminium oxide can be restricted within quite narrow limits.

The original pilot plant for the anodic treatment of aluminium conductors, which was developed at the Russian Electro-technical Institute on the basis of the laboratory data, consisted, in the main, of winder and reel with interposed measuring machine, and an anodic bath having initially a capacity of 40 litres. Cooling of the electrolyte was effected by means of luminium tubes through which cold water was circulated. The speed of the aluminium wire through the bath was 2.5 metres per minute, with the application of alternating current at 200 volts.

As a result of technical improvements suggested by experience, this equipment was supplemented by a more perfect installation, which, whilst retaining its original feature of compactness, had a bath of 300 litres capacity, operating on a.c. with superimposed direct current. This led to a considerable acceleration of the anodic treatment. From the stock of aluminium conductors, anodized in this plant, the following experimental machines were built:—

Asynchronous motor of 1.5 kW., wound with anodized aluminium inductors and completely free from copper. All-aluminium asynchronous short-circuited motor of 2.5 kW., at 220 volts, as illustrated in Fig. 5. Lighting transformer for 10 k.V.A. Welding transformer for 15 k.V.A. at 220/65 volts. Experimental power transformer with transformation ratio of 6,600/380 volts, for 20 k.V.A., which is shown in Fig. 3. Various types of electromagnet windings and other devices, all provided exclusively with anodized aluminium coils.

Fig. 4 depicts a power transformer for three-phase alternating current with anodic insulation of the aluminium windings, as produced by the Italian aluminium concern "Oxal." Transformers to various power capacities have also been built by Siemens-Schuckert in Germany with the application of the "Eloxal" anodizing process, and by other makers.

As has been abundantly demonstrated during the last decade or so, electric traction motors furnished with exciting windings of anodized aluminium, have amply justified the expectations both of the designer and the user alike, and are now being built by various concerns on an increasing scale.

The principal features of electrical construction with anodic insulation are: (1) high coefficient of filling of the slots of the machines, (2) great thermal stability allowing for the possibility of appreciable overheating, (3) reduction of weight. All the foregoing types of aluminium-built machines and apparatus have displayed a considerably greater power capacity as compared to the ordinary units based on copper.

Thus the simplicity of the production of the film of aluminium oxide, its high heat conductivity, reduction of the overall dimensions of the electrical machines (as the thickness of the insulating anode film is of the order of a few thousandths of a mm.), renders its further development and utilization of exceptional importance to electrical engineering.

*(To be continued.)*

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# NEWS—General, Technical and Commercial

## Aluminium Foundry Alloys

IN " Light Metals " for March, 1945 (page 103), appeared an account by E. Carrington, M.Sc., entitled " Selection and Preparation of Aluminium Foundry Alloys "; this was the subject of a letter by F. N. Smith, reproduced on page 170 of the April issue of " Light Metals." To this last letter Carrington replied in the letter given on page 212 of " Light Metals " for May. The following further correspondence has now been received from F. N. Smith:—

" I would refer to Mr. Carrington's letter (" Light Metals," May, 1945, pp. 212-3).

" I am in complete agreement with Mr. Carrington in his emphasis of the need for the strictest laboratory control in both foundry and heat-treatment of DTD 298—304 alloy. I would, however, stress that I consider such control to be essential in the founding of all aluminium and magnesium alloys if the maximum advantage is to be taken of the mechanical and physical properties obtainable in light-alloy castings.

" My reference to the use of aluminium dies has, unfortunately, been misunderstood by Carrington. Viewed strictly from a consideration of quality only—i.e., mechanical properties, soundness, finish, etc.—castings produced in aluminium-alloy dies are in no way superior to those obtained from, say, Meehanite cast-iron moulds. From a theoretical basis no appreciable improvement in properties should be expected to result merely from the employment of a die with higher thermal conductivity (K 0.45 and 0.12 cals/cm/cm$^2$/seo/°C for aluminium alloy (DTD 304) and Meehanite cast-iron respectively) since the resistance to heat flow is small in either case when compared with that of the metal to die interface which includes the oxide film of the liquid metal, the die dressing, the air-film between the liquid metal and the die surface, and the oxide film on the die. It was, in fact, found in a series of experiments carried out in these laboratories that no practical difference existed between the mechanical properties of test pieces produced in each of four identically shaped dies made of pure copper, aluminium bronze, aluminium alloy DTD 304 and Meehanite cast-iron, all protected on the die face by a proprietary coating. When no coating was used, the individual results showed considerable scatter, the mean values being higher in the test pieces from the Meehanite and bronze dies than in those obtained from the copper and aluminium dies. It is also of interest to note that, although in each case specimens were poured with a die temperature range of 25°C. to 370°C., there was no apparent relation between the temperature of the die and the mechanical properties of the casting.

" Carrington wishes to know why the coefficient of thermal expansion of a die material is not an important factor in determining the constraint of a casting cooling in the die. The explanation is, I think, fairly simple. As the first and then successive castings are poured, the temperature of the die will rise until it assumes a temperature alternating between two fairly narrow limits. This range and the mean temperature will depend upon many factors, including the size and shape of both casting and die and the interval between successive castings. This maximum die temperature is, of course, that attained when the loss of heat from all the die surfaces is equal to the heat input to the die from the castings in each cycle. It may have any value between 200°C. and 400°C. It follows, then, that, since the temperature of die assumes a constant value (with a fluctuating range of, say, ± 10°C.), the coefficient of thermal expansion cannot be an operating factor and that whatever metal is used for the die, the casting must cool to the die temperature under the same degree of constraint for similar die temperatures.

" By means of an externally applied coolant, as suggested by Carrington, the rate of heat transfer through the die could, of course, be increased. Advantage could only be taken of this increased conductivity, however, if, despite the high thermal resistance of the casting to die interface, the flow of heat across this interface were sufficiently rapid. As previously stated, when a die dressing is used, this becomes the controlling factor and any metal die (of practical use) could potentially conduct away the heat more rapidly than it could be transferred from the casting to the die. To return to the use of an external coolant, this would result obviously in a lower die temperature and could, therefore, be expected to increase the constraint under which the casting would cool, since the cooling range would be greater. Far from being eliminated, cracking would be expected to increase. This applies, of course, only to cracks occurring from constraint in cooling and not to stresses arising from other causes.

"To refer to the last point in Carrington's letter, it is not necessarily true, neither is it my experience, that 'the higher conductivity permits aluminium dies to be used at a much lower average temperature than with iron dies.' As he has already pointed out, the temperature of the die depends upon the rate at which heat can be extracted from it. In general practice it is usual to rely upon radiation, and air cooling by convection and conduction increased, if necessary, by utilizing a larger surface area, i.e., finning. Of these factors, radiation depends directly upon the nature of the die surface, and it should be stressed that the emissivity of the dull, slightly oxidized surface of cast-iron is considerably higher than that of aluminium, even when, in the latter case, it is increased by anodizing. Considered in relation to the previous points, it would follow that for identical dies the operating die temperature would be lower for an iron die than for an aluminium die, and this, in fact, was our experience, although the difference was small.

"In conclusion, I would like to stress that a high, and not a low, die temperature is preferable (apart from the difficulty of operating) and although more rapid cooling can be obtained by avoiding die dressings and by external cooling of the die, this must inevitably, and does, in fact, result in loss of detail and sharp edges in the resulting casting. Too rapid cooling also increases the possibility of cold shuts, and may, as has been shown, prevent adequate feeding of the casting during solidification."—For Kent Alloys, Ltd., F. N. Smith, Chief Metallurgist.

## Light-alloy Bicycles

THE letter from E. V. Pannell, reproduced below, refers to the discussion on light-alloy bicycles, the first part of which was presented in the July issue of "Light Metals" and which is concluded in this present issue.

"The article on Light-alloy Bicycles is very timely, and I look forward to reading the later instalment. As you may have noted, Fig. 1, described as illustrating the Caminargent, actually shows the Delage principle, whilst in Fig. 3 just the contrary is the case.

"I have owned and ridden several light-alloy machines, one of which was a Delage weighing 17 lb. This design gained for its promoter a prize given by the Bureau Internationale. It was a composite rather than an all-light-alloy frame, however, as the use of a magnet showed the front forks and steering column as well as the rear forks and stays to be of steel. Moreover, the principle of expanded ferrule joints, although patented by Gaetan Py, of the Delage Co., was anticipated as long ago as 1896 in a British patent granted to Jensen.

"A later bicycle which I owned and rode was built in England of RR56 tube and weighed only 16 lb. The joints were made by low-temperature brazing without apparently impairing the mechanical strength. It seems hardly necessary to go to such expedients as the Delage expanded ferrules or the Caminargent bolted lug design, if a sweated connection can be made in soft metal or plastic compound.

"Development work is now in progress by some of the most important manufacturers, and the light-alloy frame problem is practically solved. It must be admitted, nevertheless, that the frame forms only 20 per cent. of the weight of the complete cycle and light alloy can hardly save more than 1 lb. to 1½ lb. deadweight. The other 80 per cent. is made up of such components as wheel rims and hubs, handlebar and brake fittings, chain wheel, pedals and the like, all of which have been commercially produced in aluminium (no fewer than 30 manufacturers were engaged in such production in France prior to 1939 as against three or four in this country). All these components commanded a higher price in light alloy than in steel by reason of their average weight economy of 40 to 50 per cent. In passing, it is interesting to note a recent statement by Sir Harold Bowden to the effect that in normal times the trade turnover of cycle accessories and components is equal to the trade in complete cycles.

"Recent correspondence in the cycling Press indicates that cyclists are sharply critical of the way in which British manufacturers have neglected light alloys. Some of the writers are looking forward to the time when they can once again acquire lightweight components of Continental origin.—Ernest V. Pannell."

It should be pointed out, incidentally, that the statement that "it is doubtful whether a detailed analysis of all the factors, particularly performance and response in terms of stresses, strains, moduli of elasticity and so on has ever been worked out" made in the opening paragraph of the first part of the account is not strictly correct. Archibald Sharp in "Bicycles and Tricycles," Longmans, Green and Co. (1896), deals very fully with every aspect of the mechanics of the bicycle, not only as a complete assembly, but also with respect to each component part. We are indebted to the Editor of "Cycling" for this observation.

Pannell's reference to the successful use of a low-temperature-brazing technique for bicycle-frame assembly, coupled with the alleged use of (special) soft-soldered joints in certain light-metal kitchen utensils, points to the need for a re-orientation of the (usually adverse) publicity accorded to these methods of construction in aluminium. Prospective users of "solders" for light alloys frequently complain that inquiries directed to nominally official bodies appear to elicit discouraging negative answers, or, at least, half truths in reply.

## Light Alloy Foundry Industry

IN connection with the paper, "The Future of the Light Alloy Foundry Industry," read recently by Col. W. C. Devereux before the Institute of British Foundrymen, and reviewed on page 376 of this issue of "Light Metals," we have received the following letter:—

"We have read with interest the recently published paper by Col. W. C. Devereux on 'The Future of the Light Alloy Foundry Industry,' and, no doubt in common with other readers, have found in it much food for thought.

"In one respect, however, we are puzzled, viz., by the reference to prices of aluminium alloys. Col. Devereux quotes the example of a casting made in Hiduminium RR 50 (DTD 133c) at 2s. 3d. per lb., and implies that the casting could be made from an alloy to the same DTD specification for 1s. 7d. per lb.

"On the face of it, only one logical conclusion can be drawn from this. Since it is feasible to assume that the user of castings wishes to buy in the most economical market, the founder seeking his business surely has no choice. This seems too easy a solution of the problem, however, and, as users of aluminium castings, we would be interested to learn what difference exists between RR 50 and DTD 133c, and what guide the user of castings has concerning the incidence of this wide price variation on his purchase.

"The issue is complicated by the fact that, in general, foundries vary very little in their quotations for castings to DTD 133c, and, since the price variation quoted above is far too great to be covered by relative efficiency, we are left with a problem to which we cannot find the answer."—J.B.T.

## News Flashes from U.S.A.

ALUMINIUM lightning rods, which are now available in America, are produced under specifications of the Underwriters' Laboratories, Inc. These rods have distinct advantages in respect of high electrical conductivity, light weight, and freedom from maintenance due to high corrosion resistance.

The use of aluminium for the connecting cables permits the provision of larger radiating surfaces without undue increase in weight.

Designed by engineers of America Car and Foundry Company, Louisville and Nashville Railroad Company, and the Aluminum Co. of America, the 20 aluminium coaches and four aluminium dining cars are planned for early construction for the Louisville and Nashville Railroad. The effectiveness of the ultra-modern design is enhanced by the finish, which consists of fluted panels of aluminium against a background of royal blue.

## Economics of Die-casting

IN the letter given below are presented certain aspects of the economics of die-casting production as seen from the consumer's standpoint.

"With the enormous increase in the country's output of aluminium, I trust that we may expect a considerable reduction in basic cost.

"In order that manufacturers may be encouraged to use it in their products, I hope that the British die-casting industry will modify its ideas of economic quantities.

"It always made me envious when I went to the Leipzig Fair before the war to see die-cast components that from their nature were obviously needed in small quantities. The same applied to bakelite mouldings.

"At home, when I investigated die-casting, I found that the brain of the average die-caster could not comprehend any quantity less than 10,000, with dies to match, yet a business such as mine, producing a very large variety of motors and specializing in adaptations of our standard products for individual applications, often wants a few dozen or a few hundred simple aluminium castings, to meet special requirements. These have to be sand-cast, at the expense of appearance and machining time, because the die-casters do not want small quantities. The total cost of the moulder's time in moulding each article would surely more than pay for the setting-up time of a die-casting machine, and the die required, if modern die-making machinery were used.

"Even without the latter, a little co-operation between the die-caster and the designer would usually reduce the component to a form which could be cast in a simple die, made by ordinary turning or milling. For heaven's sake, let us forget the magic word 'Toolroom,' with its tradition of slow and loving craftsmanship, and make dies in an ordinary machine shop.

"Expensive dies and large quantities 'freeze' a design in a way that is bad for progress. Perhaps the war has taught quicker and cheaper methods of die making and casting. Competition, when it returns, may do the rest, but in the meantime much precious time will have been lost.—Electric Motor Manufacturer."

# ALUMINIUM KITCHEN "QUIZ"

THE "Kitchen Quiz," organized by the Aluminium Development Association as a feature of the Aluminium Exhibition at Selfridges, was designed to determine whether users had any special requirements or preferences as to the types of aluminium kitchen equipment the holloware manufacturers are about to manufacture. The competition proved amazingly popular, and hundreds of forms were returned with most practical and original suggestions for saucepans, frying-pans and kettles. Some 30 per cent. of the entries came from men.

The youngest competitor was a boy aged nine years, who asked A.D.A. for: "A good pan that does not wear out and does not burn the hands." Another entry came from a 16-year-old boy at school at Charterhouse. He has received a consolation prize for a paper and sketches which show his kitchen awareness is already well developed. Many other competitors are in the Services, and the third prize goes to a corporal in the R.A.F. The entries prove convincingly that certain changes and adaptations of many current models of pots, pans and kettles would be welcomed by the public.

## Analysis of Results

*Aluminium Saucepans*

Handles: 85 per cent. ask for plastic handles, 15 per cent. for metal handles. There is a marked preference for much shorter handles, and comfortable, non-slip grips.

Lids: 56 per cent. prefer lids with plastic handles, 44 per cent. ask for knobs.

Pouring lips on each side are popular on all types of pans provided lids are designed to cover the lips when close cooking is required.

*Aluminium Frying-pans*

Competitors condemn very light-bottomed frying-pans that buckle with the heat after short wear; also those with uselessly long handles (relics of open-fire cookery) that unbalance and tip an empty or lightly filled pans.

Uninsulated handles are universally condemned, so are handles fixed to the pan at an angle from which it is difficult to clean accumulated grease and dirt.

Competitors' preferences are as follow:—

Shape: Round, 48 per cent.; oval, 44 per cent.; square, 7 per cent.

Depth: 1 in. to 1½ ins., 17 per cent.; 2 ins., 44 per cent.; 2½ ins., 22 per cent.; 3 ins., 11 per cent.; 4 ins., 2 per cent.; 5 ins., 2 per cent.

Pouring Lips: 90 per cent. of the competitors ask for a pouring lip on their aluminium frying-pan—many want one each side; 70 per cent. want a lid also, and 70 per cent. ask for a flat, insulated handle. The remaining 30 per cent. want a rounded handle. Five ins. to 6 ins. is a popular length.

*Aluminium Kettles*

Our competitors have strong feelings about their kettles! There is universal complaint about fingers first burned in grasping uninsulated, too-small knobs on hot lids, and then scalded by the rising steam from central filling apertures placed directly below the kettle handle.

Hinged lids placed to one side, or at the back of the aluminium are asked for by many entrants. This they offer as a solution to the scalding problem and also for easier filling from the tap.

Whistles are extremely popular. So are kettles with wide bottoms for quick boiling.

Spouts: 74 per cent. prefer a wide, curved spout to a narrow or straight one.

Handles: There are many requests for kettle handles to be brought down farther to the back of the kettle for easier balance when pouring.

Capacity: 3 to 4 pints is the most popular size.

Designs based on suggestions and sketches from the principal winners will be found reproduced in accompanying illustrations.

First prize was awarded to **Mrs. W. K. Beck,** 18, Upstall Street, Myatts Park, S.E.5.

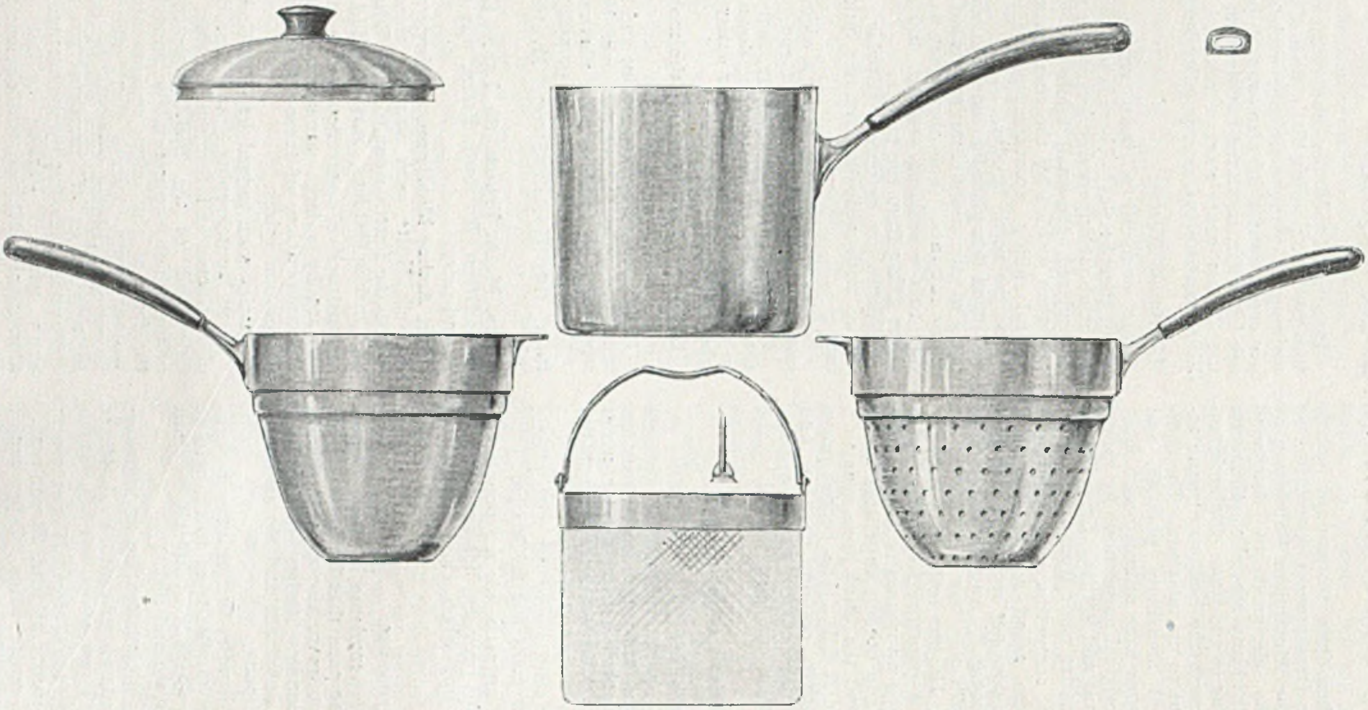
**Mrs. M. A. French,** 39, Laurel Crescent, Rush Green, Romford, Essex, was awarded second prize.

**Mr. Arthur Middleton,** of Musters Street, Bulwell, Notts, was awarded third prize, whilst the fourth went to **Mrs. Wheeler,** of 58, Onslow Gardens, Muswell Hill, N.10.

Constructive suggestions were also put forward by a large number of entrants to the competition; of these 50 were awarded consolation prizes.

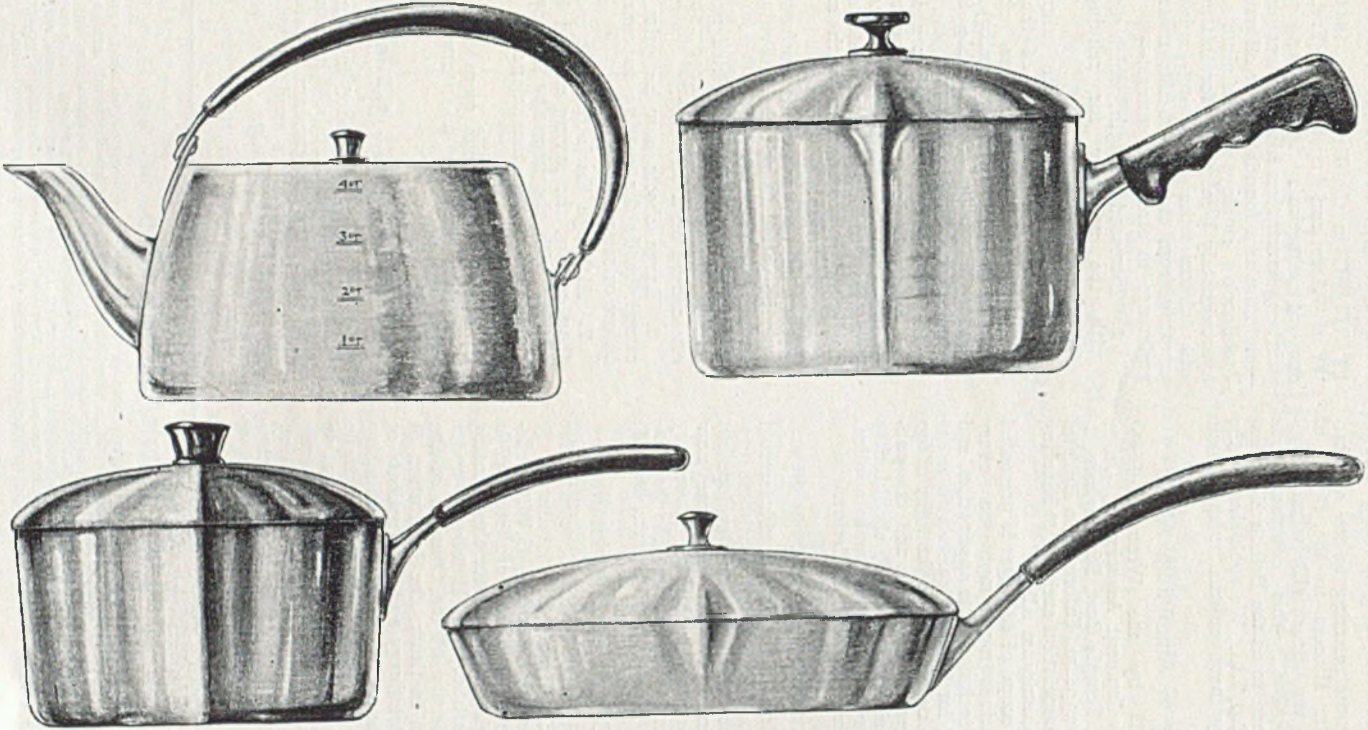
Entries were judged by Miss Garbutt, of "Good Housekeeping," and Mrs. Whitlow, of "Homes and Gardens." Mr. Freddy Grisewood, of the B.B.C., presented the prizes which, appropriately enough, took the form of aluminium cooking utensils of various types. In a short address, Mr. Grisewood pointed out the opportunities for new design still presented not only by cooking utensils, but by the average kitchen as a whole. Various exhibits in the aluminium exhibition lent obvious force to the speaker's remarks.

# A.D.A. KITCHEN "QUIZ"



ILLUSTRATED here (one-fifth actual size) is a series of aluminium utensils developed by J. Starkie Gardner Ltd. from a prize-winning suggestion. The knob on the lid is of plastic, whilst the handles of the saucepan, the shaped container, and perforated container are also in plastic moulded over a tubular metal reinforcement (a cross-section of these handles is shown in the top right-hand corner of this page). The lower vessel shown in the centre of the group consists of an aluminium anulus, to which is attached a hinged aluminium wire handle. The anulus supports a wire-mesh basket. (For details of Kitchen "Quiz" see preceding page.)

## A.D.A. KITCHEN "QUIZ"—*concluded.*



FURTHER group of aluminium utensils evolved for the Aluminium Development Association by J. Starkie Gardner Ltd. from suggestions received in response to the kitchen "quiz." All are shown about one-quarter natural size. The handle of the kettle is of swivel type, covered with plastic for heat insulation; the kettle knob is also in plastic and a whistle is attached to the lid. The frying-pan is provided with a lid and the handle, again, like those of the saucepans, is insulated with plastic.

## Brush Electrical Engineering Co.

IN a recent note referring to the appointment of Mr. Mitman to the Board of Directors of the Brush Electrical Engineering Co., Ltd., this company was wrongly referred to as the British Electrical Engineering Co., Ltd. We apologize for the error and any inconvenience it may have caused.

## Riveting of Aluminium Alloys

PUBLISHED by the Wrought Light Alloys Development Association, Union Chambers, 63, Temple Row, Birmingham, 2, there has just appeared Information Bulletin No. 8 of the Association entitled, "Riveting of Wrought Aluminium Alloys."

Within the scope of 48 pages is presented an authoritative monograph on every aspect of this technique, its application, and tools required for its practice.

Prospective users of wrought light alloys are strongly recommended to add this publication to their libraries and, should they not already have done so, to make application for the previous seven Bulletins.

## Zinc Development Association

WE would draw the attention of interested readers to the fact that abstracts previously published by the Zinc Development Association in duplicated form are now available as printed brochures. These may be obtained on application to the Association, Lincoln House, Turl Street, Oxford.

## National Certificates in Metallurgy

FROM the secretary of the Committee for National Certificates in Metallurgy, 4, Grosvenor Gardens, London, S.W.1 (telephone, Sloane 0061), has been received a circular outlining a scheme for the granting of National Certificates in Metallurgy under the joint authority of the Councils of the Iron and Steel Institute, the Institution of Mining and Metallurgy and the Institute of Metals with the co-operation of the Ministry of Education. The scheme outlined is to be operated under Ministry of Education Rules III, and represents a notable advance towards the broader official distinction between the chemist, engineer and metallurgist.

## Aluminium as Artists' Material

WRITING in the December, 1944, issue of "American Artist," Paul Trebilcock, one of America's best-known portrait painters, summarizes his experience in using aluminium as a foundation for oil paintings. Trebilcock employs aluminium sheet, approximately ⅛ in. thick, for this purpose, and claims the following advantages accruing from the use of this material in preference to stretched canvas:—

1. Increased strength, which dispenses with the necessity for relining and restoring.

2. Permanency of the aluminium panel, and the attributes of the oxide skin (close bond, hardness, chemical neutrality and minute porosity) which render it particularly suitable for the application of the oil-ground.

3. The aluminium panel is unaffected by atmospheric conditions, water, or cleaning agents. Expansion and contraction, due to temperature changes, are negligible in comparison with suitably prepared canvas.

4. The texture of the surface finish may be varied to suit the individual preference of the painter.

5. Seven or eight completed paintings can be stored in the space occupied by one canvas on a stretcher.

6. Large sheets can be primed and stored, ready for cutting to exact size, before or after painting.

7. Although the initial cost is greater than canvas, the saving effected by dispensing with the necessity for expensive restorations, turns the balance in favour of the light metal.

It is hoped to deal more fully with Trebilcock's work in a future issue of "Light Metals."

## Current Light-alloy Specifications

IN an amendment published in a previous issue of "Light Metals," it should be noted that the magnesium content of DTD 133b should now read 0.50-0.20 per cent. The modification was wrongly referred to silicon.

## "Light Metals" Lunch Club

As many of our friends know, it has, for the past seven years or more, been our custom to hold, once every month, if possible, a small and informal luncheon, to which have been invited friends directly attached to the light-metal industry, together with others interested either in the possible use of aluminium, or in other materials complementary to light alloys in the foundry trades and plastic working groups. It is now felt that a need has arisen for broadening the basis of these meetings, and for their institution on a more formal basis. In order that some definite scheme may be drawn up, we should be grateful if readers interested in this project would write in to us at this office, outlining their reactions to the suggestion.

# *Light Alloys in*
# Rectifiers, Photocells and Condensers

*Continued from "Light Metals," 1945/8/359. In Order to Present as Complete a Picture as Possible of Problems Involved in Condenser Manufacture, this Part of the Account Summarizes Practical Requirements for Interleaving Papers*

FOLLOWING the publication of Roman's study of the porosity of condenser tissues, considerable attention has been given to the matter in this country as well as in America. Nevertheless, outside America a porosity clause does not appear to be included in industrial purchasing specifications for this material. This does not reflect upon Roman's conclusions, for his investigation work was very convincing, and his conclusions in relation to the influence of porosity, and of uniformity in this respect upon the breakdown values of condensers, were sound and should be accepted. However, initial breakdown values on test shortly after manufacture were the criteria of his evaluation. Thus stability and shelf life were not included in the survey. In this country, insulation resistance values are apparently more widely specified than they are in America, and they are more difficult to satisfy than are breakdown voltage minima. Further, it is considered certain that a good, stable condenser must start life with a high insulation value and show very little falling off in this characteristic with the lapse of time. The higher the initial insulation value, the greater confidence there is in the condenser maintaining this value, presumably because it indicates a trend towards maximum purity of raw materials, minimum contamination in processing, and maximum efficiency of drying, impregnating and sealing. These qualities of high insulation, and of retention of high insulation in storage or during service, have no relation to the porosity of the paper, or at least there is no direct bearing between them; this can be stated with a high degree of certainty. This possibly explains why the porosity feature has not been given the prominence that it deserves.

Table 54.—Porosity Values (c.c. Air Passed in 30 secs.) for Condenser Papers Covered by Characteristics in Tables 44 to 49. ("Light Metals," July, pp. 349–353.)

| Sample No. | Origin | Porosity |
|---|---|---|
| 1 | American | 2.7 |
| 2 | American | 3.0 |
| 4 | French | 3.5 |
| 5 | French | 3.6 |
| 6 | German | 5.0 |
| 7 | German | 3.9 |
| 8 | German | 4.5 |
| 9 | British | 5.7 |
| 10 | British | 5.6 |
| 11 | British | 9.2 |
| 12 | British | 10.5 |

Porosity naturally varies widely in a paper unless low values are specifically requested. This can be illustrated by test values, expressed in terms of c.c. of air passed in 30 secs. on the range of papers for which general test results have already

Table 55.—Average Test Results Showing Influence of Varying Degree of Calendering on Same Type of Paper.

| Sample No. .. .. | 1 | 2 | 3 |
|---|---|---|---|
| Degree of Calendering | Normal (comparatively heavy) | None | Light |
| Porosity (cc. air passed in 30 secs.) .. .. | 12.0 | 18.0 | 16.5 |
| Insulation resistance, megohms per M.F. .. | 7,000 | 15,000 | 11,000 |
| Breakdown, volts A.C. | 1,200 | 1,000 | 1,200 |
| Thickness (inches) .. | 0.00030 | 0.00045 | 0.00035 |
| pH value .. .. | 8.2 | 8.1 | 8.0 |
| Water soluble matter % .. .. | 0.78 | 0.85 | 0.80 |
| Alcohol soluble matter % .. .. | 0.45 | 0.55 | 0.52 |
| Substance, gms./sq. in. | 9.0 | 8.9 | 8.9 |
| Density gms./cc. .. | 1.18 | 0.78 | 1.00 |

been given. These values are given in Table 54.

The manner in which porosity can be controlled and brought below a specified limit is obviously a problem for the experts in paper manufacture. Users of the paper are concerned with the methods employed in so far as they influence the quality of the dielectric material they require. It can be conjectured that the logical process is to select the right grade of fibre, reduce it to the optimum size, or range of size, including the optimum degree of heating, felt it correctly on the paper machine, and finally impose the optimum extent of calendering. Excessive heating is suspected of promoting excessive hydration and added difficulty in drying-out during the processing of condensers, and excessive calendering is also thought to give poorer insulation values. Hence the need for caution and control to the optimum extents to which these mechanical processes are applied. This stresses the trickiness entailed in the manufacture of low porosity papers that still have regard to electrical qualities other than electric strength. Again, porosity can be improved by "filling" the pores of the paper by means of appropriate additions to the suspension fed to the paper-making machine, additions such as starches or resin size. These too are liable to influence the paper adversely with respect to electrical properties such as insulation resistance and power loss. These features can be demonstrated, at least in some considerable measure, by testing specially treated batches of paper made with variations only in the mechanical or chemical respects mentioned. Everything indicates that the paper manufacturer has little latitude in which to work if a consistent quality of raw material of all-round good electrical quality is to be maintained.

Average test results on papers calendered to varying degrees and on condensers produced from these papers are shown in Table 55. The paper concerned was a linen stock material, normally calendered to a thickness of 0.0003 in. Uncalendered, it was 50 per cent. thicker, and lightly calendered about 16 per cent. thicker. Porosity was high even in the normal condition and 50 per cent. worse without calendering. Light calendering did not improve the porosity very perceptibly. The average insulation resistance (measured at 68 F. at 400 volts d.c. after one minute's electrification) was twice as good in the uncalendered condition and 50 per cent. better in the lightly calendered state. Average breakdown voltage was undoubtedly lowest in the uncalendered (most porous) condition, but only 20 per cent. better in the other two forms. The chemical purity of the paper as shown by pH value and soluble matters was reasonable without being exceptionally good. Even though the paper was not a low-porosity material, and therefore could not be expected to illustrate Roman's conclusions, the breakdown results do fall in line with the latter, and the highest insulation in the absence of calendering and with the lowest density is significant.

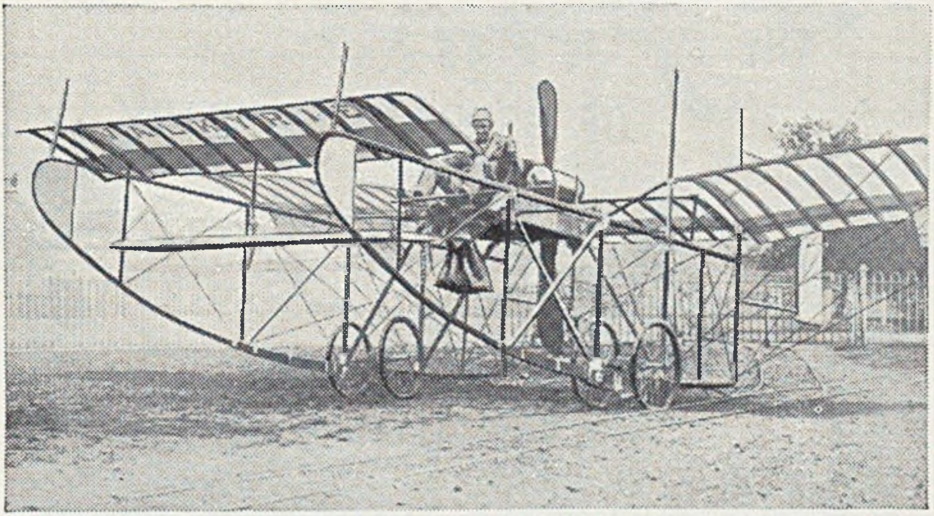
On the whole, the conclusion arrived at in this country seems to be towards regarding porosity as a very useful control test to check those undeterminable factors of degree of beating and degree of calendering. In this way it can be used for routine control of the uniformity for a particular grade of paper of specific source and process of manufacture, and initially established as satisfactory on trial.

Table 56 deals with low-porosity linen base condenser tissues purchased specifically as low-porosity papers. Material to sample No. 4 gave concordant test results over an extended period of consignments. Insulation resistance values on condensers were good, and the range between minimum and maximum was narrow. The average breakdown voltage was good, but some low values were obtained. Sample No. 3 was a substitute for it, a reasonable substitute, except that on the average breakdown values were lower. Samples Nos. 1 and 2 from subsequent makings of this were very poor because of the wide variation in insulation resistance values which ranged down to a very low level indeed. The chemical quality of Sample No. 1 could explain this, particularly on account of the high soluble contents, but the recorded laboratory results give no indication for the inferiority of No. 2. The results again stress that factors other than porosity require consideration.

Table 57 deals with thin linen tissues, purchased as 0.0003-in. thickness material. Chemically all are reasonable. Regarding condenser characteristics, on insulation, the best is from the paper having highest porosity, and the second best from that having second highest porosity. The best breakdown is shown by condensers from the paper of lowest porosity, and the worst breakdown from that of highest porosity. However, all the breakdown values are of low order.

Table 58 analyses some wood stock papers; all are of 0.0004 to 0.0005-in. thickness. Chemically they are reasonably good, No. 1 being the poorest. Nos. 1 to 3 are low-porosity types and No. 4 a high-porosity paper. All produced condensers of high insulation value, but Nos. 3 and 4 (the latter being high porosity) gave condensers of very low breakdown voltage values.

The wood-base papers are less expensive than linen stock materials, and therefore they are likely to be exploited as far as



*The first aerial post in Great Britain from Hendon to Windsor. A 'rehearsal' to make sure that it will be all right on the day, Sept. 9, 1911.*

# WHEN WE WERE YOUNG

From such beginnings grew the aircraft industry. It has been Cellon's privilege to march in step with this phenomenal development and, in some respects, help to speed it. Cellon was founded in 1911 and has found the succeeding years pregnant with opportunity; it has flourished during the days of the greatest industrial and scientific advance in history. That Cellon now holds a position in the van of the production of industrial finishes is proof of the progress made since 1911.

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Table 56.—Variable Electrical Results on Condensers made with Low Porosity Linen-base Condenser Tissues.

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Composition | Linen stock | Linen stock | Linen stock | Linen stock |
| Ash on incineration % | 0.50 | 0.30 | 0.15 | 0.44 |
| Alcohol soluble matter % | 3.75 | 0.65 | 0.44 | 0.40 |
| Water soluble matter % | 1.25 | 0.45 | 0.92 | 0.72 |
| pH Value | 7.1 | 7.2 | 7.9 | 7.0 |
| Porosity (cc. air passed in 30 secs.) | 4.0 | 4.0 | 5.0 | 4.3 |
| Substance, grams/sq. metre | 10.4 | 10.3 | 10.0 | 10.0 |
| Thickness, average inches | 0.00041 | 0.00042 | 0.00045 | 0.00043 |
| Density grams/cc. | 0.98 | 0.96 | 0.87 | 0.91 |
| Insulation resistance megohms/MF at 68° F.:— | | | | |
| Min. | 1,000 | 1,100 | 8,300 | 10,800 |
| Max. | 11,000 | 15,600 | 12,100 | 12,300 |
| Mean. | 8,000 | 9,300 | 10,500 | 11,350 |
| Breakdown voltage, volts A.C.:— | | | | |
| Min. | 1,750 | 600 | 1,250 | 1,000 |
| Max. | 3,500 | 2,000 | 2,000 | 3,500 |
| Mean | 2,600 | 1,430 | 1,450 | 2,400 |

possible. Their dielectric constant seems to be a little higher because condensers made from them are about 20 per cent. higher in capacity than those from linen paper of exactly the same thickness.

The apparently higher specific inductive capacity of wood stock paper, as compared with that of linen-base paper, can be shown by the higher capacity values obtained on condensers made with the two types of paper, everything else being equal, of course. The same paper thickness, number of papers and foils, winding information with respect to mandrel size and number of turns (or length of paper), identical process conditions and the same impregnating medium; all these are essential. Some results of this kind are given in Table 59, and they clearly demonstrate the advantages of the wood stock paper in this particular quality. The figures do not, of course, give the true ratio of the S.I.C.'s of the two papers, because the dominating influence upon the overall S.I.C. of the condenser dielectric, and upon the capacity of the condenser itself, is the impregnating medium. The actual difference between the papers is, therefore, probably very much higher than that indicated.

Returning to the chemical aspects of paper quality it must be admitted that the characteristics so far mentioned are insufficient in themselves to provide a full assessment, and the values obtained in test are often difficult to interpret. It will be helpful to explain this briefly.

The permissible magnitude of the ash value must depend upon the nature of this ash or, more correctly, upon the nature of the chemicals from which it is formed. It is usually alkaline in nature, consisting of calcium compounds, silicates and perhaps a little phosphate, chloride and sulphate; some alkali, sodium or potassium may be inevitably present. Inert calcium compounds can be tolerated more than the alkali-metal compounds.

A reaction test gives a good guide to neutrality, while the pH value test gives a more minute assessment of this. In general, this can be taken as a very sound assessment of the paper, but it is always possible that an organic buffering agent, particularly as cellulosic products are available, may be present to suppress true acidity or alkalinity, and cause a better picture to be revealed than is truly the case.

The extraction tests, although giving consistent values on the same paper, yield widely varying results as will have been seen from the tabulated data. The extracted matter is foreign matter and generally consists of starchy or gummy product, including traces of soluble salts. The values obtained are not directly related to the effects produced upon the resultant condensers, although it has to be assumed that high soluble matter must contribute to lack of homogeneity of the condenser and, therefore, if not to poor initial characteristics, to instability.

Some users of condenser tissues have gone a long way towards satisfying the lack of conciseness in these chemical tests by introducing a test for the electrical conductivity of a water extract of the paper. The same type of test is included in the British Standard Specification for Unvarnished Papers for Electrical Purposes (No. 698-1936). This test, in conjunction with a pH value determination, should go a long way towards providing a solution to all the problems associated with a quick assessment of the chemical quality of the paper. It is true that the more injurious impurities that are likely to influence insulation resistance and stability are those retained chemical compounds that are water soluble and more readily ionized. These will yield relatively high-conductivity aqueous extracts.

The conductivity of the extract can be determined using apparatus comprising a conductivity cell which is, in effect, a U-capillary tube with platinum electrodes in each limb of the U just above the termination of the capillary. The cell can be kept at constant temperature during the measurement by means of a bath which surrounds it, this being provided with a thermometer and stirrer. The two limbs of the U-capillary tube are extended through double right-angled bends, one to a receiver into which the paper extract is filtered, the other into an aspirator bottle. By means of these accessories, and with the aid of a stop-cock in the aspirator line, it is practicable to fill the cell with the extract for test, or with distilled water used as a blank, or again with a standard solution of known conductivity value for establishing the cell constant.

The electrodes are extended by means of platinum wires through the glass tubing for connection to the electrical measuring apparatus. A 500-volt d.c. megger is usually used, and the dimensions of the cell are chosen so that the resistivity of the column of any liquid in the cell is at least 1 megohm (conductivity maximum of 1 micromho). This minimizes the possibility of polarization effects at the electrode surfaces.

To determine the cell constant (which, of course, only has to be done once for any particular cell), a solution of known conductivity is used. The cell is first flushed through with distilled water, and then two or three times with the solution that is to be used. Finally the cock is closed, leaving the cell full of this liquid; about 15 mins. is allowed for the solution to attain the temperatures of the bath, and the conductivity or resistivity value is read on the megger.

For this standard solution a chemically pure salt is used in aqueous solution, one of which the specific conductivity value is known. Potassium chloride is usual, and for this the following are the specific conductivities in micromhos at 25 degrees C. for various concentrations:—

| | |
|---|---|
| Normal solution ... ... | 111,800 |
| Deci normal solution ... | 12,800 |
| Centi normal solution ... | 1,413 |

The cell constant is the product of the measured resistance in megohms and the specific conductivity of the solution in micromhos.

For the actual test on the extract from the paper the procedure is similar. The cell is flushed through with distilled water and a check reading taken on it. The cell is then flushed with the test solution and finally its value measured.

The specific conductivity of the test extract is the cell constant divided by the test reading in megohms. If not measured at 25 degrees C., the value can be corrected to 25 degrees C., provided the temperature does not deviate from the temperature by more than plus or minus 10 degrees C. For this purpose the value is divided by $(1 \pm 0.02T)$, in which T is the deviation, the " plus " or " minus " indicating above or below 25 degrees C.

With this commercial form of test, the total experimental error will not exceed 5 per cent. either way, provided, of course, all precautions are taken to avoid contamination and to ensure scrupulous cleanliness. The required quality of water gives the greatest difficulty, and failure to obtain this is shown by the blank test, so that no misleading results are obtained from this source. The same extract can, of course, be used for the pH value test.

The aqueous extract test for conductivity and for pH value is strongly advocated as the two combined are considered to cover

Table 57.—Characteristics of Condenser Tissues of Nominal 0.0003 in. Thickness.

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Supplier | G | H | H | E | H | G |
| Composition | Linen stock | Linen stock | Linen | Linen | Linen | Linen |
| Ash % | 0.38 | 0.48 | 0.35 | 0.10 | 0.42 | 0.40 |
| Alcohol soluble matter % | 0.50 | 0.55 | 0.62 | 0.85 | 0.55 | 0.62 |
| Water soluble matter % | 0.65 | 0.80 | 0.89 | 1.03 | 1.30 | 0.70 |
| pH value | 6.8 | 8.2 | 7.7 | 6.6 | 7.2 | 6.6 |
| Thickness, average, inches | 0.00030 | 0.00030 | 0.00030 | 0.00036 | 0.00034 | 0.00035 |
| Substance, grams/sq. metre | 9.2 | 9.0 | 10.5 | 11.3 | 9.6 | 8.3 |
| Density, grams per cc. | 1.15 | 1.18 | 1.38 | 1.24 | 1.09 | 0.90 |
| Porosity ccs. air passed in 30 secs. | 7.1 | 12.0 | 5.0 | 4.8 | 5.5 | 6.9 |
| Insulation resistance megohms/MF at 60°F.:— | | | | | | |
| Min. | 9,000 | 4,500 | 4,000 | 1,000 | 3,000 | 6,000 |
| Max. | 15,000 | 9,500 | 10,000 | 3,500 | 8,000 | 11,500 |
| Mean | 12,000 | 7,500 | 7,500 | 2,500 | 6,000 | 9,000 |
| Breakdown voltage, volts A.C.:— | | | | | | |
| Min. | 500 | 750 | 750 | 500 | 750 | 750 |
| Max. | 1,250 | 1,500 | 2,000 | 1,500 | 1,750 | 2,000 |
| Mean | 900 | 1,200 | 1,400 | 1,200 | 1,200 | 1,200 |

the chemical side of the problem very fully. The remaining chemical tests are useful and are considered essential if conductivity measurements are not made.

The salient features from some commercial specifications are deemed of interest to show the extent to which users go, and the variance in the degree of severity of these specifications. An American specification includes the following points to cover paper for radio condensers:—

(a) The fibre stock to be 95 per cent. minimum of flax, or 95 per cent. wood cellulose as called for on the purchase order.

(b) Ash to be maximum 0.60 per cent.

(c) Moisture content to be max. 7.0 per cent.

(d) Acidity to be equivalent of max. 0.10 mgm. of NaOH/grm. of paper.

Alkalinity to be equivalent of max. 0.30 mgm. of $H_2SO_4$/grm. of paper.

(e) Thickness for nominal 0.0004 and 0.0005-in. papers to be within plus and minus 0.00003-in.

(f) The width to be within ± 1/64th in. of the specified width for widths up to 4 ins.

(g) Conducting particles to be maximum 30 per sq. ft.

(h) Covering capacity in sq. ins./lb. on a dry basis to be 63,000 min., 73,000 max. for 0.0004-in. paper and 50,000 min., 57,000 max. for 0.0005-in. paper.

(i) To be in rolls, free from wrinkles and creases, or burred ends. Ends not to be smoothed by means of abrasive paper. Core tube to be of adequate strength, and its inner wall to be concentric with the paper windings. Rolls to unwind freely without sticking or tearing.

Another American specification for general purposes condenser tissue is somewhat more searching in its scope and requirements, viz.:—

(a) The material required defined as a thin paper having good dielectric properties, suitable for the production of condensers.

(b) The paper to be free from dirt inclusions, electrically conducting particles, wrinkles, holes, cuts or other imperfections.

(c) Fibres to be distributed uniformly in the paper to form a well-closed homogeneous paper of uniform thickness and having a smooth surface.

The fibre to be all linen rag stock, bleached or unbleached, and the paper to be natural white in colour.

(d) Water soluble matter (10 hours extraction) to be max. 2.0 per cent.

(e) Alcohol soluble matter (8 hours extraction following the water extract) to be max. 2.0 per cent.

(f) Deviation from neutrality not to exceed 0.02 per cent. of either acidity or alkalinity.

(g) Thickness tolerances in accordance with nominal thickness, viz.:—

| Nominal. Thickness, in. | Tolerance. Plus. | Minus. |
|---|---|---|
| 0.00030 | 0.00005 | 0.00003 |
| 0.00040 | 0.00003 | 0.00005 |
| 0.00050 | 0.0000[illegible] | 0.00005 |

(h) Tolerance of plus and minus $\frac{1}{16}$ in. on widths greater than 3 ins., and plus and minus 1/32 in. on lower widths.

(i) Covering capacity, sq. ins./lb. to satisfy the following minimum values:—

| Nominal Thickness, in. | Min. sq. ins./lb. |
|---|---|
| 0.0003 | 75,000 |
| 0.0004 | 69,000 |
| 0.0005 | 55,000 |

(j) Density to be 0.890 grms./c.c. min.

Table 58.—Characteristics of Wood-Stock Condenser Tissue.

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Composition | Wood stock | Wood stock | Wood stock | Wood stock |
| Ash % | 0.40 | 0.30 | 0.19 | 0.72 |
| Alcohol soluble matter % | 1.43 | 0.32 | 0.10 | 0.14 |
| Water soluble matter % | 0.85 | 0.57 | 0.93 | 0.73 |
| pH value | 7.4 | 7.2 | 7.2 | 8.2 |
| Thickness, average, inches | 0.00046 | 0.00046 | 0.00043 | 0.00046 |
| Substance, grams/sq. metre | 12.6 | 12.3 | 12.1 | 11.9 |
| Density, grams/cc. | 1.08 | 1.05 | 1.11 | 1.02 |
| Porosity, ccs. air passed in 30 secs. | 4.9 | 4.1 | 4.4 | 19.8 |
| Insulation resistance, megohms/MF at 60°C.:— | | | | |
| Min. | 9,500 | 13,250 | 15,000 | 10,500 |
| Max. | 14,000 | 17,000 | 17,500 | 16,000 |
| Mean | 12,000 | 15,000 | 16,000 | 13,500 |
| Breakdown voltage, volts A.C.:— | | | | |
| Min. | 750 | 1,250 | 500 | 700 |
| Max. | 3,000 | 2,500 | 1,500 | 1,600 |
| Mean | 1,750 | 1,750 | 1,150 | 1,200 |

(k) Porority ccs. air passed in 15 secs., to be max. average of 3.0 and 6.0 for high voltage and ordinary grades respectively, and maximum individual porosity values of 5.0 and 8.0 respectively.

(l) Conducting paths to be max. 30 sq. ft.

It will be noted that this specification is quite generous with respect to chemical properties, but rigorous with regard to porosity.

A British specification for wood or linen stock tissue covers the following clauses:—

(a) To be free from conducting particles, pin-holes and slime spots.

(b) Reaction to be neutral and pH value of water extract to be 6.0 min., 8.5 max.

(c) Ash to be 0.40 per cent. max.

(d) Water soluble matter to be 1.0 per cent. max.

(e) Alcohol soluble matter to be 0.75 per cent. max.

(f) Moisture content to be 7.0 per cent. max.

(g) Substance, in grms./sq. m., to be within the following limits:—

| Nominal Thickness. in. | Substance. Min. | Substance. Max. |
|---|---|---|
| 0.00030 | 8.5 | 9.5 |
| 0.00040 | 9.5 | 10.5 |
| 0.00050 | 11.0 | 13.0 |

(h) Tensile strength to be 12.0 lb./mil/in. min. and to be unaffected by dry heat test of 24 hrs. at 100 to 110 degrees C.

Table 59.—Apparent Higher S.I.C. of Wood Paper, compared with Linen Paper, shown by Capacity Tests on Condensers.

| Wood-stock paper .. .. | No. 1 | No. 2 |
|---|---|---|
| Thickness of paper, average inches | 0.00040 | 0.00046 |
| Capacity in microfarads of condenser units.. .. .. .. | 1.21 | 1.01 |
| Capacity in microfarads of units wound with linen paper of same length, width and thickness .. | 1.10 | 0.90 |
| Ratio of S.I.C. of wood paper to S.I.C. of linen paper .. .. | 1.10 | 1.11 |

(i) Tolerance on thickness to be within the following limits:—

| Nominal Thickness. in. | Tolerance—in. Plus. | Tolerance—in. Minus. |
|---|---|---|
| 0.00030 | 0.00003 | 0.00003 |
| 0.00040 | 0,00003 | 0.00004 |
| 0.00050 | 0.00003 | 0.00005 |

(j) Tolerance on width to be plus and minus 1/64 in.

(k) Rolls to be uniformly wound with even tension, free from creases and wrinkles. Paper to be in continuous lengths. Core to be cardboard of length exactly the same as the width of the paper. Inside diameter of core to be 2.5 ins., and overall diameter of roll not to exceed 6 ins.

British Standard Specification No. 698 (1936) includes rag condenser tissue paper under Class 5 material, defining it as that made from flax and/or hemp only, and covering thicknesses from 7 to 22 microns (approx. 0.00028 to 0.00088 ins.). Limits are laid down as under:—

(a) Thickness, plus and minus 5 per cent. from specified thickness.

(b) Substance, plus and minus 5 per cent. from agreed weight/sq. m.

(c) Electric strength at 90 degrees C., min. 600 volts, A.C./mil.

(d) Tensile strength on nominal thickness of 0.4 mils to be 3.5 to 5.0 lb./in. of width in machine direction, and 1.5 to 3.0 lb./in. of width in cross direction.

(e) Tearing resistance (Marx-Elemendorf) to be 4 to 8 grms. in machine direction and 6 to 10 grms. in cross direction on 0.0004 in. nominal thickness.

(f) Bursting strength. Decrease after 48 hours at 150 degrees C. shall not exceed 10 per cent.

(g) Oil absorption. Rise in height of transformer oil in 2 hours at 95 to 100 degrees C. to be $\frac{3}{4}$ to $1\frac{1}{4}$ ins.

(h) Air permeability. Measured on 10 sq. cm. of paper under 10 cm. of water pressure at 25 degrees C. To be 5 to 10 for lightly calendered paper, and max. 6.0 for heavily calendered paper, these values being millilitres of air per min. passed through the paper.

(i) Ash to be max. 0.50 per cent.

(j) pH value to be 6.4 min., 8.5 max.

(k) Conductivity of aqueous extract to be 20 micromhos per cm. cube max.

(l) Conducting paths to be max. 10 per sq. ft. max.

No additional comments on the specification aspects are required. Provided close specification limits can be maintained, the wood papers seem to be as good as linen stocks. Thicknesses down to 0.0003 in. are satisfactory, but close tolerance on thickness is essential for maintenance of capacity limits and for safeguarding minimum breakdown strength. Chemically, pH value and conductivity of extracts at least should be covered. Physically, substance or density and porosity need to be stipulated to control uniformity. Origin of fibre, degree of beating and calendering are critical factors, controllable only by co-operation with supplier.

*(To be continued.)*


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

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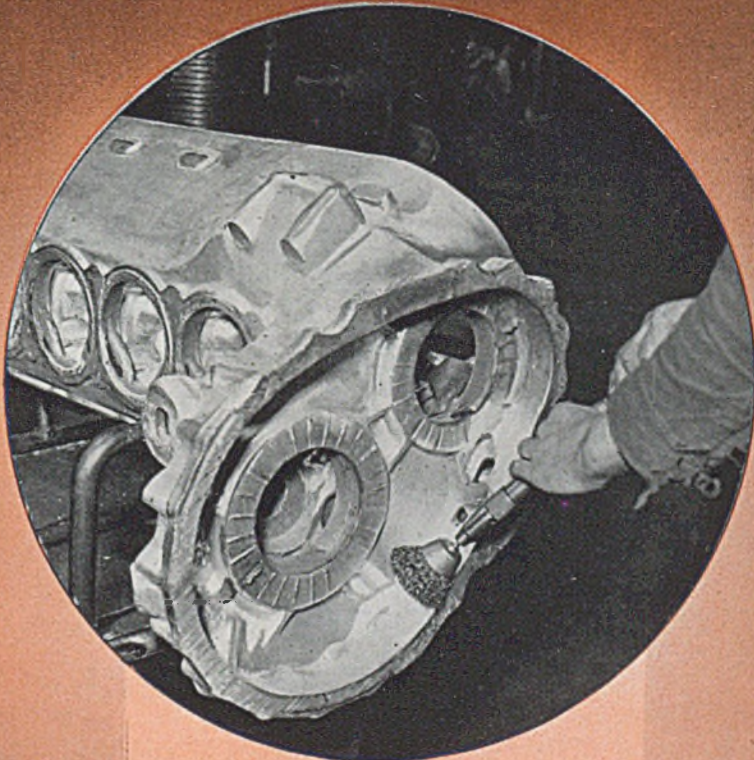
*Inland Telegrams* - - - "*Pressimus, Phone, London.*"
*Cables* - - - - - - "*Pressimus, London.*"
*Telephone* - - - *Terminus* 3636 *(Private Exchange).*




Printed in England and Published Monthly by the Proprietors, TEMPLE PRESS LTD., BOWLING GREEN LANE, LONDON, E.C.1



Vol. VIII. No. 91 LIGHT METALS AUGUST, 1945